JOSH GREEN, M.D.
GOVERNOR OF HAWAIʻI
KE KIAʻĀINA O KA MOKUʻĀINA ʻO HAWAIʻI

KENNETH S. FINK, MD, MGA, MPH
DIRECTOR OF HEALTH
KA LUNA HOʻOKELE

STATE OF HAWAIʻI
DEPARTMENT OF HEALTH
KA ʻOIHANA OLAKINO
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In reply, please refer to:
File:

Testimony in SUPPORT of SB0426 HD1
RELATING TO CESSPOOLS

REPRESENTATIVE MARK M. NAKASHIMA, CHAIR
HOUSE COMMITTEE ON CONSUMER PROTECTION & COMMERCE
Hearing Date: 3/16/2023 Room Number: 329

Fiscal Implications: None.

Department Testimony: The Department of Health (Department) strongly supports this measure. The Department concurs with the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversion and connections to sewers for cesspools located in priority 1 and 2 areas according to the University of Hawaii's 2022 Hawaii cesspool hazard assessment and prioritization tool. The Department also concurs with the exemption criteria that are provided in the measure.

Thank you for the opportunity to testify.

Offered Amendments: None.

JOSH GREEN, M.D.
GOVERNOR | KE KIAʻĀINA

SYLVIA LUKE
LIEUTENANT GOVERNOR | KA HOPE KIAʻĀINA

STATE OF HAWAIʻI | KA MOKUʻĀINA ʻO HAWAIʻI
DEPARTMENT OF LAND AND NATURAL RESOURCES
KA ʻOIHANA KUMUWAIWAI ʻĀINA

P.O. BOX 621
HONOLULU, HAWAII 96809

DAWN N.S. CHANG
CHAIRPERSON
BOARD OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMENT

LAURA H.E. KAAKUA
FIRST DEPUTY

M. KALEO MANUEL
DEPUTY DIRECTOR - WATER

AQUATIC RESOURCES
BOATING AND OCEAN RECREATION
BUREAU OF CONVEYANCES
COMMISSION ON WATER RESOURCE MANAGEMENT
CONSERVATION AND COASTAL LANDS
CONSERVATION AND RESOURCES ENFORCEMENT
ENGINEERING
FORESTRY AND WILDLIFE
HISTORIC PRESERVATION
KAHOOLAWE ISLAND RESERVE COMMISSION
LAND
STATE PARKS

Testimony of
DAWN N. S. CHANG
Chairperson

Before the House Committee on
CONSUMER PROTECTION & COMMERCE

Tuesday, March 21, 2023
2:00 PM
State Capitol, VIA VIDEOCONFERENCE, Conference Room 329

In consideration of
SENATE BILL 426, SENATE DRAFT 2, HOUSE DRAFT 1
RELATING TO CESSPOOLS

Senate Bill 426, Senate Draft 2, House Draft 1 proposes to implement the recommendation of the Cesspool Conversion Working Group to accelerate the dates for required upgrades, conversions, or connections of Priority Level 1 cesspools and Priority Level 2 cesspools by requiring Priority Level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, with certain exceptions, and Priority Level 2 cesspools to be upgraded, converted, or connected before 1/1/2035, rather than before 1/1/2050. **The Department of Land and Natural Resources (Department) supports this bill.**

Cesspools can cause harm to water quality within adjacent groundwater, anchialine, and coral reef systems by introducing elevated amounts of organic nitrogen and phosphorus, pathogens, and other contaminants. Contaminants emitted from cesspools can harm aquatic ecosystems by encouraging algal blooms and can also pose a threat to human health. The Department supports the acceleration of upgrades for identified high priority cesspools that pose the greatest threat to nearshore water quality and human health (i.e., identified Priority Levels 1 and 2) to help minimize future contamination of Hawaiʻi's fragile aquatic areas.

The Department supports the language in House Draft 1 that allows the recreational residence leases within Kōkeʻe/Waimea Canyon State Parks to convert by 2035 (as is presently proposed for the Priority 2 cesspools), rather than 2030 (as is presently proposed for the Priority 1 cesspools). This grace period of 5 years is sufficient to allow for a smooth transition for these cherished leased properties, as well as to meet the intent to convert these cesspools to more environmentally friendly technologies well before the current 2050 mandate.

Mahalo for the opportunity to provide testimony in support of this measure.

JOSH GREEN, M.D.
GOVERNOR

GWEN S. YAMAMOTO LAU
EXECUTIVE DIRECTOR

HAWAII GREEN INFRASTRUCTURE AUTHORITY

No. 1 Capitol District Building, 250 South Hotel Street, Suite 501, Honolulu, Hawaii 96813 Mailing Address: P.O. Box 2359, Honolulu, Hawaii 96804

Telephone: (808) 587-3868
Web site: gems.hawaii.gov

Testimony of
Gwen Yamamoto Lau
Executive Director
Hawaii Green Infrastructure Authority
before the
COMMITTEE ON CONSUMER PROTECTION & COMMERCE
Tuesday, March 21, 2023, 2:00 PM
State Capitol, Conference Room 329
in consideration of
SENATE BILL NO. 426, SD2, HD1
RELATING TO CESSPOOLS

Chair Nakashima, Vice Chair Sayama, and Members of the Consumer Protection & Commerce Committee:

Thank you for the opportunity to testify and provide comments on Senate Bill No. 426, SD2, HD1 relating to cesspools. The Hawaiʻi Green Infrastructure Authority (HGIA) **strongly supports** this bill which provides for staggered deadlines to upgrade priority level 1 and level 2 cesspools ahead of the existing 2050 deadline.

Prioritizing and accelerating conversion dates for systems with the most severe impacts will not only provide more timely protection of our groundwater sources, but it will also provide a sense of urgency while allowing the industry to gear up for increased demand from roughly 2,300 cesspool conversions annually (between 2024 to 2030); to 2,500 cesspool conversions annually (between 2031 to 2035) to 3700 cesspool conversions annually (between 2036 to 2050).

Thank you for this opportunity to testify and provide comments on Senate Bill No. 426, SD2, HD1.

OFFICE OF HAWAIIAN AFFAIRS

SB426 SD2 HD1
RELATING TO CESSPOOLS
House Committee on Consumer Protection & Commerce

March 21, 2023	2:00 PM	Room 329

The Office of Hawaiian Affairs (OHA) respectfully **COMMENTS** on SB426 SD2 HD1, which would implement the recommendations of the Cesspool Conversion Working Group of Act 132 (SLH 2018) to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools to 2030 and 2035 respectively. **OHA makes these comments in light of the potential disproportionate impact that this measure will have on Native Hawaiians and other residents of our rural communities that face constant economic disparities and inequities. OHA offers amendments to this measure that would mitigate OHA concerns with regard to the financial hurdle that affected Native Hawaiians will face, while also advancing the necessary protections to better preserve and protect ʻāina.**

OHA wishes to express its deep understanding for the purpose of this measure to expedite cesspool upgrades, conversions, and connections in order to mitigate and better protect against devastating impacts to Hawaiʻi's treasured coral reefs and their integral role to the integrity and stability of natural systems upon which we rely – often times, for our own survival. At the same time, with the constitutional mandate to ever-seek the betterment of conditions of Native Hawaiians[1] and as the principal public agency in the State responsible for the performance, development, and coordination of programs and activities relating to Native Hawaiians,[2] OHA approaches this complex issue with the priority to address potential negative impacts on Native Hawaiian economic stability[3] and protections for ʻāina, our natural world, to which Native Hawaiian health, culture, and identity is so deeply rooted.

OHA asks the Legislature to Appropriate Necessary Funding to OHA for the Purpose of Providing Beneficiary Grants for Cesspool Conversion

OHA wishes to emphasize that Native Hawaiians, generally, face greater vulnerability to poverty;[4] this vulnerability is exacerbated among those living in rural and remote communities.[5] The majority of Native Hawaiian families, in Hawaiʻi, are unable to makes

[1] Haw. Stat. Con. Art. XII, Section 4-6 (1978).
[2] HRS §10-3.
[3] Mana i Mauli Ola, OHA's 15-year Strategic Plan for 2020-2035, available at: https://www.oha.org/wp-content/uploads/Mana-i-Mauli-Ola.pdf.
[4] Honolulu Civil Beat, Poverty Persists Among Hawaiians Despite Low Unemployment, Sep. 19, 2018, available at: https://www.civilbeat.org/2018/09/poverty-persists-among-hawaiians-despite-low-unemployment/.
[5] ʻApoākea (Infinite Reach) Native Hawaiian Innovation Institute, Hānai ʻAi Hawaiʻi Program manual, 2022.

ends meet,[6] with 63% of Native Hawaiians reporting that they are finding it difficult to get by.[7] Native Hawaiians have the lowest household income.[8] Native Hawaiians have the highest poverty rates for individuals and families.[9] Native Hawaiians make less money,[10] with lower average earnings for both men and women.[11] Native Hawaiians have the highest rate of using public assistance and homeless services.[12]

OHA notes that the Working Group's final report approximated the total cost of cesspool conversions to be at $2 billion with an actual range between $880 million and $5.3 billion[13] – a substantial cost for the State to fully subsidize. The final report emphasizes that this issue is further compounded by the sheer lack of necessary staff to process applications and dispersals, and to provide adequate follow-up.[14] **The Working Group's final report further stated that "homeowners with an annual income of less than $126,000 would realize a financial hardship by the cost to covert."[15] According to DBEDT's 2020 census data highlights, the State's median family income was $96,462;[16] the median family income for Native Hawaiian households in that same year was $73,065.[17]**

OHA has the capacity to assist the State in this endeavor to address Hawai'i's environmental protection needs in so far as it is within OHA's authority to do so, while also mitigating potential disproportionate and disparate impact on Native Hawaiians in rural communities facing cesspool upgrade, conversion, and connection needs. OHA offers the

[6] Aloha United Way / United for ALICE, *ALICE in Hawai 'i: 2022 Facts and Figures*, Nob. 2022, p.6.
[7] Id. at 9.
[8] Dept. of Business, Economic Development and Tourism, *Demographic, Social, Economic, and Housing Characteristics for Selected Race Groups in Hawaii*, Mar. 2018, p.3.
[9] Id. at 13.
[10] OHA Report, *Affordable Housing for Hawai 'i and Native Hawaiians: Exploring Ideas and Innovation*, Aug. 2020, p.10.
[11] Dept. of Native Hawaiian Health, John A. Burns School of Medicine, *Assessment and Priorities for the Health and Well-Being in Native Hawaiians and Pacific Islanders*, 2020, p.12.
[12] Id.
[13] Cesspool Conversion Working Group Final Report to the 2023 Legislature, p.40.
[14] Id.
[15] Id. at 43.
[16] Hawai'i State Department of Business, Economic Development, and Tourism, Census Data Highlights, Sep. 17, 2020.
[17] OHA Databook, Chapter 04: Income, Table 04.22 Native Hawaiian Household Income by Selected Characteristics in the United States, and Hawai'i: 2010-2021, available at: https://www.ohadatabook.com/go_chap04.21.html.

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following amendment, which would add a new section to this measure beginning on Page 6, line 14, and to read:

SECTION 4. There is appropriated out of the general revenues of the State of Hawaii the sum of $ or so much thereof as may be necessary for fiscal year 2023-2024 and the same sum or so much thereof as may be necessary for fiscal year 2024-2025 for office of Hawaiian affairs beneficiary advocacy. The sums appropriated shall be expended by the office of Hawaiian affairs for beneficiary grants to cesspool upgrades, conversions, or connections in accordance with the purposes of this Act. The office of Hawaiian affairs shall submit a report to the legislature of all uses of this authority no later than twenty days prior to the regular sessions of 2024 and 2025.

SECTION 5. Statutory materials to be repealed is bracketed and stricken. New statutory material is underscored.

SECTION 6. This Act shall take effect on July 1, 2050.

OHA appreciates the opportunity to testify on SB426 SD2 HD1 and **respectfully asks the Legislature to take into consideration OHA's concerns and recommendations to advance the needs to protect Hawai 'i's precious natural resources, while also mitigating disproportionate and disparate impacts on Native Hawaiians.** Mahalo nui loa!

Testimony Presented Before the
House Committee on Consumer Protection & Commerce
Tuesday March 21, 2023 at 2:00 p.m.
By
Darren T. Lerner, PhD
Director, University of Hawaiʻi (UH) Sea Grant College Program,
School of Ocean and Earth Science and Technology
And
Thomas Giambelluca
Director, UH Water Resources Research Center
And
Michael Bruno, Provost
University of Hawaiʻi at Mānoa

SB 426 SD2 HD1 – RELATING TO CESSPOOLS

Chair Nakashima, Vice Chair Sayama, and Members of the Committee:

The University of Hawaiʻi Sea Grant College Program (Hawaiʻi Sea Grant) and UH Water Resources Research Center **support** SB 426 SD2 HD1.

This bill would effectuate a primary recommendation of the Cesspool Conversion Working Group to move up upgrade and conversion timelines for Priority 1 and 2 areas, which have been found to have the most severe impacts on our state's resources.

The upgrade and conversion of cesspools to advanced forms of wastewater treatment is critical to avoiding outcomes that could impair Hawaiʻi's drinking water and ecosystem health. Bringing forward the conversion timelines for Priority 1 areas to 2030 and Priority 2 areas to 2035 would demonstrate the time-sensitive nature of cesspool upgrade and conversion. To further support the success of this measure, the state should champion workforce development and capacity expansion for the wastewater management field.

Thank you for the opportunity to testify on this measure.

SB-426-HD-1
Submitted on: 3/17/2023 3:42:38 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Lisa Bishop	Friends of Hanauma Bay	Support	Written Testimony Only

Comments:

Aloha Chair, Vice Chair, and Committee Members,

Friends of Hanauma Bay urges you to pass this important bill!

With Aloha,

Lisa Bishop

President

SB-426-HD-1
Submitted on: 3/19/2023 8:46:06 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
philip ganaban	waianae neighborhood board	Oppose	Written Testimony Only

Comments:

The resident of makaha and Waianae oppose this bill. The bill will create financial hardship on residents that own cesspools or septic sytems to convert.

Cesspools have not shown in recent studies that it is affecting water tables and has proven to be safer than the current municipal system which has over flows and breaks.

Also there is no reason supported by law that provides reasons for septic systems to be shut down for city sewage systems

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1259 A'ala Street, Suite 300
Honolulu, HI 96817

March 21, 2023

The Honorable Mark M. Nakashima, Chair
House Committee on Consumer Protection & Commerce
State Capitol, Conference Room 329 & Videoconference

RE: Senate Bill 426, SD2, Relating to Cesspools

HEARING: Tuesday, March 21, 2023, at 2:00 p.m.

Aloha Chair Nakashima, Vice Chair Sayama, and Members of the Committee:

My name is Lyndsey Garcia, Director of Advocacy, testifying on behalf of the Hawai'i Association of REALTORS® ("HAR"), the voice of real estate in Hawai'i and its over 11,000 members. HAR provides **comments** on Senate Bill 426, SD2, HD1, which implements the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, with certain exceptions, and priority level 2 cesspools to be upgraded, converted, or connected before 1/1/2035, rather than before 1/1/2050. Effective 6/30/3000.

Hawai'i REALTORS® supports the goal of protecting our drinking water, streams, ground water, and ocean resources. We recognize that cesspool conversion is important to preserve our environment. According to the Cesspool Working Group Final Report[1], there are 13,821 cesspools categorized as Priority Level 1 and 12,367 cesspools categorized as Priority Level 2. By accelerating the mandate, Priority Level 1 cesspools would need to be converted in 5.5 years by December 31, 2029, and Priority Level 2 in 10.5 years by December 31, 2034.

While it may vary greatly depending on existing infrastructure and property location, it can take 8 to 9 months or longer for a homeowner to convert their cesspool to a Department of Health ("DOH") approved wastewater system. Steps include but are not limited to, identifying and securing financing, architects drawing up site plans, civil engineers drawing up and submitting the proposed system, obtaining DOH preliminary approval, engaging a contractor, obtaining permits, construction, and engineers getting final approval from DOH. As such, it is crucial that we properly plan and find ways to assist communities and homeowners as resources and manpower are limited, especially on the neighbor islands and in rural areas.

[1] Cesspool Conversion Working Group. (2022). *Final Report to the 2023 Regular Session Legislature*. State of Hawai'i Department of Health. https://health.hawaii.gov/opppd/files/2022/12/Act-170-SLH-2019-Nov-2022.pdf

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Moreover, moving up the mandate does not solve the financial dilemma for homeowners. The Cesspool Conversion Working Group conducted an affordability analysis[2] for homeowners. Based on the analysis, **97% of homeowners would be financially burdened by cesspool conversion costs.** Equally concerning, even with a $10,000 rebate 82% of homeowners would still be financially burdened. Costs to convert will vary greatly depending on resources, labor, permitting delays, property terrain, and other variables. While we appreciate and support the legislature's proposed tax credits and the approved DOH Cesspool Pilot Grant Program[3], neither will assist with upfront costs and will only reimburse certain homeowners with some of the cost after the conversion is done. Finding the funds to do a cesspool conversion in the first place is a major impediment for homeowners, especially kupuna on a fixed income. Most homeowners will not be able to afford to do this alone. Therefore, we respectfully recommend that efforts to aid communities and homeowners with cesspool conversion focus on upfront financial assistance in addition to wastewater infrastructure planning and development.

Thank you for your consideration of our comments. Mahalo for the opportunity to testify.

[2] Cesspool Conversion Working Group. (2022). *Final Report to the 2023 Regular Session Legislature*. State of Hawai'i Department of Health. https://health.hawaii.gov/opppd/files/2022/12/Act-170-SLH-2019-Nov-2022.pdf
[3] State of Hawai'i Department of Health Wastewater Branch. (2023). *Cesspool Pilot Grant Program (CPGP)*. https://health.hawaii.gov/wastewater/home/ccpgp/

To: The Honorable Chair Mark Nakashima, the Honorable Vice Chair Jackson Sayama, and Members of the Committee on Consumer Protection and Commerce

From: Hawai'i Reef and Ocean Coalition (by Ted Bohlen)

Re: **Hearing SB426 SD2 HD1 RELATING TO CESSPOOLS**

Hearing: Tuesday March 21, 2023, 2:00 p.m., room 329

Aloha Chair Nakashima, Vice Chair Sayama, and Members of the Committee on Consumer Protection and Commerce:

The Hawai'i Reef and Ocean Coalition (HIROC) is a group of scientists, educators, filmmakers and environmental advocates who have been working since 2017 to protect Hawaii's coral reefs and ocean. HIROC is deeply concerned about polluted runoff, particularly nutrients, running into the ocean from cesspools, especially the ones that cause the most pollution, those in Priority Levels 1 and 2.

The Hawai'i Reef and Ocean Coalition STRONGLY SUPPORTS SB426 SD2 HD1!

This bill is needed now because the health of Hawaii's people and quality of Hawaii's waters and aquatic life are being harmed by pollution from cesspools.

Hawai'i has over 80,000 cesspools that discharge about 50 million gallons of raw sewage into our groundwater every day! Cesspools are antiquated, substandard systems that damage public health, pollute drinking water, and lower water quality in streams, ground waters, nearshore marine areas, and the ocean. This discharge exposes people to sewage pathogens that can make them sick. The release of nutrients from cesspools causes algae growth, which can smother the precious coral reefs that are essential to protecting our shorelines, nurturing our fisheries and native species, and enabling our lucrative recreational economy.

Sea level rise will further exacerbate the public health and environmental problems as it will cause more cesspools to overflow onto the surface.

The cesspool conversion working group (working group) was established pursuant to Act 132 of 2018 to develop a long-range, comprehensive plan for conversion of cesspools statewide by 2050 and consider and recommend means by which the Department of Health can ensure that cesspools are converted to more environmentally-responsible waste treatment systems or connected to sewer systems.

In its final report at the end of 2022, the working group indicated that over the past four years, it had gathered and considered new scientific and policy data, studies by wastewater experts, activities in other jurisdictions, owners' ability to pay, financing mechanisms, and the latest technologies for treating wastewater. Based on this work**, the working group recommended ways to facilitate the upgrading of cesspools in Hawaii.**

This is the most important bill to implement the recommendations of the working group. The working group recommended staggering the timing of upgrades of cesspools and prioritizing them based on updated information about their pollution impacts. It makes sense to stagger the cesspool conversions, starting with the highest pollution impact first. This will both ensure reductions in the pollution to waters and facilitate implementation of the large number of wastewater system installations.

The Hawaii cesspool hazard assessment and prioritization tool was developed for the working group and applied to determine which cesspools should be upgraded first.

This bill implements the working group’s recommendation to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools.

Priority level 1 cesspools are those that represent **the greatest contamination hazard.** The report categorized **13,821 cesspools** in the State as **priority level 1 and recommended that they be upgraded, converted, or connected to sewers by 2030**.

Priority level 2 cesspools are those cesspools that **cause the next greatest amount of pollution** and represent a significant contamination hazard. The report categorized **12,367 cesspools in the State as priority level 2 and recommended that they be upgraded, converted, or connected to sewers by 2035**.

The working group recommended that the remaining cesspools categorized as priority level 3 (55,237, or approximately **sixty-nine per cent of the total) not be required to upgrade until 2050**, pursuant to existing law.

The bill authorizes the Director of Health to grant **exemptions** for homeowners who show it is infeasible to upgrade, convert or connect their cesspools. Legitimate reasons it is infeasible include **small lot size, steep topography, poor soils, or accessibility issues**. The bill also includes **exemptions where there is a planned development of sewerage upgrades to cesspools.** It authorizes the Director of Health to grant **extensions of up to five years at a time based on a demonstration of financial inability to pay or finance** a cesspool upgrade, conversion, or sewer connection and to **adopt rules necessary to grant those extensions.**

The working group also investigated technology issues. **New wastewater technologies** are being developed and may be an important part of the conversion effort.

The working group also investigated **financing issues**. Upgrades, conversions and connections will all be expensive. **Financing from federal, State, county and private resources will be needed to alleviate the financial burden on homeowners.**

This important bill will begin to address Hawaii's serious cesspool pollution problem in a reasonable way. The **Hawaiʻi Reef and Ocean Coalition STRONGLY SUPPORTS this bill** and asks the committee to pass it.

Mahalo!

Hawaiʻi Reef and Ocean Coalition (by Ted Bohlen)

Environmental Caucus of The Democratic Party of Hawai'i

To: The Honorable Mark M. Nakashima, Chair
The Honorable Jackson D. Sayama, Vice Chair
Members of the Committee on Consumer Protection & Commerce

Re: **SB 426, SD2 HD1 – RELATING TO CESSPOOLS**
Hearing: Tuesday, March 21, 2023, 2:00 p.m., Conference Room 329 & Videoconference

Position: **Strong support**

Aloha, Chair Nakashima, Vice Chair Sayama and Members of the Committee on Consumer Protection and Commerce:

The Environmental Caucus of the Democratic Party of Hawai'i with its 7,500 voting enrolled members, stands in strong support of SB 426, SD2 HD1. This measure would Implement the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, with certain exceptions, and priority level 2 cesspools to be upgraded, converted, or connected before 1/1/2035, rather than before 1/1/2050.

The Democratic Party of Hawai`i Platform plank on the environment provides that its members are to "protect and preserve Hawai'i's environment and achieve energy sustainability, advance measures to re-establish a healthy climate and environment for humans and fellow species, including actions to urgently address climate change, and work towards 100% renewable energy goals.

We believe that all people have the right to live in a clean, healthy and safe environment. We believe that the preservation of our natural environment and its ecological well-being is essential to ensuring a safe, healthy, bountiful life for future generations in Hawai'i. We support policies that create a more sustainable society. We support the restoration, preservation, and protection of native ecosystems.

We believe in the resource management principles outlined in the Public Trust doctrine of [Article XI, Section 1 of] the Hawai'i State Constitution." OUR PLATFORM | DPH (hawaiidemocrats.org)

Hawaii currently has an official goal to replace all its cesspools with better sewage treatment systems that cause less harm to the local environment and public health by 2050; however, as many as 83,000 cesspools release about 53 million gallons of untreated sewage into the islands' soil, streams and nearshore waters daily making the 2050 deadline too late to prevent substantial harm.

In the Report of the Cesspool Conversion Working Group, nearly 14,000 of the worst Hawaii cesspools – the ones that would potentially cause the most damage based on their location – are to be removed by 2030; followed by more than 12,000 "priority two" cesspools to be removed by 2035; and the remaining "priority three" 55,000 cesspools are to be removed by the original 2050 deadline.

"There are no benefits to human health or the environment if homeowners wait or postpone conversion until closer to the 2050 … deadline," the 17-member task force of scientists, public health officials, private industry representatives, elected leaders and environmental advocates wrote in a new 1,182-page report to the Legislature. Microsoft Word - Cesspool Conversion Plan Draft Final-copy-blue wave-FINAL use this one (hawaii.gov)

Implementing the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, with certain exceptions, and priority level 2 cesspools to be upgraded, converted, or connected before 1/1/2035, rather than before 1/1/2050 would be consistent with the state and counties' duties under the Public Trust Doctrine under Article XI, Section 1, of the Hawaii State Constitution, and the DPH Platform environmental plank to restore, preserve, and protect our native ecosystem.

Please support and pass this bill.

Mahalo for the opportunity to testify on this measure.

/s/ Melodie Aduja and Alan Burdick
Co-Chairs, Environmental Caucus of the Democratic Party of Hawai`i

SB-426-HD-1
Submitted on: 3/20/2023 1:36:05 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Manuel Mejia	Coral Reef Alliance (CORAL)	Support	Written Testimony Only

Comments:

To: The Honorable Chair Mark Nakashima, the Honorable Vice Chair Jackson Sayama, and Members of the Committee on Consumer Protection and Commerce
From: CORAL (Coral Reef Alliance)
Re: Hearing SB428 SD1 HD1 RELATING TO CESSPOOLS
Hearing: Tuesday March 21, 2023, 2:00 p.m., room 329

Aloha Chair Nakashima, Vice Chair Sayama, and Members of the Committee on Consumer Protection and Commerce:

I support this bill which will provide accelerated conversion deadlines for cesspools in Priority 1 & 2 areas as identified by Hawaiʻi Cesspool Prioritization Tool. These earlier deadlines will ensure that cesspools posing a greater risk (higher priority) to coastal ecosystems and public health are converted sooner rather than later to help reduce sewage pollution and ensure clean water for the people of Hawaiʻi.

Now, more than ever, we need to protect our coral reefs by providing clean water to them. Please pass this bill and thank you for all that you do to protect Hawaiʻiʻs waters, ecosystems and communitieis.

Mahalo,
Manuel Mejia

Regional Program Manager, CORAL

mmejia@coral.org

Email: communications@ulupono.com

HOUSE COMMITTEE ON CONSUMER PROTECTION & COMMERCE
Tuesday, March 21, 2023 — 2:00 p.m.

Ulupono Initiative supports SB 426 SD2 HD1, Relating to Cesspools.

Dear Chair Nakashima and Members of the Committee:

My name is Micah Munekata, and I am the Director of Government Affairs at Ulupono Initiative. We are a Hawai'i-focused impact investment firm that strives to improve the quality of life throughout the islands by helping our communities become more resilient and self-sufficient through locally produced food, renewable energy and clean transportation choices, and better management of freshwater resources.

Ulupono supports SB 426 SD2 HD1, which implements the recommendation of the Cesspool Conversion Working Group to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, with certain exceptions, and priority level 2 cesspools to be upgraded, converted, or connected before 1/1/2035, rather than before 1/1/2050.

Ulupono supports statewide cesspool conversion, working toward a more sustainable and environmentally sound approach to waste management and water security. Hawai'i has more than 88,000 cesspools statewide that discharge more than 53 million gallons of untreated sewage into the state's waters each day. This poses major health and environmental risks to our drinking water, groundwater, streams, and shore waters. By prioritizing conversions based on environmental impact and establishing interim benchmarks along the way to our 2050 goal, the State can start to chip away at the conversion of Hawai'i's most hazardous cesspools and provide for responsible waste management.

Thank you for the opportunity to testify.

Respectfully,

Micah Munekata
Director of Government Affairs

WASTEWATER ALTERNATIVES & INNOVATIONS

March 20, 2023

In Support of **SB426 SD2 HD1** Relating to Cesspools
House Committee on Consumer Protection and Commerce (CPC)
Hearing on March 21, 2pm,, Rm. 329

Aloha, Chair Nakashima,, Vice-Chair Sayama and Members of the Committee:

On behalf of the non-profit WAI: Wastewater Alternatives & Innovations, I am writing in **strong support of SB426 SD2 HD1.** This bill will provide accelerated conversion deadlines for cesspools in Priority 1 & 2 areas as identified by Hawaiʻi Cesspool Prioritization Tool. These earlier deadlines will ensure that cesspools posing a greater risk (higher priority) to coastal ecosystems and public health are converted sooner rather than later to help reduce sewage pollution and ensure clean water for the people of Hawaii.

Hawaii has more than 83,000 cesspools across the state, discharging 52 million gallons of raw sewage each day into Hawaii's waters. That's similar to a massive sewage spill every day! The people of Hawaii need this law to make sure their wastewater systems aren't polluting the groundwater, drinking water sources or nearby surface waters.

As a member of the State's Cesspool Conversion Working Group over the last four years, I believe that accelerating the deadlines for higher priority cesspools is essential to reduce sewage and nutrient pollution in coastal waters which impact Hawaii's reef ecosystems. In addition, converting these higher priority cesspools will also reduce the contamination of groundwater and drinking water resources as well.

WAI is dedicated to protecting our drinking water, groundwater and near-shore ecosystems by reducing sewage pollution from cesspools and failing septic systems. Our goal is to help find more innovative, affordable, and eco-friendly solutions to wastewater management. Better sanitation systems reduce sewage pollution and make properties more valuable, while also protecting our groundwater, streams and the health of our coral reefs and coastal areas.

Hawaii is struggling with serious sewage pollution problems, and the state has a mandate to make sure all cesspools are converted in the next three decades. Accelerated deadlines is the only way to help ensure that Hawaii reaches that goal by 2050, paying specific attention to converting higher priority cesspools (which have a higher impact to the environment) sooner. I support amendments for the DOH Wastewater Branch to grant temporary exemptions to those who can't convert cesspools due to small lot size, poor soil conditions or proven inability to afford the full costs.

This bill creates a practical and expedient phased deadline approach to start the conversion process as soon as possible, and it's the only way the state will be able to meet the mandate to convert all cesspools by 2050. Mahalo for your leadership on this issue and support of this bill.

Aloha,
Stuart Coleman
Stuart H. Coleman, Executive Director

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SB-426-HD-1
Submitted on: 3/17/2023 7:44:56 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
gina salcedo	Individual	Oppose	In Person

Comments:

Statement of Amendments to be provided in person

SB-426-HD-1
Submitted on: 3/17/2023 7:46:23 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
austin salcedo	Individual	Oppose	In Person

Comments:

Statement of Amendments to be provided in person

SB-426-HD-1
Submitted on: 3/19/2023 1:57:43 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Kevin McClintock	Individual	Comments	In Person

Comments:

Issue 1; Cesspool Pilot Grant Program (CPGI). Program Effective qualification date of 1 July 2022 "disqualifies" Individual Wastewater Systems (IWS) upgrades (cesspool to septic/ATU) completed between 1 Jan 2021 and 30 June 2022 elimibnating **ANY** and **ALL**incentives to upgrade cesspools in that period. My upgrade cost exceeded $50,000.00 and was completed 6 Apr 2022, 54 days prior to CPGI qualification and after the upgrade tax credit expired and was neccessitated by the Wastewater branch requirement to upgrade IWS's prior to approval of a city/county building permit for home improvements, additions or new construction. This represents a significant financial and public health mandate in the absence of public infrastructure with arbitrary qualification dates for homeowners executing upgrades in aforementioned time period. Additionally there is possibly a group of disenfranchised homeowners who completed cesspool upgrades in the post taxcredit/pre-CPGI period.

Relief Sought: Appropriate agency/body Revise CPGI qualification dates to include cesspool upgrade post tax credit period (1 Jan 2021 thru 1 July 2022)

Issue 2: Due to the high cost of Cesspool upgrades to septic systems (with a multi-decade life expectancy and by design contaminant containment), a **sewer connection exemption** (thru bill language) should be made for "mandated sewer connection" in the event sewer infrastructure becomes available to the upgraded property. Typically cesspool upgrades are amortized over extended periods and with a sewer connection mandate a significant financial burden would imposed on homeowners.

Relief Sought: Insert "sewer connection exemption" language in bill for appropriate time period for upgraded properties.

SB-426-HD-1
Submitted on: 3/19/2023 11:53:18 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Ken Suiso	Individual	Oppose	In Person

Comments:

Having clean drinking water and oceans are a goal that is universally shared by all residents of Hawaii. However the SB426 will seriously negatively impacts on almost landowners Statewide. It appears this legislation was drafted to benefit of special interest. The acceleration of cesspool conversions by 2030 is unreasonable. The unintended or intended consequences are as follows:

1. There was no direct outreach to affected landowners as required by act 132 objectives of the Cesspool Conversion Working Group.
2. Conversion from cesspools will be a severe financial burden. Conversion of cesspools may exceed $50,000 per site this in a burden to landowners statewide in the 100s of millions of dollars.
3. This is a particularly burdensome for those on fixed incomes.
4. SB426 will force will force some local families to sell their properties to affluent non Hawaii resident land and negatively effect the entire Hawaii real estate market.
5. The Dept of Health (DOH) Cesspool Conversion Working Group make up is flawed. It has no members that represent landowners.
6. I have Conflict of interest/corruption and profiteering concerns: The DoH Cesspool Conversion Working Group member Stewart Coleman is listed as a required representative of the Surf Rider Foundation, a California based organization. However, he is also the Executive Director for Wastewater Alternatives Innovations. It appears that Wastewater Alternatives Innovations will greatly benefit from the passage of SB426. https://waicleanwater.org/aboutus

7. The selection of priorities (1,2 & 3) to require the conversions of cesspools are inconsistent and arbitrary may violate State and Federal laws.

8. SB426 will increase the price of housing Statewide.

9. SB426 will require some landowners to sell their homes. Which will be likely to then purchased by Non-residence of Hawaii.

10. SB426 will cause more homelessness.

11. The homeless on Hawaii Beaches with out and proper restroom facilities present a greater threat of fecal contamination of beaches and near shore waters than cesspools.

12. Having arbitrary deadlines to convert cesspools prior to approved solutions, programs and funding in place first is a recipe for failure.

13. Under SB426 a land owner may be required to convert to a Septic system (at $50,000) by 2030 , only to be then required to connect to a sewer system only a few years later.

14. If the roll out of the $20,000 Cesspool reimbursement plan is any indication, Implementation of SB426 will be a colossal failure.

1. Cesspool Grant was put together with application available and submission start March 15, 2023.
2. Despite my pleads, I was told that the application would only be available starting on the 15th of March. I was never told that you had to come down in person to get an application. I foolishly assumed that the Applications for the Grants would be available online….. Big mistake.
3. Why would not the priorty for grants be for landowners in Priority 1?

I plead with you to not “bow” to the special interest of Big Business, Big Developers and the EIC (Environmental Industrial Complex)

Please reject SB426 and put Hawaii’s struggling families and farmers before special interest and their lobbyist.

Thank you for this opportunity to testify against Bill SB 426. By way of introduction, I have a PhD in hydrogeology and undergraduate degrees in chemistry and geology and am an avid environmentalist. I have lived in Hawaii for almost 40 years, raised my family here and believe in the values of *Mālama ʻĀina.* I have no affiliation to any of the parties involved with Bill SB 426 and do not own property with a cesspool.

SB 426 should be rejected because the rationale for the bill is overstated and does not stand up to scientific scrutiny. In addition, implementation of this bill will disenfranchise underserved communities, including Native Hawaiians.

A small minority of legacy cesspools located in specific hydrogeologic settings around the State undoubtedly contribute raw sewage to public waters and efforts should be taken by the appropriate city and state agencies to correct these isolated cases. However, most existing legacy cesspools in the State of Hawaii do not pose a threat to the environment. The proposed legislation will require mostly low-income homeowners throughout the State (97 percent of those impacted by SB 426 have household incomes less than $126,000) to spend up to 5 billion dollars on cesspool conversions which will produce insignificant ecosystem and human health benefits. Bill 426 will saddle these low-income citizens with monthly financing and maintenance costs up to seven times higher than monthly costs paid by generally more affluent citizens that live in areas served by a county sewer system. The numbers I am quoting come from the reports prepared by the Cesspool Conversion Working Group.

As a result, I recommend that Bill SB 426 be rejected and that the companion Bill SB 285 be modified to direct the Hawaii Department of Health to produce defensible scientific data for those specific areas around the State where legacy cesspools are believed to be causing detrimental harm to the environment. This proposed modification would be a far more efficient approach for protecting human health and the environment while sparing mostly low-income citizens living in mainly rural portions of the State from an onerous financial burden.

The Cesspool Working Group report acknowledges that the mandatory statewide conversion of cesspools will not eliminate nitrogen input to the environment but merely somewhat reduce it. Their report states:

"*However, septic tank systems do not provide significant treatment for total nitrogen. Upgrading cesspools to septic tanks in areas with a high density may not provide significant protection to groundwater or near surface water quality."*

I have published several scientific publications focused on water quality on the island of Oahu. Most recently, a peer reviewed paper will be published later this month in the International Journal of Environmental Impacts. This paper evaluated the environmental impact of legacy cesspools and leaky sewer pipes on stream and spring water quality on the island of Oahu.

This new study found:

1. The average concentration of conservative wastewater tracers measured in Oahu streams and springs is extremely low; in fact, they were about one percent of the average concentration measured in over 1,200 streams sampled worldwide in a separate study.
2. The average pharmaceutical and nutrient levels in streams and springs sampled in areas with high densities of cesspools and sewer lines were not statistically different from concentration levels measured in streams and springs located in areas with low densities of cesspools and low sewer line densities.
3. Little evidence of wastewater was detected in streams located within the Priority 1 Areas delineated by the Hawaii Cesspool Hazard Assessment Group for expedited cesspool closure.

A separate study published in 2021 found that more total nitrogen discharged from a small watershed into Kaneohe Bay during a 12-hour storm event than the Cesspool Working Group estimates daily discharges to the ocean from all cesspools on Oahu. No cesspools exist within this mixed residential/forested watershed which includes Castle High School. Most of the total nitrogen exiting this watershed during the storm event originated from the undeveloped forested areas surrounding the residential community. These findings illustrate that the annual flux of total nitrogen entering coastal waters around Oahu from natural sources is significantly greater than the incremental reduction in cesspool derived nitrogen that would result from implementation of the proposed legislation.

I have attached the publications cited above to my written testimony and am available to meet with anyone who would like more details.

Mahalo nui loa

Steven Spengler

IDENTIFICATION OF SEWAGE EXFILTRATION IN COASTAL AREAS THROUGH THE MONITORING OF DRUGS AND STIMULANT CONCENTRATIONS IN URBAN STORM DRAINS

STEVEN SPENGLER[1] & MARVIN HESKETT[2]
[1]Pacific Rim Water Resources, Hawai‘i
[2]Element Environmental, Hawai‘i

ABSTRACT

One of the major barriers for municipalities responsible for mitigation of sewage exfiltration is locating grossly leaking sections of the sewage conveyance system in a time-, labor- and cost-efficient manner. In this study, water samples were collected from the dense network of manholes overlying the storm drain systems in the tourist area of Waikīkī and inland residential areas on the island of O‘ahu, Hawai‘i. The majority of the sewage conveyance infrastructure in this coastal area is submerged and the storm drains are routinely subject to backflow during high tide. Exfiltration of sewage from the aging conveyance system in this coastal area contaminates the surrounding shallow brackish aquifer, which then enters leaking pipe joints and cracks in the storm water conveyance system. Samples collected from the storm drains were analyzed for the presence of carbamazepine, a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug, which behaves as a conservative tracer in the environment (> 50 days half-life, low sorption). Samples were also analyzed for the more labile anthropogenic tracer caffeine (~4 day half-life). The higher stability of carbamazepine enables detection of this compound at greater distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage, given its ephemeral nature and relatively high and ubiquitous presence. The concentration levels and spatial distribution of detection of these two anthropogenic biomarkers were successfully used to identify areas of ongoing sewage exfiltration in Waikīkī and surrounding residential communities. The variation in carbamazepine and caffeine concentrations measured in Waikīkī storm drains over a 1 year period generally correlate with daily visitor arrivals to O‘ahu.

Keywords: sewage exfiltration, Hawaii, Waikiki, pharmaceutical tracer, storm drain contamination.

1 INTRODUCTION

An average of 394 million liters per day (mld) of sewage is conveyed through O‘ahu’s 3,380 km web of underground sewer lines. The majority of sewer lines in urban Honolulu are over 65 years old with an overall age range distribution on O‘ahu as follows: <25 years; 22.2%, 26–50 years; 18.3%; 51–75 years; 42.7%, 76–100 years; 11.8% and >100 years, 1.2%. In coastal areas on O‘ahu, the sewage conveyance system is largely immersed in the shallow, brackish to saline groundwater aquifer that underlies the coastal plain. The warm climate in Hawai‘i combined with the high sulfate content of the saline groundwater produces corrosive hydrogen sulphide gases that results in constant challenges in maintenance of the aging sewage conveyance system. Thus, there is an ongoing need to replace and upgrade Hawai‘i’s sewer lines and force mains due to both capacity and structural integrity issues [1].

The exfiltration of sewage in coastal settings such as Waikīkī contaminate the surrounding shallow brackish aquifer, which then enters leaking pipe joints and cracks in the portions of the aging storm water conveyance system that conveys tidal water inland from either the Ala Wai Canal or the Pacific Ocean during the upper part of the tidal cycle. One study by the United States Environmental Protection Agency reported between 12% and 49% of wastewater flows are lost due to leaking infrastructure in United States cities [2]. A recent

WIT Transactions on The Built Environment, Vol 208, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/FRIAR220061

survey completed by the Water Environment Foundation in Milwaukee (315 outfalls, n = 1,500 samples) estimated that 30% of stormwater outfalls show high and consistent levels of untreated wastewater and 8% had very high levels of wastewater.

The system-wide amount of wastewater exfiltration from Oʻahu's sewage system is unknown. A rough, upper-limit estimate of the magnitude of exfiltration can be made by comparing the average daily groundwater withdrawals on Oʻahu by the island-wide water utility, the Honolulu Board of Water Supply (BWS), during the wet winter months of January to March 2021 (127.6, 124.8 and 121 mgd, respectively) with the daily average volume of wastewater treated at the nine Waste Water Treatment Plants (WWTP) operated by the City and County of Honolulu (CCH) on Oʻahu during 2021 (103.7 mgd). The difference in the volume of groundwater pumped by the BWS during these wet months (when use of water for irrigation purposes is at a minimum) and the volume of wastewater is around 20 mgd. It is likely that at least half (10 mgd) of this difference is used during these wet winter months for purposes (residential irrigation, small-capacity private WWTP, wash cars, fill pools, etc.) that doesn't result in a return of the spent water to the sewer system. By comparison, the average daily groundwater withdrawal by the BWS during the dry summer months of June, July and August 2021 were 150, 151 and 150 mgd, a difference of around 45 mgd from the volume of water processed at the nine CCH WWTPs. This simple analysis suggests that the system-wide exfiltration rate on Oʻahu is somewhere in the order of 10%, with the majority of exfiltration likely occurring in the older sections of pipes present in urban Honolulu.

One of the major barriers for municipalities responsible for mitigation of sewage exfiltration is locating grossly leaking sections of the sewage conveyance system in a time-, labor- and cost-efficient manner. The City and County of Honolulu sewers are currently monitored and rehabilitated through extensive CCTV inspection of sewer lines, and a semi-automated computer algorithm to evaluate the CCTV results [1].

The primary objective of the study was to determine whether mapping of the spatial distribution of the maximum pharmaceutical (carbamazepine and caffeine) concentration levels measured in the storm drain systems in the vicinity of Waikīkī can be used to identify areas of on-going sewage exfiltration from the aging sewer conveyance systems in these areas. Ideally, this type of study would utilize shallow groundwater data collected from a dense network of monitoring wells within the study area. Unfortunately, no such monitoring network exists. So, in this study, samples were collected between November 2020 and January 2021 from the dense network of storm water manholes present in this coastal tourist destination and the adjacent, inland McCully-Moiliili residential areas. In these areas, wastewater contaminated groundwater seeps into the stormwater conveyance pipes and mixes with the tidally driven water that enters the storm drain system from the Ala Wai Canal or the ocean (dependent on which side of Waikīkī is sampled). A secondary objective of the study was to measure the temporal variations in caffeine and carbamazepine concentrations measured in three Waikīkī storm drains and at two Ala Wai Canal locations between February 2021 and December 2021, when the number of tourists visiting Hawaiʻi varied greatly due to COVID pandemic travel restrictions to the islands.

1.1 Caffeine and carbamazepine

Carbamazepine and caffeine are known as emerging contaminants, which describes pollutants that have been detected in water bodies, may have ecological or human impact, and typically are not regulated under current environmental laws. These compounds are also known as micropollutants because they are typically present in trace quantities (part per trillion to billion levels) in the environment. These micropollutants enter the environment during our daily routines when we consume, flush away, or wash these compounds down the sink. As a result, these compounds are increasingly being used as anthropogenic (human) markers of sewage contamination. Carbamazepine and caffeine were the first and second (62.3% and 56.1%, respectively) most commonly active pharmaceutical ingredients detected in 1,052 river samples collected from 104 countries worldwide in a recently published global-scale study [3]. Caffeine was detected in river samples collected from every continent while carbamazepine was detected in rivers on all continents except Antarctica. The detection frequency of caffeine and carbamazepine in rivers were similar across all six continents where both pharmaceutical compounds were detected.

Caffeine is a naturally occurring stimulant found in coffee, soda, tea, chocolate and energy drinks. The daily consumption rate of caffeine varies worldwide. Northern European countries tend to consume higher daily doses of caffeine (190 to 260 mg/day/person) compared to warmer Southern European countries (80 to 120 mg/day/person). The average daily consumption of caffeine in the United States is 165 mg per person per day [4]. Caffeine is extensively metabolized by humans during consumption, with less than 5% excreted unchanged in the urine [5].

Carbamazepine is a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug. The dosage range for carbamazepine for those on the medication is between 400 to 1,200 mg/day. Daily per capita consumption rates of carbamazepine range from 0.03 to 0.44 mg/day/person [6]. Following consumption, up to 10% of CBZ is excreted from the human body [7].

Caffeine is effectively removed (> 95%) by conventional treatment at WWTPs while carbamazepine is poorly removed (typically less than 10%). Caffeine was found to undergo significant microbial degradation in the Jamaica Bay estuary near New York City while little evidence for removal of carbamazepine was observed [8]. These findings suggest that carbamazepine behaves as a conservative tracer in the environment whereas caffeine is comparatively labile. The persistence of carbamazepine in conventional treatment processes leads to its widespread occurrence in water bodies, especially on the mainland United States where WWTPs commonly discharge treated effluent into nearby surface water bodies [9]. The stability of carbamazepine upon release to the environment enables detection at larger distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage or grey-water, given its ephemeral nature and higher initial concentration levels in untreated wastewater.

1.2 Caffeine and carbamazepine concentration levels in sewage in Hawaiʻi

Researchers at the University of Hawaiʻi monitored the variation in sewage flow and caffeine concentration in the main sewer line exiting Manoa Valley on Oʻahu by collecting composite samples over 3 hour periods during two, week-long dry-weather monitoring periods [10]. They found that the concentration of caffeine showed reproducible daily patterns with the highest concentrations being observed in the mornings and at end of the day (i.e., 8–11 AM and 5–8 PM composite samples), which also corresponded to periods of generally higher sewage flow exiting Manoa Valley. The measured concentration of caffeine in the sewage ranged from 5,000 to 103,400 parts per trillion (ppt, ng/L), with the highest flux of caffeine (2.4 mg/sec) exiting the valley between 8 and 11 AM. The authors associated the primary source of caffeine with the preparation and consumption of coffee and tea, which is secreted to the sewer system by the regular daily metabolic activities of the residents in the valley.

The Safe Drinking Water Branch of the State of Hawaiʻi Department of Health (HDOH) conducted two rounds of sampling of raw wastewater influent at four WWTP and also collected thirteen samples of treated wastewater effluent generated at thirteen WWTP facilities that produce reclaimed water throughout the State of Hawai‘i [11]. The HDOH samples were analyzed using LC-MS-MS methods. Carbamazepine was not detected in the wastewater influent; likely due it being masked by the chromatographic peaks of higher concentration analytes. During the current study, a total of twenty samples were collected from septic tanks at various beach parks on the island of O‘ahu and analyzed for caffeine and carbamazepine using an ELISA immunoassay method. Table 1 summarizes the caffeine and carbamazepine concentrations measured. The median concentration of caffeine and carbamazepine is around 100,000 ppt and 500 ppt, respectively.

Table 1: Caffeine and carbamazepine concentrations measured in septic tanks and WWTP effluent and influent in Hawai‘i.

Source	Caffeine (parts per trillion)				
	Mean	Median	Max. Detect	Count	Detect Frequency
Septic Tanks	19,925	11,600	83,200	11	100%
WWTP Influent[1]	96,238	108,000	150,000	8	100%
WWTP Effluent[1]	152	33	1,200	23	96%
Source	**Carbamazepine (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	682	552	1,735	20	100%
WWTP Influent[1]	ND	ND	ND	8	0%
WWTP Effluent[1]	113	110	220	23	65%
ND = Not Detected					
[1]Oahu WWTP Influent/Efffluent Data from HDOH [11]					

2 DESCRIPTION OF STUDY AREA

This study was conducted on the island of O‘ahu in the 4 km^2 tourist center of Waikīkī and the coastal portion of the adjacent residential communities of McCully-Moiliili, which are comprised of a mix of high rises, low rises and single-family residential homes. Roughly 75% of the State of Hawai‘i’s population of 1.44 million people reside on O‘ahu. Waikīkī means “spouting water” in the Hawaiian language in reference to the rivers and springs that flowed into the area during historic times. The original marsh and swamp lands were considered a health hazard and drained during construction of the Ala Wai Canal in the 1920s, which directs streamflow and storm runoff from the Manoa and Palolo watersheds to the Pacific Ocean and separates Waikīkī from the inland McCully-Moiliili communities. During development of the McCully-Moiliili areas in the 1940s, inland stream flow, spring flow and storm runoff through these areas were routed into lined channels known as the Hausten and Makiki Ditches, which empty into the Ala Wai Canal.

Waikīkī became a major tourist destination in the 1950s with the advent of long-distance air travel to the islands from the mainland United States which prompted the beginning of the construction of the numerous high-rises and resort hotels that dominate today’s skyline. As a result, most of the sewer and storm-drain infrastructure in the Waikīkī area is between 50 and 70 years old. Visitor arrivals reached one million for the first time in 1968, filling approximately 15,000 hotel rooms. From 1990 to 2013, between 4 and 5 million visitors arrived annually on the island of O'ahu [12], and the number of hotel rooms in Waikīkī had expanded to 30,000 rooms. Between 2013 to 2019, annual tourist arrivals to O'ahu increased to between 5 and 6 million visitors. Peak visitor arrivals tend to occur during the months of December and July and international visitors (largely from Japan) contribute around one-third of the travelers to Hawai'i. Travel restrictions imposed due to the COVID-19 pandemic caused the annual visitor arrivals to O'ahu to plummet to 1.5 million in 2020 followed by a partial rebound of 3.3 million annual visitor arrivals in 2021.

The sampling effort presented in this study was conducted between November 2020 and December 2021, roughly 6 to 20 months into the global pandemic. The spatial distribution of sewage exfiltration in the Waikīkī and inland McCully-Moiliili areas was based on sampling conducted between November 2020 to January 2021 while temporal variations in caffeine and carbamazepine concentrations were monitored in three Waikīkī storm drain and two Ala Wai Canal locations between February 2021 and December 2021.

3 STUDY METHODOLOGY

A total of 70 storm drain and canal sampling locations were established within Waikīkī, the inland residential McCully-Moiliili communities and along the Ala Wai Canal which separates these two areas. The Ala Wai Canal receives input from the storm drain systems that underlie both the Waikīkī and the inland residential McCully-Moiliili communities. Samples were collected directly from the storm drains by inserting a 1.3 cm diameter PVC pipe through the vent hole in the storm drain manhole cover to the bottom of the storm drain, capping the top of the pipe, withdrawing the pipe from the manhole, and directly transferring the collected sample to a labelled sample container. A PVC pipe was also used to collect samples from the Ala Wai Canal, which allowed a vertical composite sample from the entire depth of the canal (~0.5 to 1.7 m) to be collected. Three rounds of sampling were conducted from this monitoring network between November 2020 and January 2021 under mid- to high-tide conditions to evaluate the spatial distribution of sewage exfiltration in the Waikīkī and inland McCully-Moiliili areas. Additional sampling was conducted between February 2021 and December 2021 from three Waikīkī storm drains and two Ala Wai Canal locations to monitor the temporal variation in concentration levels of these compounds. Samples were collected during the global COVID pandemic, when the number of tourists staying in Waikīkī greatly fluctuated due to travel restrictions imposed by the State of Hawai'i. Fig. 1 shows the location of the five repetitively monitored sites along with two canal and groundwater monitoring locations in Waikīkī previously sampled in 2018 for pharmaceuticals [13].

The samples were analyzed for general water quality parameters (temperature, specific conductance, salinity, dissolved oxygen, pH and turbidity) in the field and frozen shortly after collection. Enzyme Linked Immunosorbent Assay (ELISA) test kits manufactured by Eurofins were used to measure the concentration of caffeine and carbamazepine, typically in batches of 80 samples at a cost of less than $8 per sample.

3.1 Pathway of sewage contamination entering coastal storm drain systems

Water levels were measured during this study using transducers under dry weather conditions in the Ala Wai Canal and in the coastal storm drain network underlying Waikīkī and the coastal portion of McCully-Moiliili. Water level fluctuations were identical in amplitude and timing as the tidal changes measured at the National Oceanic and Atmospheric Administration (NOAA) gauge in Honolulu Harbor (NOAA Station ID: 1612340).

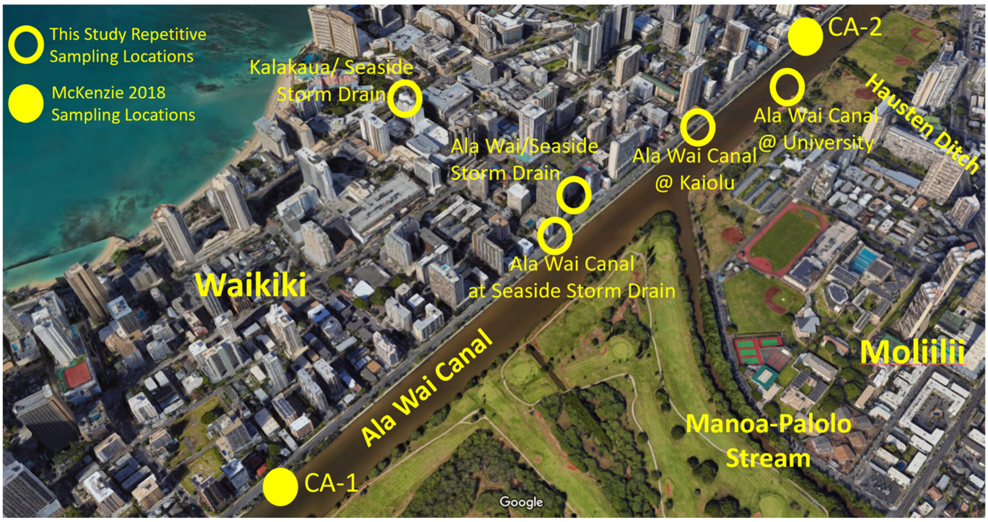

Figure 1: Repetitively sampled locations in Waikīkī during this study (open circles) and two 2018 monitoring locations (closed circles) [13].

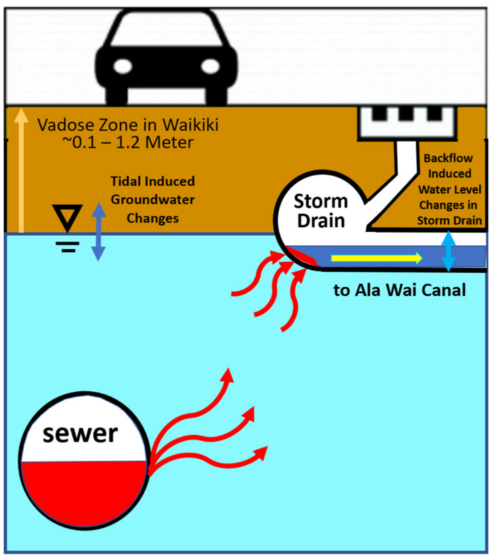

Figure 2: Depiction of mechanism of how sewage exfiltration enters storm drain system in tidally influenced coastal areas on O'ahu.

Previous studies have shown that leaking sanitary sewers can directly contaminate nearby leaking storm drains with untreated sewage during dry weather conditions [14]. Discharges can also enter the storm drain system indirectly, when groundwater contaminated by leakage from a nearby sewer enters the stormwater system. Fig. 2 depicts how leaks in sewer lines in coastal areas contaminate the surrounding brackish aquifer which can then enter cracks in the storm drain conveyance system during the lower portions of the tidal cycle when the groundwater levels are above the tidally driven water levels in the storm drain pipes. In Waikīkī, wastewater leaking outward from cracked pipes (exfiltration) in the study area migrates into the stormwater system, which acts as a very effective conduit to deliver leaking wastewater into the Ala Wai Canal. Based on the pattern of human consumption of caffeine (breakfast and dinner) and carbamazepine (taken orally twice per day), the concentration levels of these compounds in sewage tend to peak in mid-morning and early evening [10]. However, the caffeine and carbamazepine concentrations that leak into nearby storm drains have likely reached a quasi-steady state concentration in the contaminated groundwater during advective transport between the leaky section of sewer line and the cracks in the storm drain lines through which the contaminated groundwater enters.

Fig. 3 compares the salinities measured in the storm drain located at the intersection of Seaside and Kalakaua Boulevard in central Waikīkī with the salinities present in a storm drain located at the intersection of Seaside and Ala Wai Boulevard, directly adjacent to the Ala Wai Canal. The salinity in both the Waikīkī storm drain and the Ala Wai Canal increased by about 50% during high tide, as salt water from the Pacific Ocean is pushed landward into the storm drain with the tide. As the tide drops, the impact of brackish groundwater entering the storm drain system is seen in the falling salinities observed at both monitoring locations.

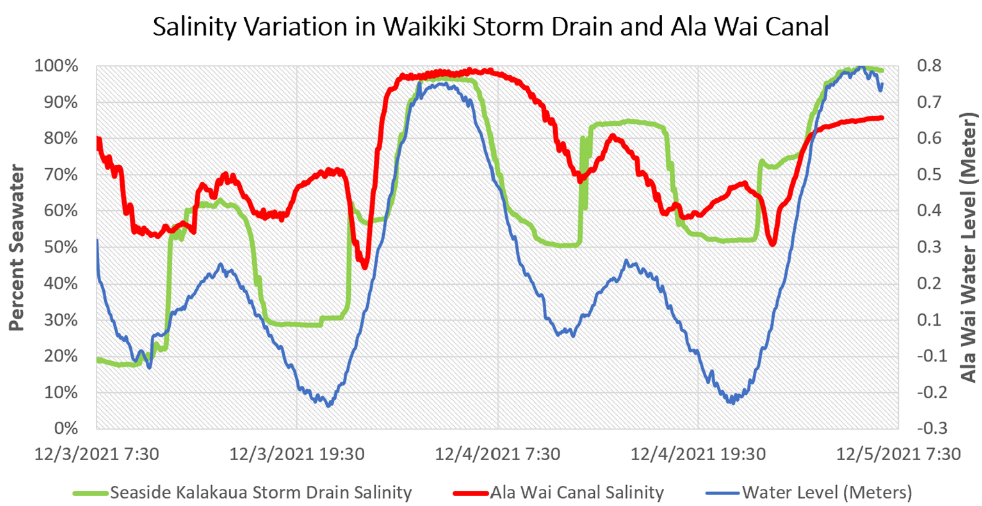

Figure 3: Variation in Salinity and water levels measured in storm drains located in the middle of Waikīkī and adjacent to the Ala Wai Canal.

Fig. 4 shows the change in water levels measured in two connected storm drains located 410 m apart in central Waikīkī and adjacent to the Ala Wai Canal during a large winter rainfall event. The annual rainfall in Waikīkī is around 635 mm per year. A total of 180 mm of rainfall fell in Waikīkī between 30 December 2021 and 3 January 2022 (weather underground station KHIHONOL275 located in central Waikīkī along the Ala Wai Canal).

As can be seen in this graph, the water levels in the storm drains in central Waikīkī quickly rise as much as 0.9 m above the water levels in Ala Wai Canal during intense rainfall events, producing a gradient hydraulic gradient of as much as 0.0022 m/m that drives runoff from the center of Waikīkī towards the canal.

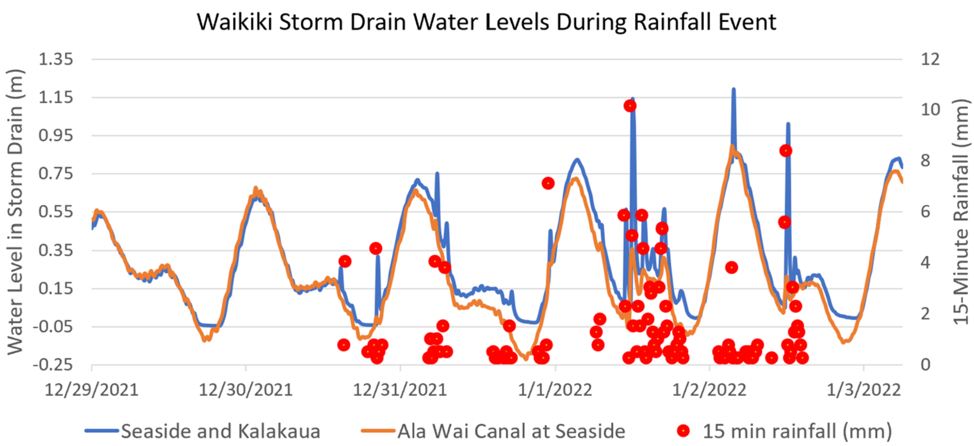

Figure 4: Water level variations in Waikīkī storm drains during a large rainfall event.

The average surface elevation of the majority of land in Waikiki is less than 1 m. Sea-level rise (SLR) is currently predicted to rise between 0.18 to 0.24 m from 1994 to 2014 sea levels by 2050 [15]. Groundwater inundation flooding of the coastal areas in this study area will occur contemporaneous with SLR related flooding as groundwater levels are lifted [16]. Fig. 4 illustrates how vulnerable Waikīkī is to future flooding events should a high-intensity rainfall event hit the area during a high or king tide. At high-tide, much of the capacity of the storm drain system in these coastal areas is filled with tidal water rendering the system unable to convey storm runoff towards the Ala Wai Canal or the Pacific Ocean.

4 SAMPLING RESULTS

The monitoring network of 70 manholes established in the Waikīkī and McCully-Moiliili areas were sampled a minimum of three times between November 2020 and January 2021 under upper mid- to high-tide conditions (typically greater than 0.55 m water levels) when tidal backflow partially fills the underlying storm drain conveyance system. Immunoassay methods were used to quantify the concentration levels of caffeine and carbamazepine present in the storm drain system and in Ala Wai Canal. Fig. 5 shows the storm drain and canal sites sampled (red dots), the layout and age of the sewer system in the area, the location of on-site sewage disposal systems in the area and the maximum carbamazepine concentration measured in the storm drain and canal samples (minimum of three samples) collected from each sampling site between November 2020 and January 2021.

Ponded water was present along the street curb under dry weather conditions near the storm drains sampled on Kaio’o Drive and Namahana Street during the 3 month sampling period (Fig. 5). The dry weather ponded water at these two sites had disappeared by April 2021 suggesting that the water present on the street was related to either a sewage line or water line leak at these locations. The elevated carbamazepine concentrations measured in samples collected from the Hausten ditch were likely related to work undertaken for the Moiliili Area Sewer Reconstruction project [17]. During the sampling work, contractors hired by the City and County of Honolulu (CCH) were replacing a section of deteriorated cast iron sewer line from 808 to 828 Hausten Street that was originally installed in 1935 and located adjacent to the inland end of the Hausten Ditch. According to a press release, CCH intended

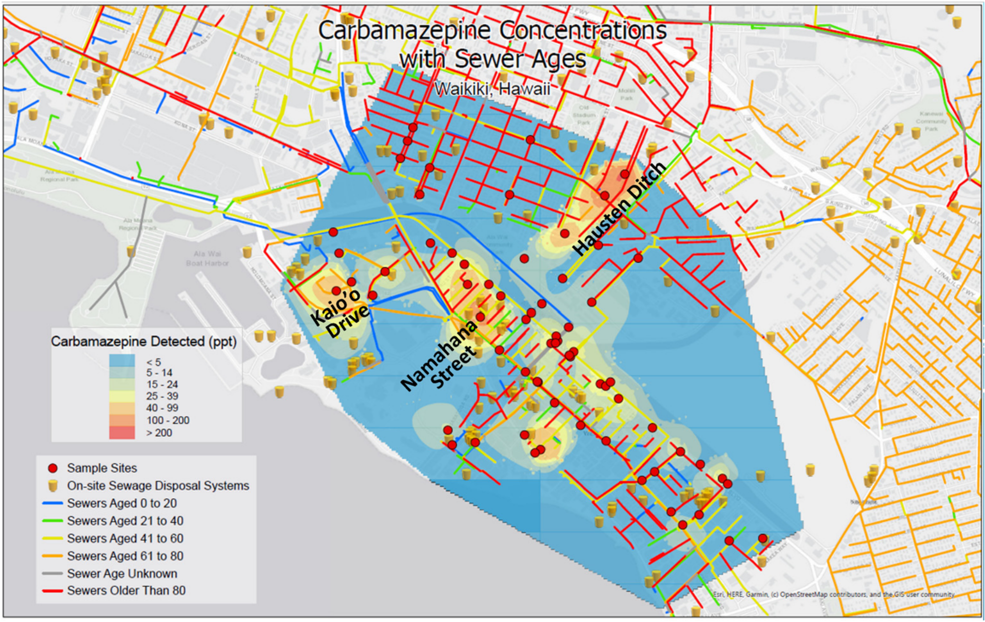

Figure 5: Spatial distribution of the maximum carbamazepine concentration measured in Waikīkī and Moiliili-McCully storm drains between November 2020 and January 2021.

to bypass the sewer line continuously, for 24 hours, 7 days a week during construction using pumps and generators. Based on the elevated carbamazepine concentrations measured in the Hausten Ditch between November 2020 and January 2021, the sewer line being repaired was not successfully bypassed. A follow-on sample collected from the Hausten Ditch in early February 2021 after the sewer repair work was completed did not contain detectable levels of carbamazepine.

4.1 Time variation in caffeine and carbamazepine concentrations

The COVID pandemic had a dramatic impact on the Hawaiian tourist industry. Annual visitors to O‘ahu plummeted from over 6 million annual visitors between 2017 and 2019 to 1.5 million visitors in 2020 and 3.3 million visitors in 2021. The decline in the number of tourists was reflected in the volume of wastewater generated. The Sand Island WWTP processes roughly 60% of the wastewater generated on O‘ahu and covers the metropolitan Honolulu area, including the Waikīkī and McCully-Moiliili areas. The average daily sewage flow processed at the Sand Island WWTP declined about 12% from a 2017 average daily volume of 260 mld to an average daily volume of 228 mld in 2021.

Five monitoring locations (Fig. 1) (three in Waikīkī storm drains and two in the Ala Wai Canal) were repeatedly sampled at both low and high tide from February 2021 to December 2021. This time series sampling was conducted to evaluate whether the caffeine and carbamazepine concentrations present in Waikīkī storm drains and in the adjacent Ala Wai Canal varied: (1) as a function of the tidal cycle (i.e., high versus mid to low tide) and; (2) over the sampling period, when the 7 day average daily number of visitors to Waikīkī varied from around 6,000 to 30,000 visitors per day as a result of varying travel restrictions related to the COVID pandemic.

Table 2 summarizes the mean, median and maximum concentration levels of caffeine and carbamazepine along with the average salinity measured in the three monitored storm drain locations in Waikīkī and in the two monitoring locations in the Ala Wai Canal between February and December 2021 along with data collected from two canal and groundwater monitoring locations (CA-1 and CA-2, Fig. 1) previously sampled in 2018 [16]. The storm drain located inland of the intersection of Ala Wai and Seaside was impacted by significant intrusion of brackish groundwater as reflected by the low average salinity measured in this storm drain (roughly one quarter of the salinity measured at the nearby the Ala Wai Canal monitoring locations). The presence of significant groundwater at this location is believed to be due to the greater degree of submersion of this storm drain (bottom depth of –1.15 m) than the other two storm drains monitored (Seaside/Ala Wai drain at the canal and Seaside/ Kalakaua bottom depths of –0.24 and –0.45 m). The median caffeine and carbamazepine concentrations measured in the two interior Waikīkī storm drains indicate a sewage or greywater component presence of between 1.3% and 6.4% in the storm drain system.

Table 2: Caffeine and carbamazepine concentrations measured in Waikīkī storm drains and Ala Wai Canal during current study (2021) and previous 2018 study [13].

Waikīkī Repetitive Sampling Locations	Caffeine (ppt)					
	Mean	Median	Max. Detect	Count	% Detect	% Seawater
Storm Drain: Kalakaua/Seaside	4,347	3,269	11,562	24	100%	58%
Groundwater Impacted Storm Drain: Ala Wai / Seaside	1,690	1,273	7,580	27	100%	21%
Storm Drain: Ala Wai Canal at Seaside	677	398	2,793	27	81%	74%
Ala Wai Canal at Kaiolu	543	207	1,735	25	88%	80%
Ala Wai Canal at University	287	82	1,439	24	71%	79%
CA-1 and CA-2 Surface Water[1]	1,091	1,010	2,700	8	75%	NR
CA-1 and CA-2 Groundwater[1]	986	1,045	1,600	8	88%	NR
Source	**Carbamazepine (ppt)**					
	Mean	**Median**	**Max. Detect**	**Count**	**% Detect**	**% Seawater**
Storm Drain: Kalakaua/Seaside	28	12	136	29	93%	58%
Groundwater Impacted Storm Drain: Ala Wai / Seaside	35	32	102	33	100%	21%
Storm Drain: Ala Wai Canal at Seaside	7	2	27	31	67%	74%
Ala Wai Canal at Kaiolu	6	0	44	30	37%	80%
Ala Wai Canal at University	6	0	36	29	48%	79%
CA-1 and CA-2 Surface Water[1]	44	0	150	8	75%	NR
CA-1 and CA-2 Groundwater[1]	83	105	130	8	75%	NR
NR = Not Reported						
[1]Surface and Groundwater Samples Collected in 2018 [13]						

The highest mean/median caffeine concentrations were measured in the storm drain in central Waikīkī while slightly higher carbamazepine concentrations were measured in the groundwater impacted storm drain at the intersection of Ala Wai and Seaside. The caffeine concentrations measured in the storm drain along the Waikīkī side of the Ala Wai Canal and at the canal monitoring location at Kaiolu Street were higher than the caffeine concentrations measured at the inland monitoring location across the canal at the end of University Avenue.

The median caffeine concentrations measured in the groundwater impacted storm drain in 2021 were similar to caffeine levels measured in groundwater in 2018 (1,273 versus 1,045 part per trillion (ppt)) while the caffeine concentrations measured in the Ala Wai Canal in 2021 were significantly lower than 2018 levels (82-398 versus 1,100 ppt). The median carbamazepine concentrations measured in the groundwater impacted storm drain in 2021 were less than a third of the carbamazepine levels measured in groundwater in 2018 (32 versus 105 ppt). This difference in concentration levels measured in 2018 and 2021 is consistent with the higher throughput of sewage in the Waikīkī area (and corresponding exfiltration) in 2018 from the 6 million annual visitors to O‘ahu that year compared to the 1.5 to 3.3 million visitors in 2020 and 2021.

The median concentration of caffeine measured in the storm drains at Seaside/Kalakaua and the groundwater impacted storm drain at Seaside/Ala Wai (Fig. 1) were higher at low tide than high tide (4,160 versus 2,750 ppt and 1,850 versus 790 ppt, respectively). The median concentration of carbamazepine measured in the groundwater impacted storm drain at Seaside/Ala Wai was higher at low tide than high tide (41 ppt versus 20 ppt) while the carbamazepine concentrations measured at the Seaside/Kalakaua storm drain at low and high tide was similar (12 ppt versus 15 ppt). It is important to note that the trace levels of carbamazepine detected during this study are significantly lower than ecotoxicological levels such as the predicted no-effect concentration of 25,000 ppt and the critical environmental concentration of 349,496 ppt determined for this pharmaceutical compound [3].

Fig. 6 shows the variation in caffeine concentrations measured in the storm drain at Seaside/Kalakaua (yellow dots) and in the groundwater impacted storm drain at Seaside and Ala Wai (red dots) along with the average 7 day daily arrival of visitors to O‘ahu in 2021.

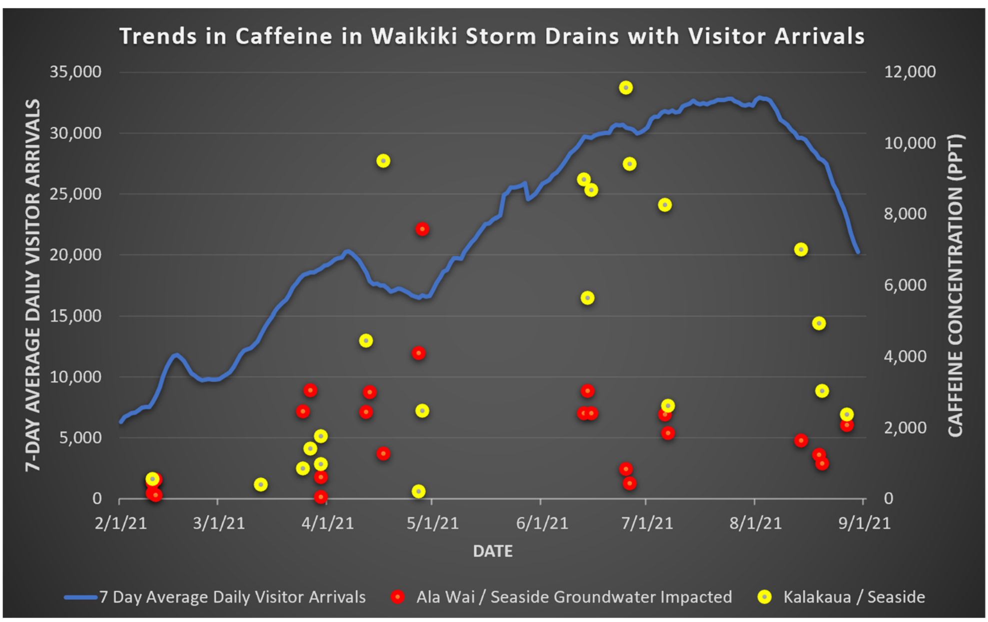

Figure 6: Trend in caffeine concentrations in Waikīkī storm drains and visitor arrivals to O‘ahu.

The caffeine concentrations measured at the Seaside/Kalakaua monitoring locations increased in the middle of the year as tourist arrivals rose then started to decline at the end of the summer as tourist arrivals declined. The trend in caffeine concentrations at the groundwater impacted storm drain at Seaside/Ala Wai are broadly similar but more variable and at overall lower concentrations suggesting the existence of additional input of caffeine to the storm drain at Seaside/Kalakaua than is present in the sewage contaminated groundwater underlying Waikīkī.

5 CONCLUSIONS

This study has shown that sampling of storm drains in low-elevation coastal portions of urban areas such as the city of Honolulu offers an attractive, inexpensive alternative for locating general areas of sewage exfiltration to the traditional exfiltration location methods used. The immunoassay methods used to quantify the concentration of caffeine and carbamazepine present in water in the storm drains and in Ala Wai Canal cost less than $8 per analysis when samples are run in baches of 80 samples. In this study, the pharmaceutical compounds caffeine and carbamazepine were used to identify areas of sewage exfiltration in the Waikīkī and McCully-Moiliili areas in urban Honolulu. Alternative pharmaceutical compounds or artificial sweeteners such as sulfamethoxazole or sucralose would also likely be effective at delineating areas of sewage exfiltration in urban coastal settings.

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IMPACT TO STREAM WATER QUALITY FROM SEWAGE EXFILTRATION AND LEGACY ON-SITE DISPOSAL SYSTEMS ON THE ISLAND OF O‘AHU, HAWAII

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ABSTRACT

The concentration of pharmaceutical compounds and nutrients present in perennial streams, springs and a lake on the island of O‘ahu, Hawai‘i were measured under drought conditions between 2020 and 2022. The combined island-wide daily release of wastewater to the environment on O‘ahu from the continued use of legacy On-Site Sewage Disposal Systems (OSDS) and from exfiltration from the 3,400-kilometer network of underground sewer lines has been estimated to be about 80 million liter per day (mld), or around 3.9% of the total island-wide groundwater flux to the ocean. The 36 streams and 11 springs sampled were located down-gradient of areas with varying densities of OSDS and sewage lines while the lake sampled (Lake Wilson) receives direct input from the wastewater treatment plant that serves Central O‘ahu.

Average pharmaceutical and nutrient levels in streams and springs sampled in areas with high densities of OSDS and sewer lines were slightly higher, but not statistically different than concentration levels measured in streams and springs in areas with low densities of OSDS and low sewer line densities. The average sulfamethoxazole and carbamazepine levels measured in Lake Wilson, the only water body on O‘ahu where treated wastewater is discharged into fresh water, are three to four times higher than average levels measured in the island's streams and springs. The presence of elevated concentrations of nitrate and silica in some streams and springs on O‘ahu predominately reflects the impact of the historical use of up-gradient lands for sugarcane cultivation rather than wastewater input.

The trace levels of pharmaceuticals detected in O‘ahu streams and springs under baseflow conditions suggest that the actual combined input of wastewater to the environment from legacy OSDS and exfiltration from sewer lines is less than 20% the wastewater flux previously estimated.
Keywords: baseflow, cesspools, Hawaii, Oahu, OSDS, pharmaceutical tracer, septic tanks, sewage exfiltration, springs, streams, wastewater contamination

1 INTRODUCTION

Hawai`i was the last state in the United States to ban the construction of new cesspools. The construction of new cesspools was banned in 2015 due to concerns about water quality threats to human and coral reef health. Legislation was passed in 2017 to replace all existing cesspools in the state by 2050.

A survey completed in 2009 found that 14,600 On-Site Disposal Systems (OSDS) exist on the most densely populated Hawaiian Island, O‘ahu, mostly within one-kilometer of the coast and in residential neighborhoods [1]. These OSDS include cesspools, which account for 77 percent of the surveyed total, along with septic tanks and aerobic treatment units. Cesspools provide minimal treatment of wastewater before it percolates to the underlying groundwater aquifer. This survey estimated that 38 million liters per day (mld) of wastewater are released to the environment island-wide from OSDS, with the majority of the released sewage reaching underlying groundwater. High densities of OSDS are found throughout O‘ahu. Estimates of OSDS density and daily wastewater release volumes range from 60 units/kilometer^2(km^2) and 1.5 mld in leeward urban O‘ahu (Makiki), 27 units/km^2 and 2.3 mld in windward O‘ahu (Waimanalo) and 20 units/km^2 and 3.3 mld on the north shore of O‘ahu (Waialua). The

ISSN: 2398-2640 (paper format), ISSN: 2398-2659 (online), http://www.witpress.com/journals
DOI: 10.2495/EI-VX-NX-1-19

authors of the OSDS survey asserted that the sheer numbers of OSDS in some communities on O‘ahu produces a cumulative effluent volume that is comparable to that of municipal wastewater treatment plants (WWTP) [1].

Groundwater quality on O‘ahu is also impacted by exfiltration of sewage from the island’s 3,400-kilometer web of sewer lines that convey an average of 394 mld sewage to WWTP operated by the City and County of Honolulu. The age range distribution of the sewage conveyance system is as follows: <25 years; 22.2%, 26–50 years; 18.3%; 51–75 years; 42.7%, 76–100 years; 11.8% and >100 years, 1.2%. In the urban areas surrounding Honolulu, the majority of the sewage conveyance system is over 65 years old and is beset by leaking joints and pipes due to the presence of corrosive hydrogen sulphide gasses produced by the combination of a warm tropical climate and the high sulfate content of the shallow groundwater surrounding the pipes and joints in the coastal portions of the conveyance systems. Maintenance of this aging and deteriorating sewage conveyance system is a challenge, and there is an ongoing need to replace and upgrade Hawai‘i’s sewer lines and force mains due to both capacity and structural integrity issues [2].

The United States Environmental Protection Agency (USEPA) reported between 12 and 49% of wastewater flows are lost due to leaking infrastructure in United States cities [3]. The system-wide amount of wastewater exfiltration from O‘ahu’s sewage system is unknown. A rough estimate of 10% system-wide exfiltration is based upon the difference in average monthly groundwater withdrawals by the water utility and the average monthly volume of wastewater treated at the WWTPs operated by the City and County of Honolulu [4]. A 10% loss suggests around 40 mld of wastewater is released to the environment from exfiltration from the sewage conveyance system, roughly the same amount of wastewater that is estimated to be released from the ongoing use of OSDS. Evidence of exfiltration from the sewage conveyance system has been observed in two coastal areas in urban Honolulu, Waikiki and Mapunapuna, based on the presence of pharmaceutical compounds in storm drains in these areas and in the Ala Wai Canal, which receives input from Waikiki storm drains [4].

The United States Geological Survey (USGS) estimates that the mean island-wide groundwater flux entering the ocean is around 2,050 mld [5]. The combined estimated island-wide release of wastewater due to the continued use of legacy OSDS and from exfiltration from the sewage conveyance system is around 80 mld, or roughly 3.9% of the total island-wide groundwater flux to the ocean. The simulated groundwater flux along O‘ahu’s shoreline varies from less than 4 mld/km in the drier and narrower portions of the island to maximum values of around 76 mld/km along the shoreline bordering Pearl Harbor [5]. Based upon these previous estimates of wastewater input, chemical evidence of wastewater should be readily detected in groundwater that underlies and streams that flow through areas on O‘ahu with high OSDS and sewer line densities. The focus of the paper is to evaluate whether the combined environmental impact from legacy cesspools and sewage exfiltration can be estimated by measuring the pharmaceutical and nutrient concentrations in island streams and springs under baseflow conditions, when the water present in the streams almost exclusively originated from groundwater discharge from the surrounding watershed. Sampling was also conducted under low water-level conditions in Lake Wilson, which is the only location on O‘ahu that receives direct wastewater input from a WWTP servicing Central O‘ahu.

1.1 Characteristics of Hawaiian streamflow

Streams on O‘ahu are typically short (<6 km long) and have relatively steep gradients [6]. Rainfall runoff to O‘ahu streams tends to be flashy due to the high intensity of rainfall that often falls in the island's interior combined with the small size of the steep drainage basins and limited channel storage present within the island's watersheds. The permeable nature of the island's volcanics and upland soils allow rapid infiltration of water to underlying aquifers resulting in very few streams on O'ahu being perennial over their entire reach. The two largest perennial streams on O'ahu, Kahana and Waikele streams, have annual median streamflow of around 1.05 cubic meters per second (cms). The majority of perennial streams on O'ahu have annual daily median flows of less than 0.1 cms. The flashy nature of runoff and the paucity of large perennial streams precludes large-scale development of surface-water on O'ahu and leads to near-total reliance on groundwater for water supply for the island's roughly 1 million residents [6].

Perennial streamflow occurs on O'ahu in watersheds that receive significant groundwater discharge. These include areas where erosion has incised valleys into rift zones and the stream course intersects the elevated water tables created by the nearly impermeable dikes within the rift zones of the volcano, in upland areas, and near sea level where the stream course intercepts shallow perched or basal groundwater.

Groundwater discharge to streams is known as baseflow, which becomes the dominant component of streamflow during periods of dry weather. Dike impounded groundwater is the dominant contributor to baseflow in streams on O'ahu. Perched groundwater also contributes to stream baseflow, especially in alluvium and rocks associated with the post-erosional phase of activity encountered in valleys in the Honolulu area and in windward O'ahu. Basal groundwater can also enter the coastal sections of streams where the bottom of the stream intercepts the top of the basal lens between streambed elevations of 0 to 7.6 meters above sea level in areas where no coastal confining layer exists. Groundwater can also enter streams through springs. Springs form when a geologic structure (e.g., fault or fracture) or topographic feature (e.g., side of a hill or a valley) intersects groundwater either at or below the water table. This can discharge groundwater onto the land surface, directly into the stream, or into the ocean [7]. Under drought conditions, streamflow in windward O'ahu streams, where flow is dominated by dike impounded groundwater discharge, can decrease to about half the median flow, while flow in perennial streams in leeward O'ahu can decline to between 10 and 25% the stream's median flow [8].

Streams in Hawai`i gain water along some reaches and lose water along other reaches depending on local geohydrologic conditions [7]. A gaining stream is simply one in which groundwater flows into the stream and adds to the discharge of the stream.

During periods of low flow, the quality of the groundwater controls surface-water quality. A vertical profile of samples was collected from two deep monitoring wells located in Central O'ahu and analyzed for solutes and isotopes [9]. The upper 100 meters of the basal aquifer in Central O'ahu was composed of water recharged from local rainfall and irrigation return water that fell or was applied over the previous few decades. Wastewater released due to the continued use of OSDS and from sewage exfiltration would also impact the upper portion of the underlying perched or basal aquifers encountered as wastewater percolates through the vadose zone. This upper portion of the basal and perched groundwater bodies is the zone that contributes groundwater to streams in their lower reaches where samples were collected during this study.

Figure 1 shows the increase in specific conductance measured in four streams in leeward O'ahu as they flow from the mountains toward the sea. This increase in specific conductance reflects the higher concentration of dissolved chemicals (anions, cations, nutrients, pharmaceuticals, etc.) present in groundwater that discharge to these streams at lower elevations compared to the levels present from water discharging from the dike impounded rift zones, which serves as the source of baseflow in the upper reaches of the streams.

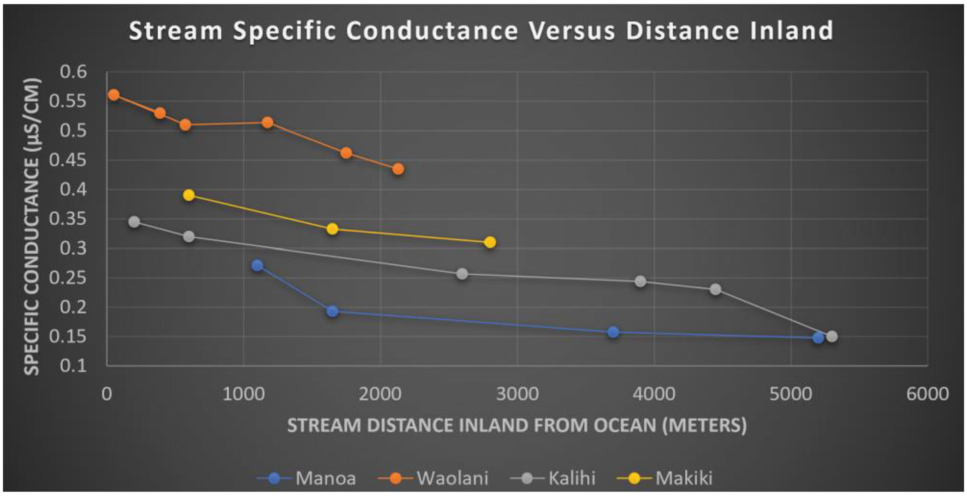

Figure 1: Increase in Stream Specific Conductance During Flow Through Urban O‘ahu.

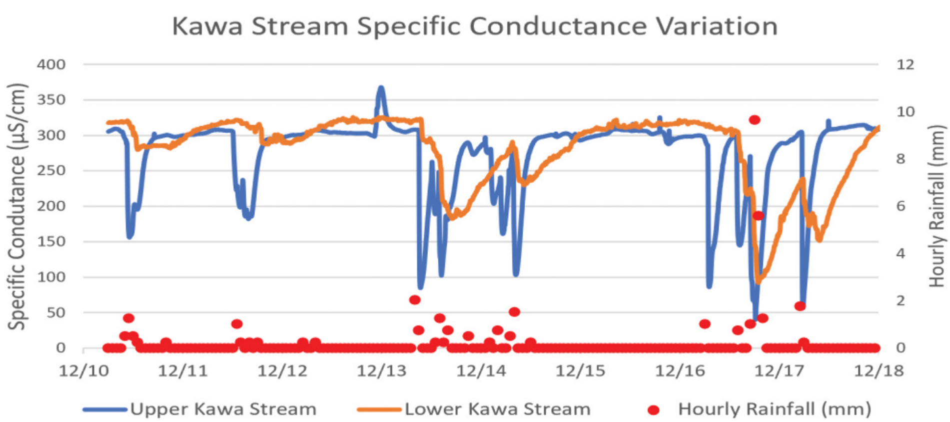

Figure 2: Variation in Specific Conductance in Kawa Stream in Response to Rainfall.

Figure 2 shows the variation in specific conductance measured in Kawa stream as a result of rainfall over an eight-day period in 2021. Kawa stream is a small (0.08 cms average annual flow), perennial spring fed stream in windward O‘ahu. The upper monitoring site was located just downstream of the upper springs which supply baseflow to the stream, while the lower monitoring site was located one-kilometer downstream. Flow in this stream becomes dominated by groundwater input within a day or two after moderate rainfall events based on the rapid recovery in specific conductance to spring conductance values (~300 µS/cm).

1.2 Anthropogenic markers of sewage contamination-carbamazepine, sulfamethoxazole and caffeine

Carbamazepine, sulfamethoxazole and caffeine are known as emerging contaminants, which describes pollutants that have been detected in water bodies, may have ecological or human impact, and typically are not regulated under current environmental laws. These compounds are also known as micropollutants because they are typically present in trace quantities (part per trillion to billion levels) in the environment. These micropollutants enter the environment during our daily routines as we consume, flush away, or wash these compounds down the sink. Carbamazepine, caffeine and sulfamethoxazole represent the most frequently detected pharmaceuticals in treated wastewater [10]. As a result, these compounds are increasingly used as anthropogenic markers of sewage contamination.

Carbamazepine is a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug. Sulfamethoxazole is an antibiotic prescribed to treat common bacterial infections including urinary tract infections, middle ear infections, bronchitis and diarrhea. Caffeine is a naturally occurring stimulant found in coffee, soda, tea, chocolate and energy drinks. Carbamazepine, caffeine and sulfamethoxazole were the first, third and sixth (62.3%, 56.1%, 40.7%) most commonly detected pharmaceutical compounds in 1,052 river samples collected from 104 countries worldwide in a recently published global-scale study [11]. Caffeine was detected in river samples collected from every continent while carbamazepine was detected in rivers on all continents except Antarctica and sulfamethoxazole on all continents except Antarctica and Oceania (Australia and New Zealand). The common detection of carbamazepine and sulfamethoxazole is attributed to their conservative behavior in the environment with carbamazepine being somewhat more persistent. The common detection of caffeine is due the high levels and ubiquitous nature of its consumption. The average concentrations of carbamazepine, sulfamethoxazole and caffeine measured in streams worldwide were 85, 262 and 1,510 nanograms per liter (ng/L), respectively [11].

The relative stability of carbamazepine and sulfamethoxazole enables detection at larger distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage or grey water, given its ephemeral nature and higher initial concentration levels in released untreated wastewater.

1.3 Pharmaceutical concentrations in sewage in Hawai‘i

Researchers at the University of Hawai‘i measured the concentration of caffeine in sewage in the main sewer line exiting Manoa Valley on O‘ahu to range from 5,000 to 103,400 parts per trillion (ppt, ng/L), with the highest flux of caffeine (2.4 milligrams/second) exiting the valley between 8 and 11 AM [12]. The Safe Drinking Water Branch of the State of Hawai‘i Department of Health (HDOH) conducted two rounds of sampling of raw wastewater influent at four WWTP and also collected 13 samples of treated wastewater effluent generated at 13 WWTP facilities that produce reclaimed water throughout the State of Hawai‘i [13]. LC-MS-MS methods were used to analyze these samples. Carbamazepine was not detected in the wastewater influent; likely due it being masked by other constituents present in the wastewater during analysis.

During the current study, samples were collected from septic tanks at various beach parks on the island of O‘ahu and analyzed for carbamazepine (26 samples), caffeine (20 samples) and sulfamethoxazole (10 samples) using an Enzyme Linked Immunosorbent Assay (ELISA) immunoassay method. Table 1 summarizes the carbamazepine, sulfamethoxazole and caffeine concentrations measured in the septic tanks along with levels measured by HDOH in influent and effluent to Hawai‘i WWTPs. Using the average concentrations of carbamazepine measured in septic tanks and the average of the sulfamethoxazole and caffeine concentrations measured in the septic tanks and in WWTP influent, the mean concentration of carbamazepine, sulfamethoxazole and caffeine in Hawai‘i wastewater is around 745, 1,300 and 61,000 ppt, respectively. The mean concentration of ammonia, nitrate (NO_3-N) and total phosphate measured during this study in wastewater collected from septic tanks (eight samples) located at a busy public beach park used by a representative cross section of island residents and tourists was 80, 13 and 47 milligrams per liter (mg/l), respectively.

Table 1: Carbamazepine, Sulfamethoxazole and Caffeine concentrations in Septic Tanks and WWTP Effluent and Influent in Hawai‘i.

Source	Carbamazepine (parts per trillion)				
	Mean	Median	Max. Detect	Count	Detect Frequency
Septic Tanks	745	707	1,735	26	100%
WWTP Influent[1]	ND	ND	ND	8	0%
WWTP Effluent[1]	113	110	220	23	65%
Source	**Sulfamethoxazole (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	1,630	1,550	4,240	10	100%
WWTP Influent[1]	986	940	2,200	8	100%
WWTP Effluent[1]	1,068	395	5,400	16	100%
Source	**Caffeine (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	23,614	13,250	83,200	16	100%
WWTP Influent[1]	98,238	108,000	150,000	8	100%
WWTP Effluent[1]	152	33	1,200	23	96%
ND = Not Detected due to dilution of sample during analysis and peak interference.					
[1]Oahu WWTP Influent/Efffluent Data from HDOH [11]					

1.4 Pharmaceutical levels measured in coastal urban settings of Honolulu

A 2022 study measured the spatial distribution of carbamazepine and caffeine concentrations present in the dense network of storm water manholes located in the coastal tourist destination of Waikiki and in the adjacent inland McCully-Moiliili residential areas between November 2020 and December 2021 [4]. Samples were also collected from storm drains in the coastal industrial area of Mapunapuna. In the coastal areas sampled, wastewater contaminated groundwater seeps into the stormwater conveyance pipes and mixes with the tidally driven water that enters the storm drain system from the Ala Wai Canal, which separates the tourist and residential areas in Waikiki. The concentration levels and spatial distribution of detection of these two anthropogenic biomarkers were successfully used to identify areas of ongoing sewage exfiltration in Waikīkī and surrounding residential communities [4]. The impacted groundwater aquifers in the coastal Waikiki and Mapunapuna areas are composed of calcareous and volcanogenic sediments locally referred to as caprock which confine the water in the underlying volcanic rock aquifers. The flux of groundwater through these caprock aquifers is significantly less than fluxes in the underlying basal aquifers, which contributed baseflow to the streams sampled during this study. Figure 3 shows the contoured maximum carbamazepine concentrations measured in storm drain and canal sites sampled (red dots) in the Waikiki and McCully/Moiliili areas while Fig. 4 shows the maximum carbamazepine and caffeine concentrations measured in storm drains (yellow dots) in the industrial area of Mapunapuna. The average carbamazepine and caffeine concentrations measured in Waikiki and Mapunapuna storm drains was 31.7 and 2,940 ppt, and 20.0 and 196 ppt, respectively. The concentrations of carbamazepine and caffeine indicate an average wastewater fraction of up to 4.8% to 2.7% in Waikiki and Mapunapuna storm drains, respectively.

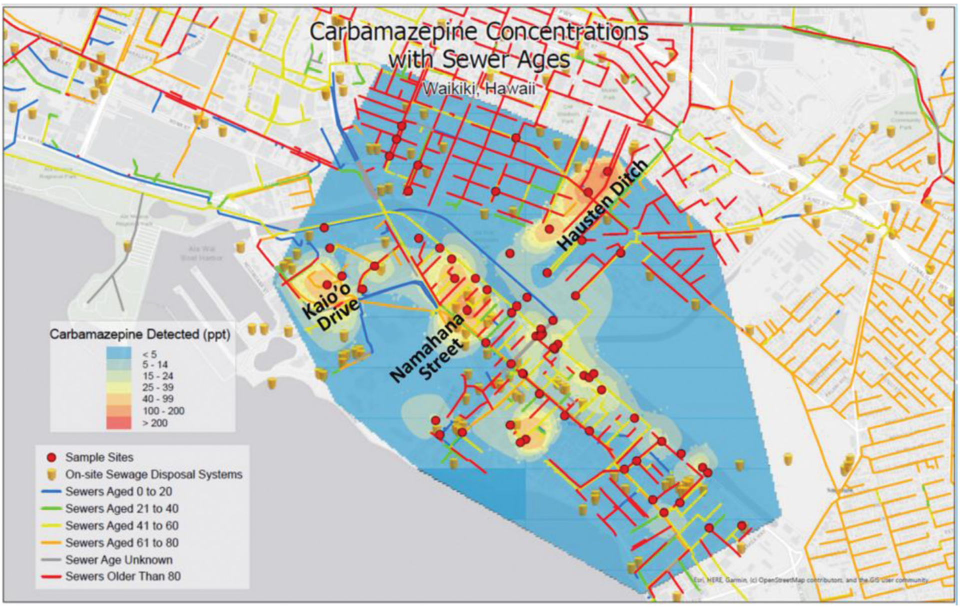

Figure 3: Contoured Maximum Carbamazepine Concentrations in Storm Drains in the Tourist and Residential Waikiki and McCully/Moiliili Areas.

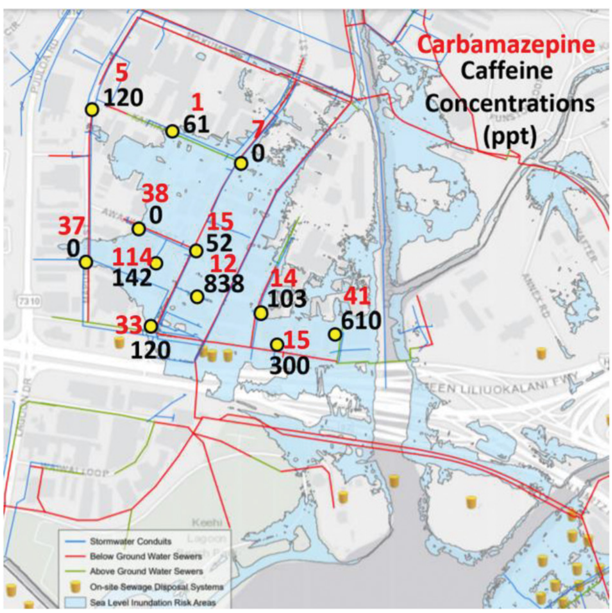

Figure 4: Carbamazepine and Caffene Concentrations in Storm Drains in the Industrial Mapunapuna Area.

2 STUDY METHODOLOGY

Thirty six streams and 11 springs on O‘ahu were sampled under low baseflow conditions between November 2020 and September 2022 during periods of extended drought. Streamflow was typically less than the 10th percentile of daily discharge recorded for the sampled stream by the USGS on the day of sampling. Low flow conditions were considered optimal for detection of a wastewater signature from OSDS use and sewage exfiltration to minimize dilution from baseflow entering the streams from the undeveloped, uncontaminated mountainous interior of the island. Samples were collected from the lower reaches of the streams to maximize the amount of groundwater contribution to the stream from the surrounding urban portions of the watershed in the mid- to lower reaches of the stream course.

Two initial rounds of sampling were conducted island-wide in November 2020 and November 2021 during which each stream and spring were sampled twice roughly one week apart. The November 2020 round of samples were analyzed for carbamazepine while the November 2021 round samples were analyzed for carbamazepine and caffeine. Carbamazepine was detected at trace and estimated levels in three springs (Waimanalo Seep, Ulupo Heiau spring and Waimano spring) during the November 2020 sampling. As a result, these springs were repetitively sampled up to August 2022 to determine whether these compounds' presence was persistent or transient in these springs.

The island of O‘ahu experienced pronounced drought-like conditions between early January 2022 to September 2022. Stream and spring samples collected during 2022 were analyzed for all three pharmaceutical compounds (carbamazepine, caffeine and sulfamethoxazole) and for nutrients (ammonia, nitrate and phosphate) and silica. An initial round of sampling from Lake Wilson was conducted in November 2021 followed by additional sampling in March and April 2022 when water levels in the lake had reached near record lows due to the ongoing drought in the first half of 2022. Figure 5 shows the location of the stream, spring and lake samples collected during this study in relation to OSDS density and the island sewer network.

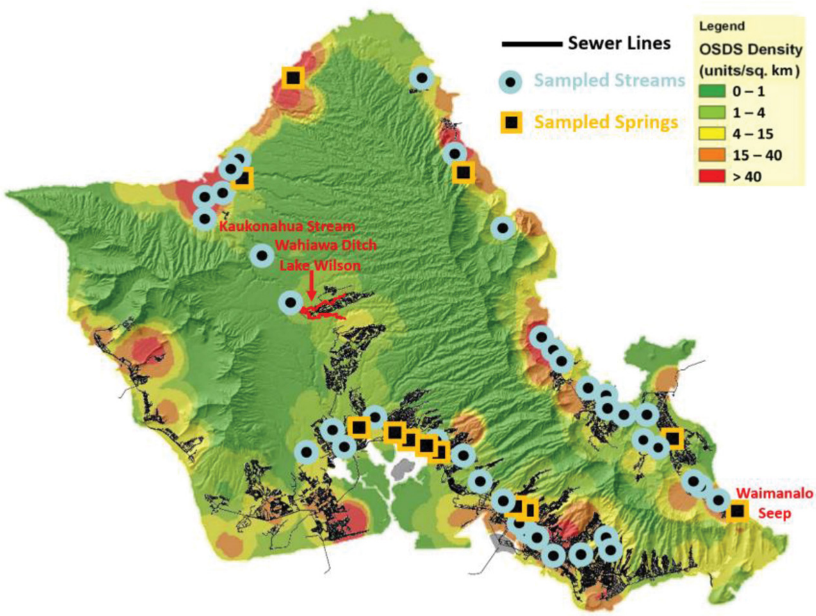

Figure 5: Location of Streams, Springs and Lake Samples Analyzed During this Study.

The streams and springs sampled were located down-gradient of areas with varying densities of OSDS and sewage lines while Lake Wilson receives direct wastewater input from the WWTP that serves Central O‘ahu. Areas of varying densities of OSDS on O‘ahu were divided into four OSDS density range categories: less than 4 units per km^2; 4 to 15 units per km^2; 15 to 40 units per km^2; greater than 40 units per km^2. The USEPA has designated areas with an OSDS density of greater than 15 units per km^2 as regions where there is a significant potential for causing unacceptable groundwater contamination [1]. Areas with OSDS densities of greater than 40 units/km^2 are shaded in orange and red in Fig. 5 along with the location of the island's sewer conveyance system (black lines).

The stream, spring and lake samples were analyzed for general water quality parameters (temperature, specific conductance, salinity, dissolved oxygen, pH and turbidity) in the field using a Hydrolab Quanta and frozen shortly after collection. ELISA test kits manufactured by Eurofins were used to measure the concentration of carbamazepine, sulfamethoxazole and caffeine, typically in batches of 80 samples. The concentrations of the pharmaceutical compounds were classified as either detected, estimated, trace or non-detect. Detected concentrations were above the concentration of the lowest calibration standard (25 ppt for carbamazepine and sulfamethoxazole and 175 ppt for caffeine). Estimated concentrations were between roughly half the lowest calibration standard (12 ppt for carbamazepine and sulfamethoxazole and 85 ppt for caffeine) and the lowest calibration standard. Trace concentrations were between the zero-calibration standard and half the lowest calibration standard. Non-detect samples had measured absorbances greater than the zero standards.

Nitrate, ammonia, phosphate and silica concentrations were determined using colorimetric methods on unfiltered samples. Nitrate concentrations were measured using the cadmium reduction method while ammonia concentrations were measured using the Nessler method. Phosphate concentrations were measured using an adaptation of the Ascorbic Acid method. Silica concentrations were measured using an adaptation of USEPA Method 370.1.

3 SAMPLING RESULTS

Thirty six streams and 11 springs located down-gradient of areas with varying densities of OSDS and sewage lines on the island of O‘ahu were sampled over a two-year period. A minimum of four samples were analyzed for pharmaceuticals and nutrients from all streams and springs. Caffeine was present in 80% and 94% of the streams and springs sampled above detected (175 ppt) and estimated (80 ppt) concentration levels, respectively. Sulfamethoxazole was present in 6%, 15% and 15% of the streams and springs sampled above detected (25 ppt), estimated (12 ppt) and trace (>1 ppt) concentration levels, respectively. Carbamazepine was present in 3%, 5% and 42% of the streams and springs sampled above detected (25 ppt), estimated (12 ppt) and trace (>1 ppt) concentration levels, respectively. Trace levels of caffeine (>80 ppt), carbamazepine and sulfamethoxazole (12 ppt) were measured in 70%, 23% and 6% of the samples collected, respectively.

Table 2 summarizes the average pharmaceutical and nutrient concentrations measured in streams and springs located in the following four categories of contributory land use: (1) areas with high densities of cesspools and high densities of sewer lines; (2) areas with high densities of cesspools and low densities of sewer lines; (3) areas with low densities of cesspools and high densities of sewer lines; and (4) areas with low densities of cesspools and low densities of sewer lines. Table 2 also includes the pharmaceutical and nutrient data collected from Lake Wilson and its two outlets (Kaukonahua Stream and Wahiawa Ditch).

Table 2: Pharmaceutical and nutrient concentrations in O‘ahu Streams, Springs and Lake Wilson.

# Pharm Analysis	Caffeine (ppt)	Sulfamethoxazole (ppt)	Carbamazepine (ppt)	Nitrate (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Silica (mg/L)
Stream and Springs: High Density Cesspool / High Density Sewer Contributory Area							
268	398 ± 502	1.5 ± 7.0	2.1 ± 7.2	0.63 ± 1.26	0.12 ± 0.18	0.42 ± 0.29	25 ± 13
Stream and Springs: High Density Cesspool / Low Density Sewer Contributory Area							
79	129 ± 155	0.0 ± 0.0	0.2 ± 0.5	0.31 ± 0.74	0.06 ± 0.11	0.42 ± 0.30	35 ± 18
Stream and Springs: Low Density Cesspool / High Density Sewer Contributory Area							
167	248 ± 678	0.4 ± 2.3	0.5 ± 1.3	0.63 ± 0.88	0.06 ± 0.03	0.73 ± 0.64	34 ± 16
Stream and Springs: Low Density Cesspool / Low Density Sewer Contributory Area							
50	181 ± 188	1.7 ± 5.0	0.0 ± 0.0	0.19 ± 0.73	0.09 ± 0.11	0.24 ± 0.24	29 ± 7
All Stream and Spring Samples Combined							
564	298 ± 524	1.0 ± 5.1	1.3 ± 5.3	0.54 ± 1.10	0.08 ± 0.15	0.52 ± 0.49	30 ± 15
Samples from Lake Wilson and Outlet Streams (Kaukonahua) and Ditch (Wahiawa)							
142	250 ± 420	2.4 ± 6.1	5.7 ± 9.1	0.01 ± 0.05	0.08 ± 0.10	0.30 ± 0.77	8 ± 3

Figure 6 shows the average caffeine concentrations measured in the streams and springs sampled during this study in relation to areas of high OSDS and sewer line densities.

Three springs (Waimanalo seep, Ulupo Heiau and Waimano spring) contained trace or estimated concentration levels of carbamazepine during the two rounds of reconnaissance sampling conducted in November 2020. The Waimanalo seep had the most consistently detectable concentrations levels of carbamazepine and caffeine of the three springs repetitively sampled. Figure 7 shows the persistent nature of and variability in concentration levels of carbamazepine and caffeine in the Waimanalo Seep over the 23-month period sampled. Waimanalo Seep is located in a narrow portion of the island with relatively low coastal groundwater flux rates.

Nitrate, ammonia and phosphorus can be indicators of the presence of wastewater since these nutrients are enriched in wastewater. The average concentration of nitrate, ammonia and total phosphate measured in wastewater collected from septic tanks was 13, 80 and 47 mg/l, respectively. However, nitrate is not unique to wastewater and on O‘ahu its presence in groundwater fed streams may reflect historical use of fertilizers, especially in areas formerly used for sugarcane cultivation [14]. High concentrations of nitrate (30 to 80 mg/kg) are adsorbed on positively charged iron and aluminum oxide particles in the subsoil and saprolite beneath pineapple and sugarcane cultivation areas of central O‘ahu at depths between 6 to 20 meters [15]. Infiltration percolating through the soils and saprolite underlying lands formerly used for sugar cultivation provides a continuous input of nitrate to the underlying basal groundwater aquifers.

The historic use of phosphorus fertilizers has not significantly affected groundwater quality on O‘ahu because phosphate is retained in the aluminum and iron minerals in the soils [7]. Most of the silica in stream water is derived from leaching of volcanic rocks and soil. Rainfall has silica concentrations of less than 1 mg/l and infiltrating water will dissolve the silica present in volcanic rocks and soils leading to silica concentrations in the basal aquifer of between 15 to 40 mg/l [16]. Groundwater concentration levels of above 40 mg/l silica are associated with areas impacted by return irrigation water [14].

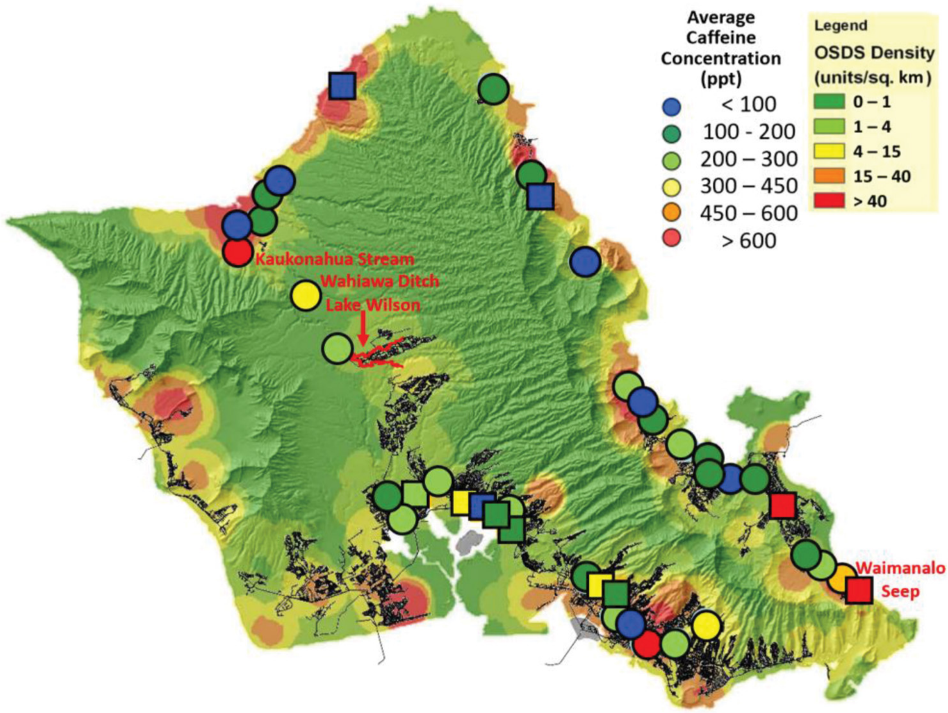

Figure 6: Average Caffeine Concentrations Measured in Streams and Springs.

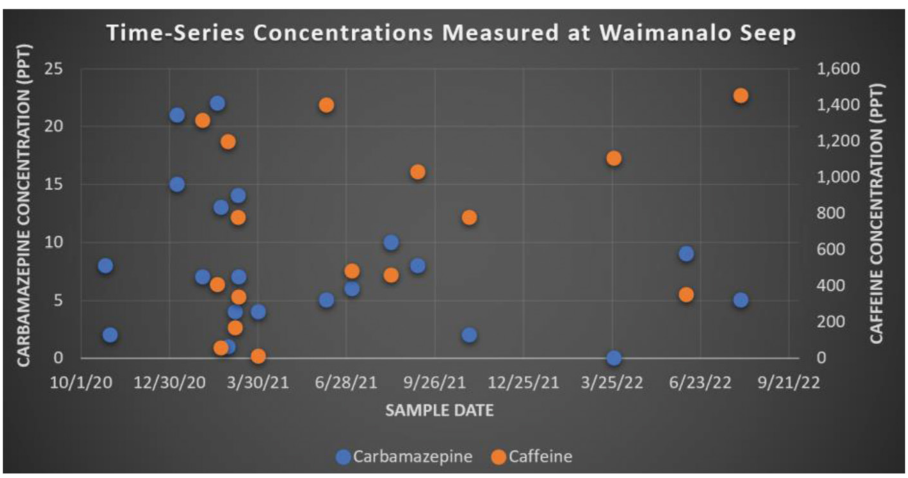

Figure 7: Carbamazepine and Caffeine Concentrations in Waimanalo Seep.

The spatial distribution of nitrate and silica concentrations measured in streams and springs during this study is shown in Figs. 8 and 9. These figures show the general spatial correlation between nitrate and silica level with areas currently or historically used for large-scale agriculture. During this study, the average concentration of nitrate and silica in streams and

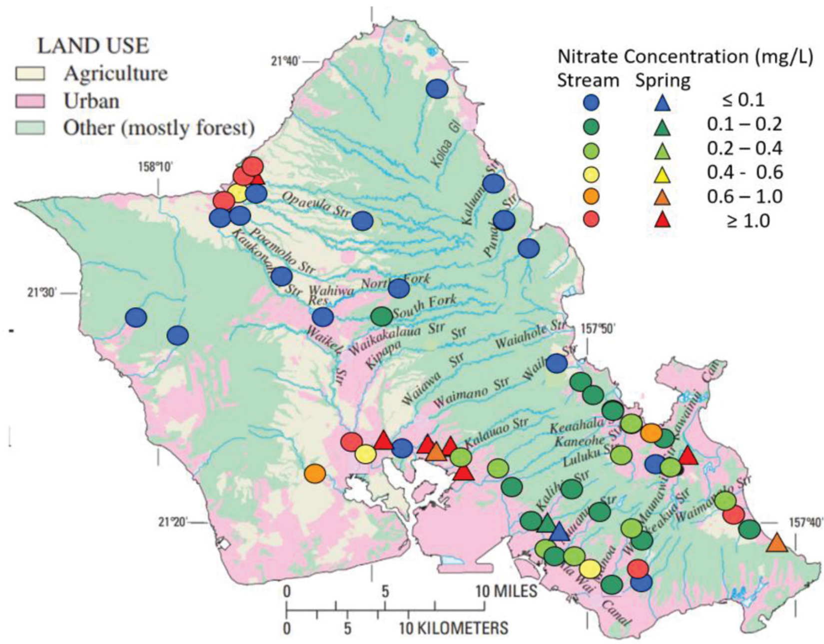

Figure 8: Nitrate Concentrations Measured in O‘ahu Streams and Springs.

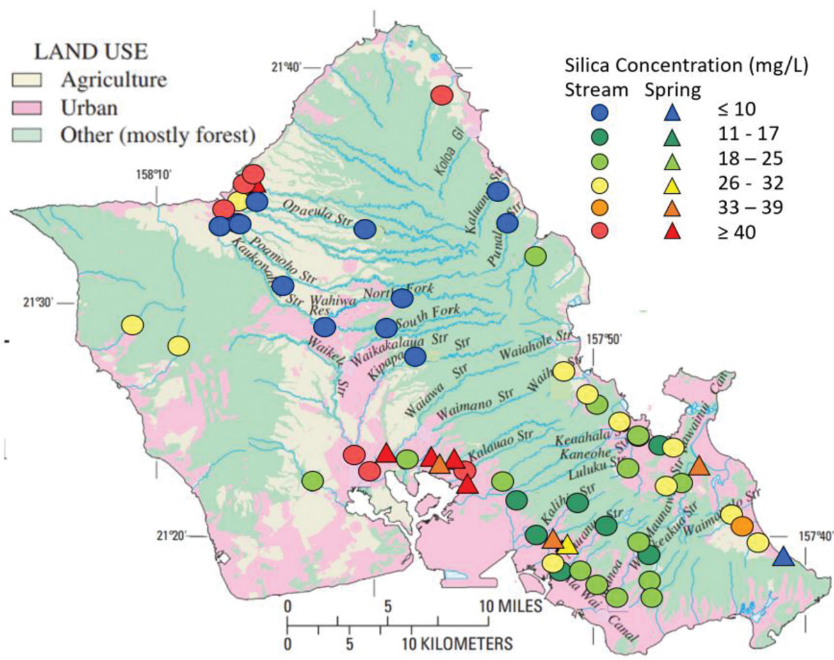

Figure 9: Silica Concentrations Measured in O‘ahu Streams and Springs.

springs located in watersheds where large-scale agricultural activities were conducted was 0.78 and 40 mg/l, compared to concentration levels of 0.40 and 24 mg/l measured in streams and springs located in areas where no large-scale agricultural activity occurred.

4 DISCUSSION

The concentrations of pharmaceutical compounds measured in O‘ahu streams and springs are very low. The mean concentrations of carbamazepine, sulfamethoxazole and caffeine measured in O‘ahu streams and springs (1.3, 0.9 and 298 ng/L, Table 2) were five to three hundred times lower than average levels measured in streams worldwide (85, 262 and 1,510 ng/L) [11]. Many of the streams sampled during the worldwide sampling effort receive direct input of either treated or untreated sewage. Direct release of wastewater to surface water does not occur on O‘ahu except in Lake Wilson which receives around 5.4 mld of tertiary-level treated wastewater from the Wahiawa WWTP. This direct input of wastewater to the lake led to slightly higher average levels of carbamazepine and sulfamethoxazole being present in the lake (5.7 and 2.4 ng/L, Table 2) than average levels measured in O‘ahu streams and springs. Samples were collected from Lake Wilson and its two outlet streams when water levels were quite low, but the volume of water in the lake at the time of sampling was still around 4.5 billion liters. The large volume of water in the lake explains the relatively low concentration levels of pharmaceutical compounds measured in the lake.

Figure 10 compares the carbamazepine and caffeine concentrations (in log-log scale) measured in wastewater collected from septic tanks on O‘ahu, in Waikiki storm drains, in the Ala Wai Canal, in Lake Wilson and in O‘ahu streams and springs to the worldwide average measured in 1,052 streams sampled in 104 countries on all seven continents [11].

The measured concentration of pharmaceuticals and nutrients in streams and springs were not statistically different in contributory watersheds with high densities of OSDS and sewer lines from watersheds with low densities of OSDS and sewer lines (Table 2). The OSDS

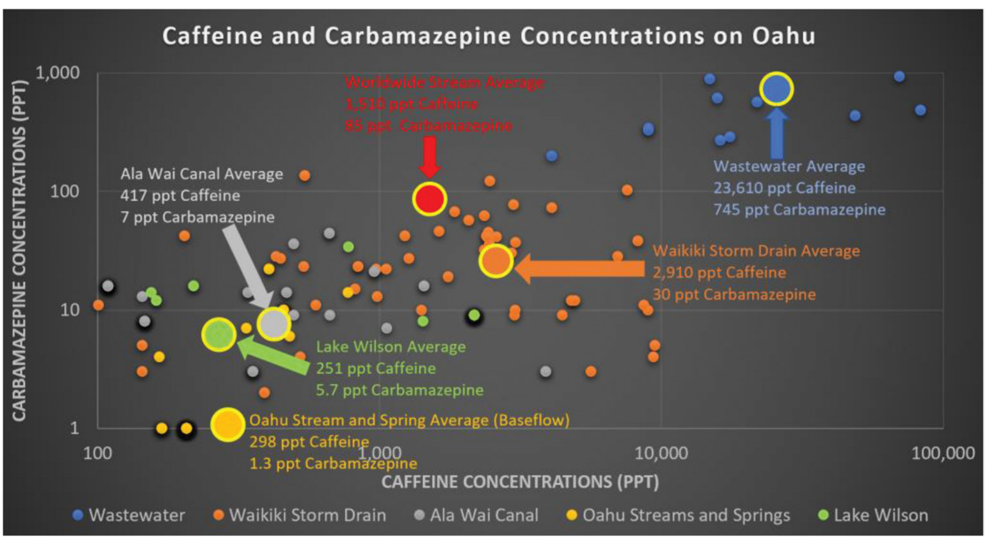

Figure 10: Caffeine and Carbamazepine Concentrations on O‘ahu. Note the log-log scale.

survey estimated wastewater flux in various areas on O‘ahu ([1], Table B-1). The estimated wastewater flux in four areas on O‘ahu where streams were sampled (Makiki, Haleiwa, Waimanalo and Waialua) were 1.25, 1.55, 1.94 and 2.77 mld. The USGS recently prepared a steady-state numerical groundwater-flow model of O‘ahu that simulated groundwater discharge along the coastline of O‘ahu [5]. Based on the simulated coastal groundwater flux in the Makiki, Haleiwa, Waimanalo and Waialua areas, the percentage of wastewater in the groundwater in these areas should be 4.6%, 2.2%, 12% and 4%, respectively. However, based on the average pharmaceutical levels in the streams and springs in these areas, the fraction of wastewater in the streams in the Makiki, Haleiwa, Waimanalo and Waialua areas is estimated to be around 2.6%, 0.7%, 3.2% and 0.7%, respectively. These calculations suggest that the actual environmental impact from cesspools in these areas is between 20 to 50% of the wastewater flux estimated based on the assumptions used in the OSDS survey, not including any impact from sewage exfiltration that may be occurring in these areas. The spatial relationship between elevated nitrate concentrations in streams and former sugar lands (Fig. 8) indicate the elevated nitrate levels originated from legacy agricultural activities rather than from cesspools and sewage exfiltration. This conclusion is supported by the elevated silica levels measured in streams that flow through former sugar lands.

Figure 11 is a generalized map of simulated groundwater discharge to the ocean in the calibrated numerical groundwater model produced by the USGS [5]. The eight streams and springs that had an average caffeine concentration greater than 300 ppt (based on a minimum of six analyses) are also shown on this figure. Kaukonahua Stream and Wahiawa Ditch

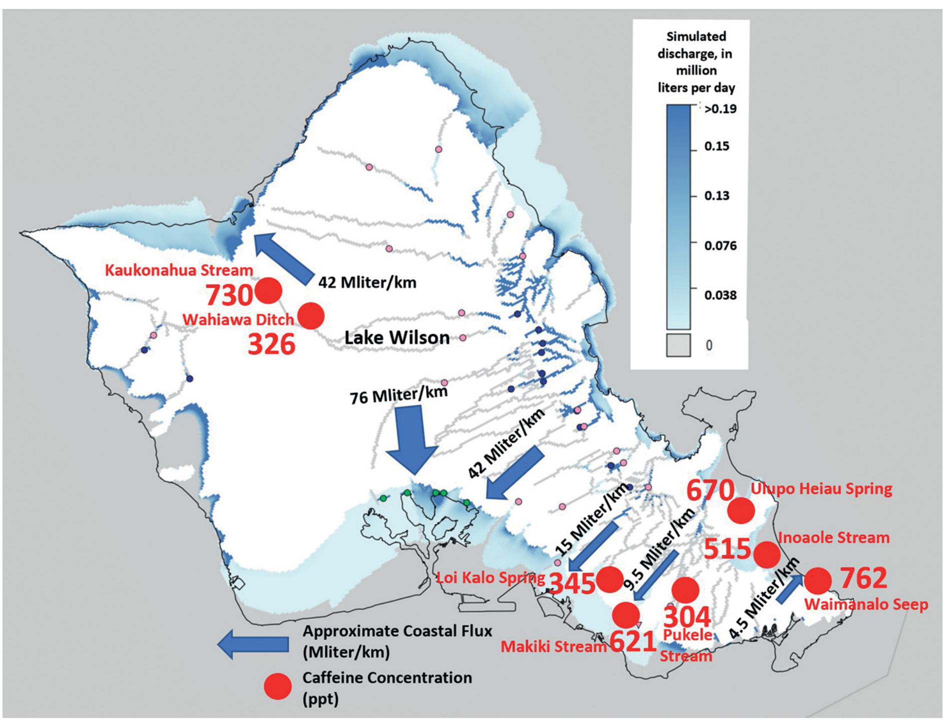

Figure 11: USGS Modeled Island-Wide Groundwater Flux and Streams and Springs with Highest Average Measured Caffeine Concentrations.

samples reflect discharge from Lake Wilson. This figure clearly shows the large differences in groundwater flux simulated to discharge along the shoreline of O‘ahu. The streams and springs where the highest average concentration levels of caffeine were detected during this study were located in areas with relatively low simulated coastal groundwater fluxes, suggesting that in portions of the island with high groundwater fluxes to the coast, wastewater entering the groundwater from cesspools and from exfiltration from sewage conveyance lines is effectively diluted to very low or non-detectable concentration levels.

These findings are consistent with results obtained by HDOH in a community on the island of Hawai`i with high OSDS densities (up to 440 OSDS/square kilometer) and high groundwater flux [13]. Despite the high density of OSDS in the area, the average nitrate concentration measured in groundwater was low (0.2 mg/L) and the measured nitrate levels did not show the expected increase along the groundwater flow paths toward the ocean. The authors suggested that that the actual wastewater contribution from cesspools may be lower than the 750 liter per day per bathroom flux used in the state-wide OSDS assessment [1].

5 CONCLUSIONS

This study found that the current impact to water quality on O‘ahu from legacy cesspools and from wastewater exfiltration from the sewage conveyance systems is significantly less than previously estimated based on OSDS density and estimates of system wide sewage exfiltration. The average concentration of caffeine measured in streams and springs under baseflow conditions was 18% the average measured in streams worldwide, while the levels of carbamazepine and sulfamethoxazole were only 1.4% and 0.6% of the worldwide average. The presence of elevated nitrate concentrations in some streams and springs on O‘ahu is predominately related to legacy agricultural activities rather than from ongoing wastewater releases.

DATA AVAILABILITY STATEMENT

Appendix A contains the average pharmaceutical (caffeine, sulfamethoxazole, carbamazepine), nutrient (nitrate, ammonia, phosphate) and silica concentrations measured in the streams, springs, lake and septic tanks sampled during this study. The streams and springs are ordered based on the estimated density of cesspools and sewer lines present in the contributory watershed of the stream or spring sampled. The last column in the appendix describes whether the contributory watershed was historically used for large-scale agricultural purposes.

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APPENDIX A

Average Pharmaceutical (Caffeine, Sulfamethoxazole and Carbamazepine) and Nutrient Concentrations in Septic Tanks and Lake Wilson and in Streams and Springs Located in Areas of Varying Densities of Cesspools and Sewer Lines

Location	# of Immuno-Assay Analyses	Caffeine (ppt)	Sulfa. (ppt)	Carb. (ppt)	Nitrate (NO3-N) (ppm)	Ammonia (NH4) (ppm)	Phosphate (ppm)	Silica (ppm)	Large-Scale Ag?
Wastewater Source									
Septic Tanks	26	23,614	1,630	745	13.1	85.5	44.9	NM	NA
High Density Cesspool / High Density Sewer Contributory Area									
Waimanalo Seep	42	762	0.0	7.1	0.7	0.22	0.41	4	NO
Makiki Stream	18	621	18.0	1.4	0.4	0.08	0.75	22	NO
Inoaole Stream	8	515	0.0	1.8	0.0	0.42	1.57	–	YES
Loi Kalo Spring	16	345	0.0	0.0	0.0	0.08	0.34	39	NO
Waolani Stream	31	256	0.0	5.3	0.6	0.11	0.54	23	NO
Kalauao Stream	9	238	0.0	0.2	0.3	0.03	0.37	48	NO
Heeia Stream	4	236	0.0	–	0.4	0.03	0.12	29	YES
Manoa/Palolo Stream	26	232	4.7	0.3	0.2	0.08	0.34	20	NO
Kahawai Stream	26	200	0.0	0.1	2.6	0.15	0.30	36	YES
Ie Ie Park Spring	18	198	0.0	0.0	0.8	0.06	0.46	48	NO
Kalihi Stream	21	196	0.0	2.2	0.5	0.05	0.40	17	NO
Kunawai Spring	8	157	0.0	0.3	0.0	0.07	0.65	30	NO
Ahuimanu Stream	10	130	0.0	0.0	0.1	0.03	0.17	25	NO
Kahaluu Stream	11	63	0.0	0.0	0.2	0.03	0.22	27	NO
Nuuanu Stream	5	0	0.0	0.0	0.1	0.08	0.30	15	NO
Pauoa Stream	7	–	–	0.0	0.0	0.05	0.70	20	NO
Waialae Nui Stream	4	–	–	0.0	0.2	0.62	0.19	–	NO
Kaupuni Stream	0	–	–	–	0.0	0.03	0.31	–	YES

Appendix A: (*Continued*)

Location	**# of Immuno-Assay Analyses**	**Caffeine (ppt)**	**Sulfa. (ppt)**	**Carb. (ppt)**	**Nitrate (NO3-N) (ppm)**	**Ammonia (NH4) (ppm)**	**Phosphate (ppm)**	**Silica (ppm)**	**Large-Scale Ag?**
High Density Cesspool / Low Density Sewer Contributory Area									
Waihee Stream	4	272	0.0	–	0.0	0.02	0.24	27	YES
Anahulu Stream	12	168	0.0	0.0	1.2	0.06	0.43	37	YES
Paukauila Stream	9	167	0.0	0.0	0.5	0.20	0.67	45	YES
Waimanalo Stream	17	141	0.0	0.2	0.2	0.06	0.23	31	YES
Loko Ea Fishpond	12	70	0.0	0.0	2.9	0.04	0.30	48	YES
Kiikii Stream	9	0	0.0	0.0	1.5	0.25	0.66	35	YES
Haaula Seep	4	–	–	0.0	–	–	–	–	NO
Kaunala Seep	12	–	–	0.3	0.0	0.49	0.29	2	NO
Anahulu River Spring	0	–	–	–	2.5	0.03	0.92	69	YES
Low Density Cesspool / High Density Sewer Contributory Area									
Ulupo Heiau Spring	17	670	0.0	2.5	1.2	0.03	1.96	33	NO
Pukele Stream	4	304	0.0	0.0	0.8	0.16	0.40	19	YES
Waimano Stream	30	295	3.0	2.2	0.4	0.08	0.45	43	NO
Waipahu Spring	23	235	0.0	0.2	0.7	0.08	0.78	47	YES
Kapakahi Stream	26	215	0.0	0.3	0.3	0.11	0.82	52	YES
Kaneohe Stream	8	173	0.0	0.3	0.8	0.03	0.22	22	NO
Waikele Stream	8	172	0.0	0.0	1.0	0.02	0.66	48	YES
Kalauoa Spring	9	128	0.0	0.0	0.0	0.01	0.78	43	NO
Keaahala Stream	14	128	0.0	0.3	0.1	0.02	0.25	28	NO
Kawa Stream	23	88	2.3	0.5	0.7	0.04	0.53	17	NO

Appendix A: (*Continued*)

Location	**# of Immu-no-Assay Analyses**	**Caffeine (ppt)**	**Sulfa. (ppt)**	**Carb. (ppt)**	**Nitrate (NO3-N) (ppm)**	**Ammonia (NH4) (ppm)**	**Phos-phate (ppm)**	**Silica (ppm)**	**Large-Scale Ag?**
HECO Spring	5	86	0.0	0.0	0.0	0.00	0.70	–	NO
Moanalua Stream	0				0.1	0.11	0.51	22	NO
Maunawili Stream	0	–	–	–	0.4	0.05	0.29	23	NO
Low Density Cesspool / Low Density Sewer Contributory Area									
Waiawa Stream	11	228	0.0	0.0	0.0	0.16	0.21	21	YES
Kapaa Stream	19	168	2.1	0.0	0.1	0.21	0.51	27	NO
Kahana Stream	18	0		0.0	0.1	0.03	0.02	22	NO
Kahuku Stream	2	–	–	0.0	0.0	0.03	0.86	48	YES
Honouliuli Stream	0	–	–	–	0.7	0.07	0.30	25	YES
Kahana Iki Stream	0	–	–	–	0.0	0.05	0.21	31	NO
Samples from Lake Wilson and Outlet Streams (Kaukonahua) and Ditch (Wahiawa)									
Kaukonahua Stream	16	730	9.7	1.5	0.0	0.13	2.63	7	NO
Wahiawa Ditch	22	326	2.8	4.9	0.0	0.09	0.22	8	NO
Lake Wilson	104	214	1.9	10.9	0.0	0.08	0.19	8	NO
COMBINED	142	251	2.4	5.7	0.0	0.08	0.30	8	NO

OCCURRENCE AND PERSISTENCE OF THE HERBICIDE GLYPHOSATE IN A SUBURBAN TROPICAL WATERSHED

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ABSTRACT

Stream, streambed sediment and suspended sediment sampling for the herbicide Glyphosate was conducted in a small, 4.05-square kilometer suburban watershed on the island of Oahu, Hawaii between December 2017 and April 2020. Over this 2.5-year study period, a total of 188 stream samples (142 runoff conditions, 46 baseflow conditions), 81 streambed sediment samples, and 9 suspended sediment samples were collected and analysed for glyphosate and a subset of sediment samples were analysed for its degradation product aminomethylphosphonic acid (AMPA).

The glyphosate concentration levels measured during stormwater runoff conditions within Kawa stream were significantly higher than levels measured under groundwater dominant baseflow conditions. The mean and median glyphosate concentrations (μg/L) and the frequency of glyphosate detection (reporting limit 0.075 μg/L) measured in Kawa stream under runoff and baseflow conditions were 0.98/0.51/92% and 0.10/0.035/28%, respectively. The glyphosate concentrations measured in this small suburban tropical stream were significantly higher than mean levels measured by the USGS between 2014 and 2020 in streams that drain small urban watersheds throughout the continental United States. The glyphosate concentration levels measured in riverbed and suspended sediments in Kawa stream were generally two to three orders of magnitude higher than levels measured in stream-water.

The majority of glyphosate (>90%) was transported to Kaneohe Bay in the dissolved phase and originated from residential areas within the contributory watershed. The mean mass flux of glyphosate measured entering the near coastal environment under baseflow conditions was around 0.16 mg/min, while the mean mass flux during runoff conditions was 106 mg/min. The estimated median half-lives of glyphosate and AMPA measured in streambed sediments during this study were 4.7 and 6.2 days, respectively. This short half-life (4.7 days) along with the high-frequency (92%) of glyphosate detection in Hawaiian streams under runoff conditions illustrates the steady, unceasing input of glyphosate to Hawaiian streams.

Keywords: glyphosate, AMPA, environmental half-life, transport mechanism, streams, stream bed sediment, suspended sediment, urban mass flux.

1 DESCRIPTION OF STUDY AREA

Kawa stream is a perennial, 4.2-kilometer long stream (including a 0.6-km long tributary, Kawa Ditch) located in Kaneohe on the windward side of the island of Oahu, Hawaii. The main branch of the stream starts in the Hawaii Memorial Park cemetery and runs in a generally north/northeasterly direction through residential areas before discharging along the southern shoreline of Kaneohe Bay. Baseflow to the stream originates from small, perched groundwater seeps and springs within the watershed that range in elevation from 15 to 70 m above mean sea level. The United States Geological Survey (USGS) began continuous streamflow monitoring of Kawa stream on 9/29/2016. The mean and median streamflow measured in Kawa stream between September 2016 and July 2020 was 0.11 and 0.03 cubic meters per second (cms), respectively.

The major land uses within the 4.05 square kilometer Kawa stream watershed are single-family residential (35.5%), forest land (34%), cemetery land (11.5%), golf course (6%), school (6%), highways and streets (4%), commercial (2%) and park areas (1%) [1]. The residential portion of the watershed is known as the Pikoiloa neighborhood and has a population

ISSN: 2398-2640 (paper format), ISSN: 2398-2659 (online), http://www.witpress.com/journals
DOI: 10.2495/EI-V4-N2-141-156

of around 4 000. The houses in the watershed range in age from 20 to 80 years old and are highly sought after for their large lot sizes by Hawaiian standards (average lot size of 750 square meters). The southwestern headwaters of the watershed contain two separate cemeteries, the private Hawaiian Memorial Park and the Hawaii State Veterans Cemetery. The watershed also contains an elementary school (Kaneohe Elementary) and high school (James B. Castle High). The coastal section of the watershed contains the 18-hole Bayview Golf Course.

Urbanization of the watershed has altered the stream's natural hydrologic and hydraulic features [2]. Concrete drop structures constructed within the stream during urban development of the area reduced stream slopes and concrete channel linings stabilized the stream banks. Rainfall generated stormwater that falls on the residential portions of the watershed are conveyed to Kawa stream through a network of approximately 260 inlets (catch basins and grated inlets), 120 manholes, and nearly 13 700 linear meters of ditches, drainage pipes and box culverts [1]. The increase of impervious surfaces and installation of an efficient storm drain system during development of the residential subdivisions, cemeteries and schools within the watershed increased peak flows in the stream since storm generated runoff within the urbanized portions of the watershed can travel at greater speeds through the conveyance systems as well as through the hardened channelized sections of the stream. The resultant increased energy of flow within the stream during runoff events has led to downcutting within the unlined sections of the stream bed and undermined some of the constructed stabilizing structures within the stream [2].

Kawa stream is currently in violation of State of Hawaii water quality standards and is included in the 1998 Clean Water Act §303(d) list of impaired water bodies in the State of Hawaii. Total Maximum Daily Load (TMDL) standards, which reflect the maximum pollutant loads a waterbody (in this case, Kaneohe Bay) may receive, were previously established for nutrients (nitrogen and phosphorous) and total suspended solids (TSS) present in Kawa stream. A TMDL study of Kawa stream concluded that the nutrients leaving the watershed could enhance unwanted algae growth within the stream and Kaneohe Bay [3].

2 GLYPHOSATE PROPERTIES AND USAGE

Glyphosate and AMPA are non-volatile, polar and very soluble in water (11.6 g L^{-1}, 25 °C for glyphosate). However, these compounds strongly adsorb to soil particles, which bind them in the upper soil layer reducing their ability to leach into deeper soil layers and into groundwater [4]. Both compounds are very hydrophilic and practically insoluble in organic solvents and thus are assumed to be non-bioaccumulative in living organisms [5].

Previous half-life values measured for glyphosate range from 2 to 215 days in soils and from 2 to 91 days in waters [6]. The wide range of observed half-lives for glyphosate is a result of variable environmental conditions at the various previous study sites including soil characteristics (i.e. extent of soil-binding), pH and endogenous microbial populations and activity. Degradation of glyphosate in soils is mainly a biological process accomplished by different microorganisms, but bacteria, in particular members of the genus *Pseudomonas*, seem to be the most important [7]. The degradation product AMPA is believed to be somewhat more persistent than glyphosate in the environment, with measured half-lives in soil ranging from 60 to 240 days [8,9]. The decay of glyphosate and AMPA under laboratory conditions was fastest under warm and moist soil conditions and slowest under cold and dry conditions [10]. For instance, glyphosate was found to decay 8.4 times faster at 30°C than at 5°C under laboratory conditions.

Table 1: Glyphosate Use in the United States (Benbrook, 2016).

Annual glyphosate usage (1 000 kg)	1974	1982	1990	1995	2000	2005	2010	2014
Agricultural usage	363	2 268	3 359	12 465	35 699	71 481	106 941	113 347
Non-agricultural usage	272	1 270	2 402	5 679	8 980	10 025	11 357	12 037

Glyphosate is the most widely used herbicide, both in terms of mass applied and geographic distribution, in the United States. By comparison, the annual mass of the second-most used weed killer herbicide applied to agricultural crops in 2016 in the United States (atrazine) was roughly one quarter the mass of glyphosate applied. Historical usage data compiled by Benbrook [11] show that glyphosate use in the United States has increased roughly 200-fold since 1974 (Table 1). The increases in glyphosate usage in the United States and world-wide resulted mainly from widespread adoption of Roundup Ready crops that were genetically engineered to be tolerant to glyphosate in the early 1990s [12].

In the United States, it is estimated that over 12 million kilograms of glyphosate are currently used for non-agricultural purposes annually, including application by municipalities and homeowners to streets, parks, lawns, backyards and along waterways in urban and suburban settings [13,14]. The upward trend in glyphosate use has contributed to significant incremental increases in environmental loadings and human exposures to glyphosate, AMPA, and various surfactants and adjuvants used in formulating end-use glyphosate-based herbicides [11].

A previous water quality study conducted in Hawaii found widespread glyphosate contamination within surface waters and stream bed sediment on the islands of Oahu and Kauai [15]. Either glyphosate or AMPA was detected in 100% of the 32 stream bed sediment samples collected from multiple streams sampled on these two islands during this study. The present-day mean concentration levels of glyphosate measured in Hawaiian stream waters are roughly an order of magnitude higher than the next most commonly detected pesticide (the atrazine degradation product, 2-hydroxy-4-isopropylamino-6-ethylamino-s-triazine (OIET), with a mean concentration of 59 ng/l and 67% detection frequency) measured by the USGS in 32 stream waters collected on the islands of Oahu and Kauai from November 2016 to April 2017 [16]. In addition, the current mean glyphosate stream and sediment concentrations are seven and ten times higher than concentration levels of persistent organic pollutants (α-chlordane in sediment and pentachlorophenol in streams) measured in the mid-1970s on Oahu [17].

3 STUDY METHODOLOGY

Stream, suspended sediment and streambed sediment samples were collected from Kawa stream for glyphosate analysis between December 2017 and April 2020. The stream samples were also analysed for total suspended solids (TSS) and specific conductance. A total of 188 stream samples were collected in order to quantify the variation in glyphosate concentration present in the stream throughout the year under both baseflow and runoff conditions and over the duration of individual runoff events. A total of nine suspended sediment samples were collected during nine separate runoff events during this 2.5-year monitoring period. In addition, a time series of 81 increment streambed sediment samples were collected from three monitoring locations within the stream between February 2019 and April 2020. Stream and suspended sediment samples were collected at the USGS Gaging Station while the streambed sediments were collected at the Upper Dam, Lower Dam and Kawa stream Mouth sampling locations depicted in Fig. 1.

A multi-incremental sampling approach was used to collect the streambed sediments in order to produce representative temporal glyphosate concentration data. Traditional discrete sampling methodologies often produce a large variability of measured concentrations between and within individual discrete sediment samples collected at a given site. Sampling theory [18] and field experiments [19,20] have determined that a representative concentration for an analyte present in a heterogeneous matrix is best achieved by a multi-increment sampling approach which involves the collection of an adequate sample mass from an adequate number of locations within a delineated area of interest known as a Decision Unit (DU). Three DUs were established along different reaches of Kawa stream during this study which were repetitively sampled. The largest sampled DU was 250 square meters in size and established in the estuary where Kawa stream discharges into Kaneohe Bay. The two other DUs were both 20 square meters in size and were located just upstream of concrete drop structures installed to reduce the natural slope of the stream. The sampled DUs correspond to the upstream areas behind these drop structures where sediments transported in the stream tend to accumulate and the segment of stream where the stream enters the bay. A total of 50 increments of approximately 5 grams of sediment per increment were collected from each DU to create an individual

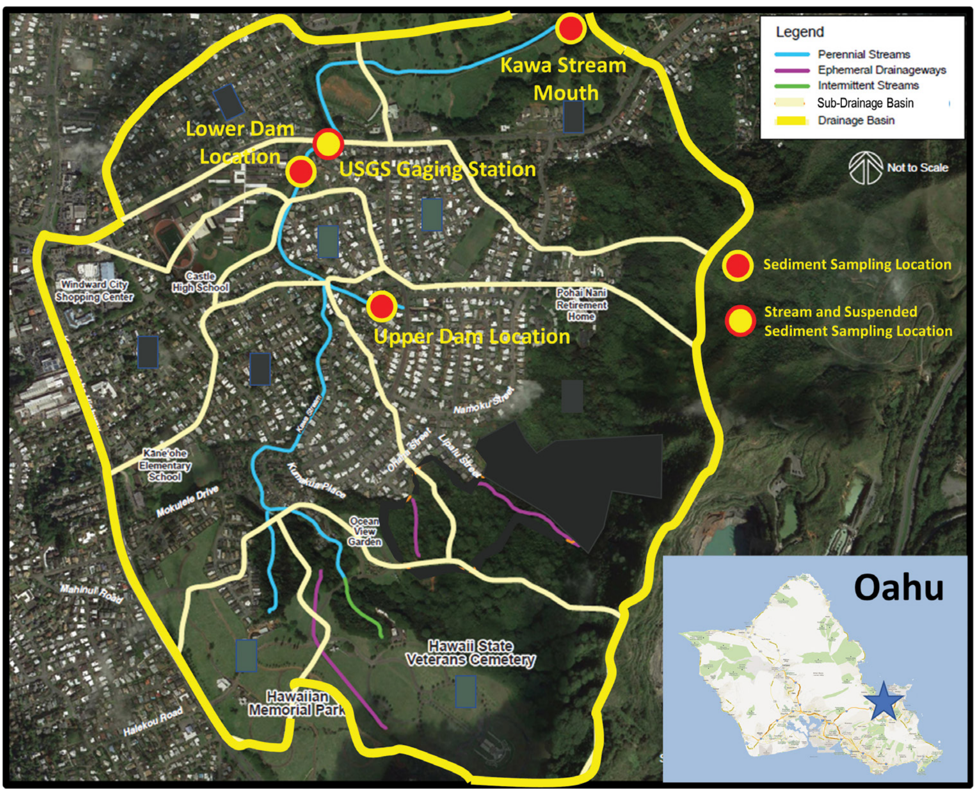

Figure 1: Kawa Watershed Kawa stream watershed and locations where stream and sediment samples were collected.

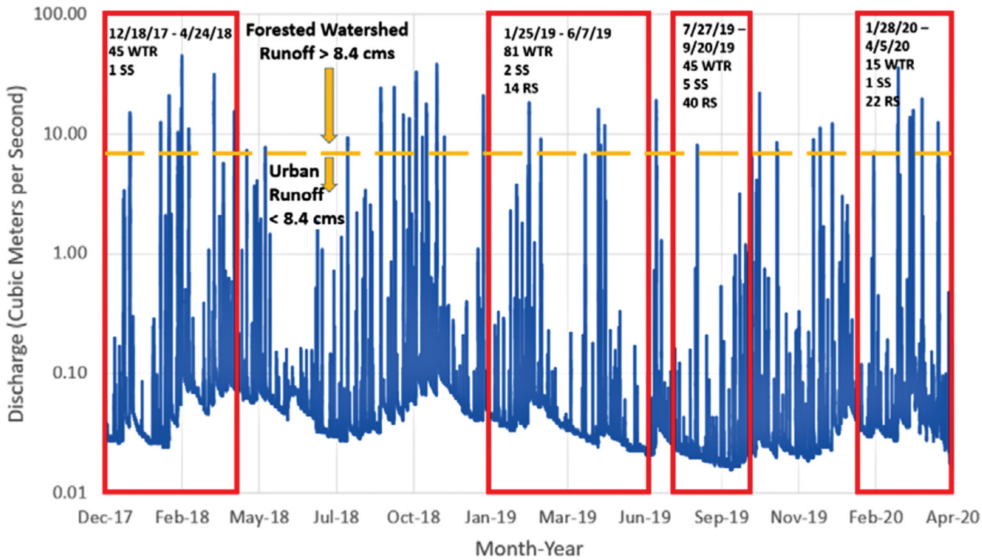

Figure 2: Kawa Stream Hydrograph Kawa stream hydrograph during study period: December 2017 to April 2020.

multi-increment sample that was then analysed for glyphosate content. An attempt was made to collect each sample from roughly the upper 1–2 cm layer of sediment present within each sampled DU. Gravel size particles (>2 mm) were removed by screening the samples prior to analysis. Suspended sediment samples were collected continuously from the stream over time periods of between 15 and 45 minutes during which time three to four coincidental stream samples were collected for glyphosate and total suspended solids analysis.

Figure 2 shows the hydrograph for Kawa stream between December 2017 and April 2020 and the four periods of time (red rectangles) when environmental samples were collected. The number of stream samples (WTR), suspended sediment samples (SS) and streambed sediment samples (RS) collected during each sampling period are also shown in this figure. The yellow dashed line shows the approximate streamflow (~8.4 cms) above which runoff from the forested watershed begins contributing to streamflow within Kawa stream. Glyphosate was not detected in three runoff samples collected from the forested portion of the watershed in early 2018.

4 STREAM, SUSPENDED SEDIMENT AND STREAMBED SEDIMENT RESULTS

Glyphosate concentrations were measured using the Abraxis Glyphosate Enzyme Linked Immunosorbent Assay (ELISA) Plate Kit. The ELISA method was used for this study since it allowed for higher frequency testing while reducing cost and time for analysis as compared to fixed laboratory methods. The Glyphosate ELISA method has a reporting limit of 0.075 and around 18 ppb for water and sediments, respectively. The sediment samples were extracted with 1 M NaOH. A total of 13 split time-series streambed sediment samples collected from the Upper Dam sampling site were submitted to Pacific Agricultural Laboratory for Glyphosate and AMPA analysis by Liquid Chromatography-Fluorescence Detection (LC-FLD). The limit of quantification for Glyphosate and AMPA in sediment with the LC-FLD method is 17 and 50 ppb, respectively. The coefficient of determination (R^2) for the glyphosate concentrations measured in the thirteen splits of sediment samples analysed by both immunoassay and LC-FLD methods was 0.66. Table 2 summarizes the glyphosate concentrations measured in suspended sediment and streambed sediments, and in stream waters under baseflow and ascending/descending runoff conditions during this study.

Stream samples collected under baseflow conditions where shallow perched groundwater was the source of streamflow typically contained undetectable or trace levels of glyphosate (28% detection frequency, 0.075 μg/L detection limit). Stream samples collected under both ascending and descending runoff conditions contained similar elevated mean glyphosate concentrations (around 1.0 part per million) and detection frequencies (around 92%). The variation in stream glyphosate concentration measured during individual runoff events suggests that glyphosate originates from both input to the stream from stormwater runoff from the surrounding residential portions of the watershed as well as from resuspension and release of glyphosate accumulated within streambed or riparian sediments deposited within and along the banks of the stream.

The highest median glyphosate concentration (724 μg/kg) was measured in the suspended sediment samples. The highest median streambed sediment concentrations were measured at the Upper Dam sampling site (573 μg/kg), which receives runoff from the surrounding residential community in the eastern portion of the watershed. The streambed sediment collected from the Lower Dam sampling site, which receives runoff from both the eastern and western portions of the watershed that contains the two cemeteries, elementary and high school, contained less than half the median glyphosate concentration (254 μg/kg) present in the sediment at the Upper Dam sampling site that receives only runoff from the eastern, residential portion of the watershed. This suggests that the residential areas within the watershed contribute higher loads of glyphosate to the stream than the cemeteries and schools within the watershed. The glyphosate concentration measured in the fine grain sediments present in the estuary where Kawa stream discharges into Kaneohe Bay are significantly lower (44 μg/kg) than levels measured in streambed sediments higher up in the watershed. This result may indicate that much of the glyphosate transported via Kawa stream discharges further out in Kaneohe Bay from the sampled DU located at the mouth of the stream during large rainfall runoff events.

Figure 3 depicts the median and range of glyphosate concentrations measured in runoff and baseflow condition stream samples, as well as the suspended sediment and streambed sediments analysed during this study. The median glyphosate concentrations measured in these media vary over five orders of magnitude. The elevated glyphosate concentrations measured in streambed sediments that accumulated at the Upper Dam site (compared to the levels measured down-stream at the Lower Dam site) suggest that the surrounding eastern residential portion of the watershed contributes the majority of the glyphosate measured within the watershed.

The mean and median concentration of glyphosate measured in Kawa Stream between 2017 and 2020, whose contributory watershed consists of residential and suburban land use, are similar to but slightly higher than glyphosate concentrations measured elsewhere on Oahu in Honouliuli Stream (mean 0.76 μg/L, median 0.22 μg/L, 54 samples collected between 2017 and 2020), which flows through the major industrial agricultural watershed on the island of Oahu, where large-scale experiments on genetically modified corn are conducted as well as diversified agriculture practiced. This illustrates the significant importance of urban and residential usage of glyphosate in the overall mass flux of this chemical within the environment.

The measured stream glyphosate concentrations are significantly lower than the U.S. Environmental Protection Agency drinking water Maximum Contaminant Level of 700 μg/L [21], and the chronic aquatic toxicity standards (1 800 μg/L) established by the State of Hawaii

Table 2: Glyphosate concentrations measured in stream and sediment samples.

Condition	**# Samples**	**% Detect glyphosate**	**Median glyphosate[1]**	**Mean glyphosate[1]**	**Maximum glyphosate**	**Minimum Glyphosate**
Stream water samples (µg/L)						
Baseflow conditions	47	27.7%	0.035	0.10	0.91	0.035
Ascending runoff conditions	93	92.5%	0.48	0.99	6.99	0.035
Descending runoff conditions	46	91.3%	0.72	0.96	6.60	0.035
Sediment samples (µg/kg)						
Suspended sediment	9	89%	724	1 056	3 934	< 97
Streambed sediment: upper dam	41	100%	573	701	4 100	51
Streambed sediment: lower dam	8	100%	254	245	418	28
Streambed sediment: stream mouth	32	31%	44	47	87	< 18

[1] Non-detect results were assigned a concentration of 0.035 ug/L.

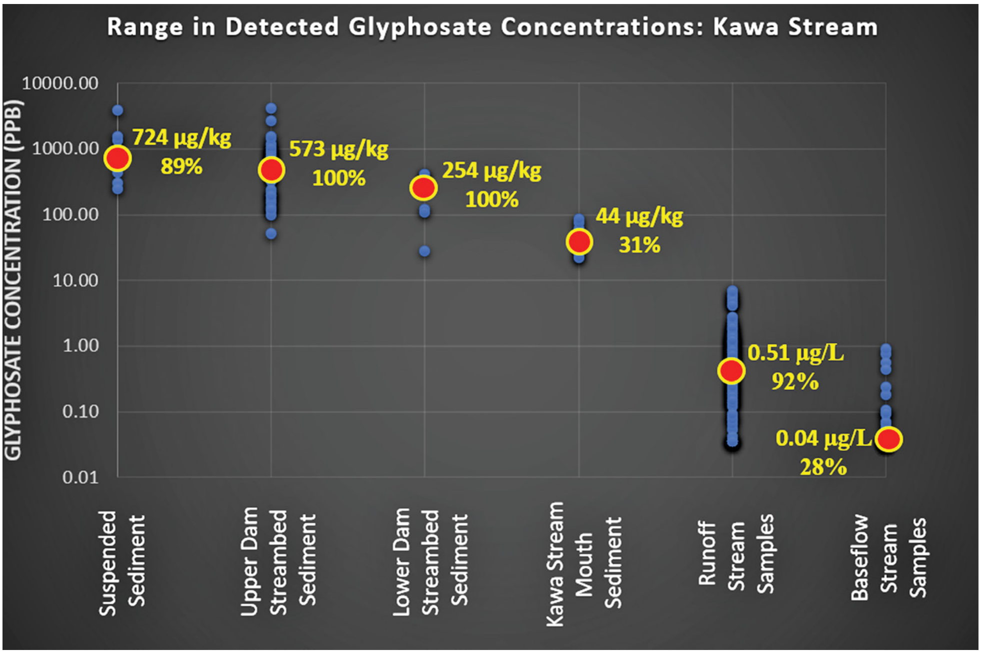

Figure 3: Median concentration and frequency of detection of glyphosate in suspended sediment, streambed sediment, runoff streamflow and baseflow streamflow.

Department of Health [22]. There are no human health or aquatic life benchmarks for AMPA. However, pesticides such as glyphosate and AMPA are often detected in the environment as chemical cocktails composed of multiple pesticides, surfactants and adjuvants. Further research is warranted on potential increased synergistic risks posed by glyphosate combined with other chemicals at the low part per billion levels commonly detected in streams.

The USGS has been conducting periodic monitoring of glyphosate and AMPA in a network of over 70 streams across the contiguous United States since the early 2000s [6,23]. The detection limit achieved by the USGS laboratory since 2009 is 20 ng/L as compared to the 75 ng/L detection limit associated with the immunoassay analysis used during this study. Table 3 compares the glyphosate concentrations measured in Kawa stream between 2017 and 2020 with glyphosate concentrations measured in small, urban watersheds in the mainland United States between 2014 and 2020 by the USGS, listed in order of median streamflow. The mean and median glyphosate concentration measured by the USGS in streams within these ten, small (<10 000 km^2) urban watersheds were 210 and 60 ng/L, respectively. By comparison, the mean and median glyphosate concentrations measured in Kawa stream were 759 and 341 ng/L, respectively, or 3.6 and 6.0 times higher. The only mainland United States stream that had similar glyphosate concentration levels as measured in Kawa stream was the Santa Ana River, which runs through the densely populated suburban metropolis surrounding Los Angeles. The elevated mean and median glyphosate concentrations measured in this small suburban Hawaiian watershed stream is likely due to three factors: (1) the small size of the Kawa watershed and the correspondingly short travel distances required for the glyphosate to enter the stream from the surrounding residential areas; (2) the extensive storm sewer

Table 3: Glyphosate levels in Hawaiian and continental United States urban watersheds.

Stream	**State**	**Median streamflow (cms)**	**% Watershed developed**	**Number of samples**	**Median glyphosate (µg/L)**	**Mean glyphosate (µg/L)**	**Detect frequency**
Kawa (All)	Hawaii	0.032	66.0%	186	341	759	76%
Kawa (Runoff)	Hawaii	0.032	66.0%	139	510	980	92%
Kawa (Baseflow)	Hawaii	0.032	66.0%	47	35	104	28%
Shingle	Minnesota	0.5	87.5%	128	50	95	73%
Swift	N Carolina	0.7	94.1%	128	80	173	96%
Cherry	Colorado	0.8	49.7%	135	130	343	85%
Fanno	Oregon	1.3	99.2%	126	90	135	98%
Sope	Georgia	1.4	99.1%	120	35	93	72%
Santa Ana	California	6.3	49.6%	85	320	800	99%
White Rock	Texas	2.6	97.8%	115	210	467	91%
Clinton	Michigan	8	70.8%	133	30	125	59%
Neuse	N Carolina	79	42.8%	97	50	70	79%
Chattahoochee	Georgia	111	66.2%	89	30	57	66%

system and moderately steep watershed topography within the Kawa watershed; and (3) the fact that ground treatment for weeds is required year-round in the tropical environment in Hawaii.

The instantaneous mass of dissolved phase glyphosate present in Kawa stream measured during the 2.5-year monitoring period was estimated by multiplying the measured glyphosate concentration by the streamflow volume at the time the samples containing detectable levels of glyphosate were collected. Under baseflow conditions, separate values were calculated based on just samples with detectable concentrations (13 samples) and for all baseflow samples collected (47 samples, 28% detection frequency). The mean, median and maximum glyphosate mass flux measured in Kawa stream is summarized in Table 4.

The total mass of glyphosate discharged in the dissolved phase from the Kawa watershed over the 2.5-year monitoring period was estimated to be around 4.4 kg (baseflow assumed for streamflow below 0.07 cms) when the median measured glyphosate mass flux under all baseflow and runoff conditions (0.0 and 19.9 mg/min) were applied to the 2.5-year flow data recorded by the USGS.

The annual mass of dissolved phase glyphosate discharging from Kawa stream is compared to the annual mass of glyphosate discharged from the larger, urban watersheds on the mainland United States in Table 5. The annual glyphosate mass for the mainland USGS stations was calculated by multiplying the median glyphosate concentration measured between 2014 and 2020 by the mean streamflow during this same period of time. The annual mass of glyphosate discharged from the Kawa watershed normalized to the urbanized area within the watershed is 7 to 110 times higher than the area normalized glyphosate mass flux measured in mainland streams. The contribution of glyphosate to Kawa stream per person living within the watershed is the second highest of the rivers compiled.

In addition to the dissolved phase, glyphosate is also transported out of the watershed in suspended sediment during runoff events. The percentage of glyphosate present in the suspended sediment load was measured during nine runoff events by continuously collecting suspended sediments over a 15 to 45-minute period as well as three or four contemporaneous stream samples. The total mass of suspended sediment during the sampling

Table 4: Mean, median and maximum glyphosate mass flux measured in Kawa stream.

Condition	# Samples	Mean glyphosate mass flux (mg/min)	Median glyphosate mass flux (mg/min)	Maximum glyphosate mass flux (mg/min)
Baseflow conditions (detects)	13	0.60	0.32	2.5
Baseflow conditions (all)	47	0.16	0.00	2.5
Ascending runoff conditions	86	113.6	19.0	1 006
Descending runoff conditions	42	90.3	26.4	872
All runoff conditions	128	106.0	19.9	1 006

Table 5: Annual and per capita mass of glyphosate mass discharged.

Stream	State	Annual glyphosate mass discharged (kg/year)	Annual glyphosate mass discharged per urban area (kg/year/km^2)	Total/urban watershed area (km^2)	Estimated population within watershed	Glyphosate contribution to stream per person (mg/year/person)
Kawa	**Hawaii**	**1.76**	**0.677**	**4.1/2.6**	**4 000**	**440**
Swift	N Carolina	1.76	0.034	54.4/51	25 000	70
Shingle	Minnesota	0.72	0.011	73.0/63.9	50 000	14
Sope	Georgia	1.49	0.019	80.0/79.0	30 000	50
Fanno	Oregon	3.59	0.044	81.6/80.9	60 000	60
White Rock	Texas	16.86	0.100	172/168	500 000	34
Clinton	Michigan	7.34	0.013	800/567	140 000	52
Cherry	Colorado	3.20	0.006	1 062/528	350 000	9
Santa Ana	California	63.23	0.022	5 858/2 905	1 500 000	42
Chattahoochee	Georgia	104.82	0.025	6 294/4 165	500 000	210
Neuse	N Carolina	125.00	0.042	6 972/2 984	65 000	1 923

interval was calculated by measuring the TSS concentrations in the stream samples collected. The glyphosate concentration in the composite suspended sediment collected and the concurrent stream samples were then measured by immunoassay. The percentage of glyphosate mass present in the suspended sediment compared to the mass present in the dissolved phase ranged from 1.2 to 27.7% during the nine sampled events. The mean/median percentage of glyphosate mass present in the suspended sediment versus the dissolved phase was 8.7% and 5.4%, respectively.

A total of 10 runoff samples collected during a large storm event (~2.3 inches daily rainfall on 3/15/20) were analysed for glyphosate and nutrients to provide insight to the relative amounts of suspended sediment, nutrients and glyphosate produced during a moderately large runoff event. Figure 4 shows the hydrograph for Kawa stream on 3/15/20 and the glyphosate, TSS and total nitrogen/phosphorous concentrations measured during the two periods of runoff that occurred on that day. The yellow dashed line delineates the portions of the hydrograph where runoff from the upland forested watershed contributed to streamflow. Previous sampling found that the forested portion of the watershed contributes no glyphosate but disproportionally large percentages of the suspended solids and nutrient loads that enter Kaneohe Bay during large runoff events.

The total mass of suspended solids, total nitrogen, total phosphorous, nitrate + nitrite and ammonia during the 3/15/20 runoff event was estimated to be 277,600, 2,085, 516, 142 and 19 kilograms, respectively, based upon the analytical results obtained on the ten samples collected. By comparison, the dissolved mass of glyphosate during this runoff event was estimated to be around 100 grams. The water quality data suggests that the watershed became

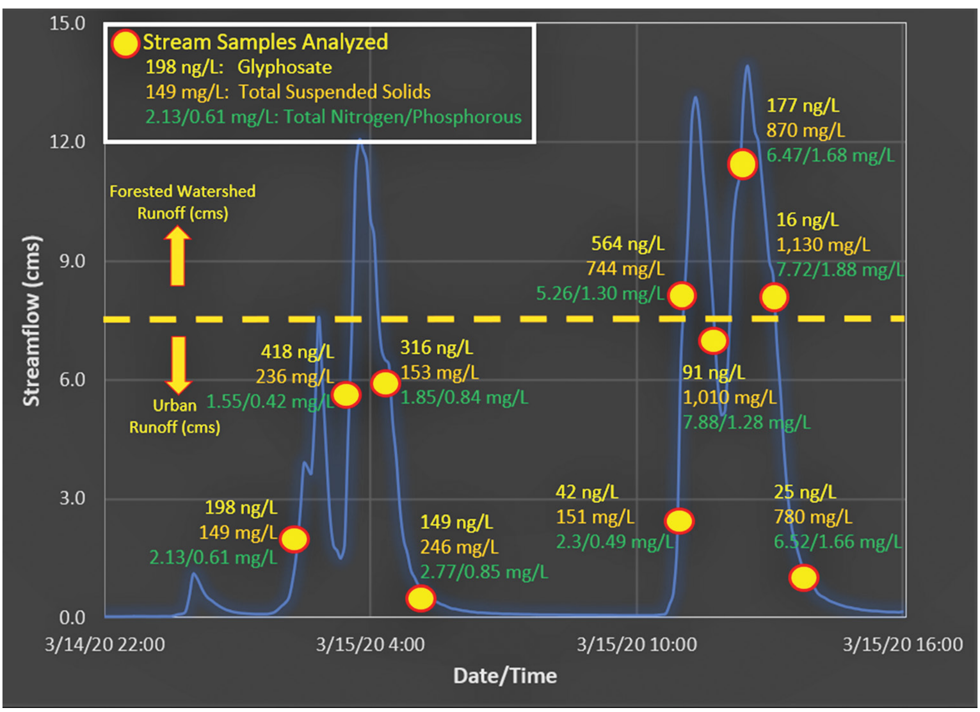

Figure 4: Variation in glyphosate, total suspended solid, nitrogen and phosphorous measured during 3/15/2020 rainfall runoff event.

almost depleted of glyphosate by around 13:00 during this storm event after 100 grams of glyphosate left the watershed since only trace levels of glyphosate were detected in the last two stream samples collected during this runoff event.

The half-life of glyphosate and AMPA in streambed sediments at the Upper Dam monitoring site was estimated by collecting a time-series of increment sediment samples from the DU established just above the concrete drop structure at this site. The decline in glyphosate and AMPA concentrations measured in the time-series of sediment samples collected during dry periods when no runoff occurred was used to derive the half-life values. It was assumed that no additional glyphosate was added to the sampled streambed sediments during these dry periods due to the near absence of glyphosate in stream samples collected under baseflow conditions.

Figure 5 plots the percentage reduction in glyphosate levels measured in sets of sediment samples collected after various durations of dry weather conditions. The degradation curves associated with half-life values of between 1 to 14 days are also shown on this figure. Measured half-lives for glyphosate in sediment ranged from 2.7 days to 7.6 days (12 measurements, median 4.7 days) while the AMPA half-lives (not plotted) ranged from 0.7 to 8.0 days (6 measurements, median 6.2 days). The median half-lives determined for glyphosate and AMPA (4.7 and 6.2 days) in stream sediments in the tropical Kawa watershed are significantly lower than typical literature values for these two compounds in soils (2–215 and 60–240 days, respectively) [6,8,9]. Despite the short persistence of glyphosate in the Hawaiian environment, the current concentration levels are seven and ten times higher than concentration levels of persistent organic pollutants (with longer half-lives on the order of years) measured in waters and sediments in the mid-1970s on the island of Oahu [15]. This attests to the significantly higher present-day mass loading of glyphosate to the Hawaiian environment than historic pesticide loading levels in urban environments.

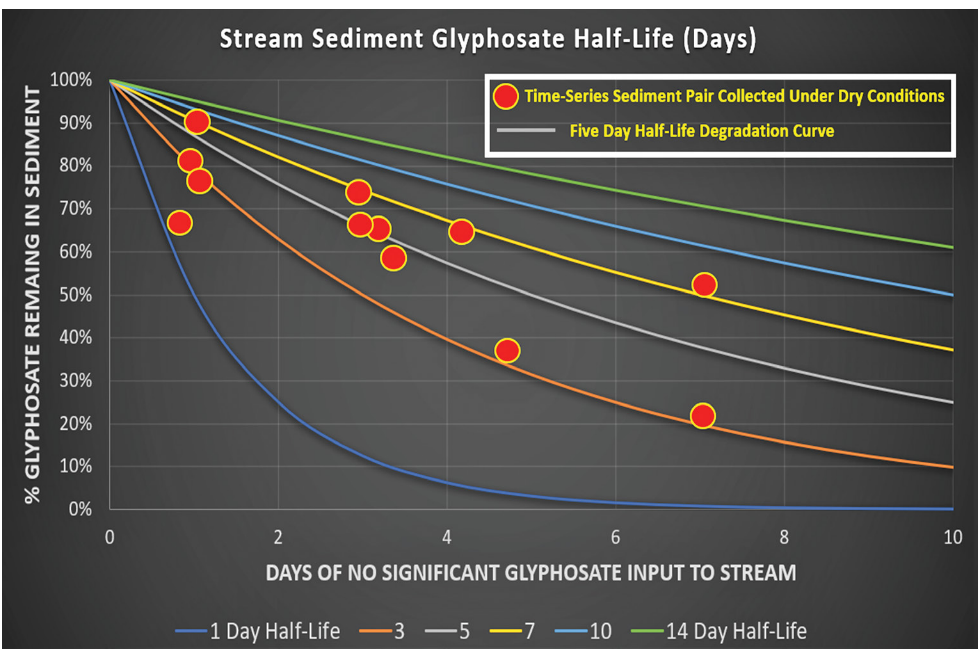

Figure 5: Range of glyphosate half-lives measured in streambed sediments.

5 CONCLUSIONS

Elevated glyphosate concentrations were measured in a stream that drains a small suburban tropical watershed in Hawaii compared to concentration levels measured in small streams in urban watersheds on the mainland United States. The present-day mean concentration of glyphosate in Hawaiian streams is an order of magnitude higher than mean concentrations levels of the next most commonly detected pesticide (the atrazine degradation product OIET, [16]) and seven and ten times higher than concentration levels of persistent organic pollutants measured in streams and sediments in the mid-1970s on Oahu [17]. Residential areas within the Kawa watershed (as opposed to golf courses, cemeteries and schools) were found to contribute the majority of glyphosate to the stream during large rainfall runoff events based on the spatial distribution of glyphosate concentrations measured in streambed sediments in Kawa stream.

The annual mass of glyphosate discharged from the Kawa watershed on Oahu normalized to the urban acreage within the watershed is 7 to 110 times higher than the area-normalized mass of glyphosate measured in mainland streams by the USGS. The small size, moderately steep topography, and extensive network of storm sewers and impervious surfaces within the watershed as well as year-round use of glyphosate for treatment of weeds likely contribute to the higher measured glyphosate fluxes in Kawa stream. The estimated mass of glyphosate (0.1 kg) discharged in Kawa stream during a well monitored runoff event on 3/15/20 was a small fraction (0.004%) of the mass of nutrients (total nitrogen and phosphorous, 2 601 kg) discharged during the same runoff event. Less than 10% of the annual glyphosate flux out of the Kawa watershed is transported in suspended sediments.

The median half-life of glyphosate and AMPA measured in streambed sediments during this study were 4.7 and 6.2 days, respectively. This short half-life combined with the ubiquitous detection of glyphosate in streams and sediments collected in Hawaiian streams during this and previous studies illustrate the unceasing nature of glyphosate input to the environment in the Hawaiian Islands. The most effective approach to reducing the mass flux of glyphosate entering the environment in the future would involve a combination of implementing governmental polices that promote reduction of nutrient, pesticide and sediment loads to urban storm drains systems and working with local health departments to provide guidance to the general public on the proper application of pesticides for homeowners.

ACKNOWLEDGEMENTS

The Pacific Islands Water Science Center (Mr. Travis Hylton) of the USGS graciously provided splits of stream samples collected by their autosampler on Kawa stream during the March 15, 2020 runoff event. The authors analysed the split samples for glyphosate while the USGS analysed the primary samples for TSS and nutrient content.

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SB-426-HD-1
Submitted on: 3/19/2023 11:22:30 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Kani Victor	Individual	Oppose	Remotely Via Zoom

Comments:

Aloha
I'm writing this testimony in opposition to Bill 426. These are just some of the statistics of sewage spills on Oahu since 2006.
Waikiki on March 24 2006
48 million gallons of raw sewage was released into a lawaia haebor over a 5 day period people who came in contact with this sewage became sick with streptococcus flesh eating bacteria this made international news and the Los Angeles times newspaper.
Koolina April 2013 there was actually 5 sewage spills in koolina over a 4 year period with over 200,000 gallons spilled on the ground and ocean and breakages in sewer lines 32 ft apart according to Civil beat the aging sewer line was 34 billion dollars to repair and replace..
Waianae Feb 2018 10,000 gallons of raw sewage was spilled into ditch from a broken line..
Waiau 2021 over a 1000 gallons of sewage spilled onto kam hwy .
Ewa June 2022 honouliuli waste water plant released 25 million gallons a day.into ewa beach waters.. it didn't say thw final volume but the cancelation of the ocean was a month later.
Pearl harbor December 2022 navy released 3500 gallons into pearl harbor..
Ewa February 2023 23,000 gallon spilled onto a neighborhood on Makule rd. Not all was cleaned up ..
Mamala bay or reef runway 14,000 gallons of raw sewage was spilled I to the ocean people advised not to go to the water
These are only some examples of the spills on Oahu there are more..
All these examples of these ecological disaster was a cesspool owner not a contributing factor.. now the state want to add 88000 families to this system not to mention places like ewa honouliuli will also have more than 18000 homes from hoopili and other new developments within the next decade and commercial businesses like kamakana Alii and all the malls in kapolei all pumping into honoulili they are being set up to fail...
And the hotels which bring in over 4 million people to the island in 2022 at a rate of 43000 a day according to the daily census.. tourist out number residents 4 to 1...all adding to our sewer system.. .. and destroying ours reefs with their sun tan lotions .. etc. Etc. yet land owners with cesspool are made to pay out to connect to this ecological catastrophe .

Thank you for this opportunity to testify against Bill SB 426. By way of introduction, I have a PhD in hydrogeology and undergraduate degrees in chemistry and geology and am an avid environmentalist. I have lived in Hawaii for almost 40 years, raised my family here and believe in the values of *Mālama ʻĀina.* I have no affiliation to any of the parties involved with Bill SB 426 and do not own property with a cesspool.

SB 426 should be rejected because the rationale for the bill is overstated and does not stand up to scientific scrutiny. In addition, implementation of this bill will disenfranchise underserved communities, including Native Hawaiians.

A small minority of legacy cesspools located in specific hydrogeologic settings around the State undoubtedly contribute raw sewage to public waters and efforts should be taken by the appropriate city and state agencies to correct these isolated cases. However, most existing legacy cesspools in the State of Hawaii do not pose a threat to the environment. The proposed legislation will require mostly low-income homeowners throughout the State (97 percent of those impacted by SB 426 have household incomes less than $126,000) to spend up to 5 billion dollars on cesspool conversions which will produce insignificant ecosystem and human health benefits. Bill 426 will saddle these low-income citizens with monthly financing and maintenance costs up to seven times higher than monthly costs paid by generally more affluent citizens that live in areas served by a county sewer system. The numbers I am quoting come from the reports prepared by the Cesspool Conversion Working Group.

As a result, I recommend that Bill SB 426 be rejected and that the companion Bill SB 285 be modified to direct the Hawaii Department of Health to produce defensible scientific data for those specific areas around the State where legacy cesspools are believed to be causing detrimental harm to the environment. This proposed modification would be a far more efficient approach for protecting human health and the environment while sparing mostly low-income citizens living in mainly rural portions of the State from an onerous financial burden.

The Cesspool Working Group report acknowledges that the mandatory statewide conversion of cesspools will not eliminate nitrogen input to the environment but merely somewhat reduce it. Their report states:

"*However, septic tank systems do not provide significant treatment for total nitrogen. Upgrading cesspools to septic tanks in areas with a high density may not provide significant protection to groundwater or near surface water quality."*

I have published several scientific publications focused on water quality on the island of Oahu. Most recently, a peer reviewed paper will be published later this month in the International Journal of Environmental Impacts. This paper evaluated the environmental impact of legacy cesspools and leaky sewer pipes on stream and spring water quality on the island of Oahu.

This new study found:

1. The average concentration of conservative wastewater tracers measured in Oahu streams and springs is extremely low; in fact, they were about one percent of the average concentration measured in over 1,200 streams sampled worldwide in a separate study.
2. The average pharmaceutical and nutrient levels in streams and springs sampled in areas with high densities of cesspools and sewer lines were not statistically different from concentration levels measured in streams and springs located in areas with low densities of cesspools and low sewer line densities.
3. Little evidence of wastewater was detected in streams located within the Priority 1 Areas delineated by the Hawaii Cesspool Hazard Assessment Group for expedited cesspool closure.

A separate study published in 2021 found that more total nitrogen discharged from a small watershed into Kaneohe Bay during a 12-hour storm event than the Cesspool Working Group estimates daily discharges to the ocean from all cesspools on Oahu. No cesspools exist within this mixed residential/forested watershed which includes Castle High School. Most of the total nitrogen exiting this watershed during the storm event originated from the undeveloped forested areas surrounding the residential community. These findings illustrate that the annual flux of total nitrogen entering coastal waters around Oahu from natural sources is significantly greater than the incremental reduction in cesspool derived nitrogen that would result from implementation of the proposed legislation.

I have attached the publications cited above to my written testimony and am available to meet with anyone who would like more details.

Mahalo nui loa

Steven Spengler

IDENTIFICATION OF SEWAGE EXFILTRATION IN COASTAL AREAS THROUGH THE MONITORING OF DRUGS AND STIMULANT CONCENTRATIONS IN URBAN STORM DRAINS

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ABSTRACT

One of the major barriers for municipalities responsible for mitigation of sewage exfiltration is locating grossly leaking sections of the sewage conveyance system in a time-, labor- and cost-efficient manner. In this study, water samples were collected from the dense network of manholes overlying the storm drain systems in the tourist area of Waikīkī and inland residential areas on the island of O‘ahu, Hawai‘i. The majority of the sewage conveyance infrastructure in this coastal area is submerged and the storm drains are routinely subject to backflow during high tide. Exfiltration of sewage from the aging conveyance system in this coastal area contaminates the surrounding shallow brackish aquifer, which then enters leaking pipe joints and cracks in the storm water conveyance system. Samples collected from the storm drains were analyzed for the presence of carbamazepine, a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug, which behaves as a conservative tracer in the environment (> 50 days half-life, low sorption). Samples were also analyzed for the more labile anthropogenic tracer caffeine (~4 day half-life). The higher stability of carbamazepine enables detection of this compound at greater distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage, given its ephemeral nature and relatively high and ubiquitous presence. The concentration levels and spatial distribution of detection of these two anthropogenic biomarkers were successfully used to identify areas of ongoing sewage exfiltration in Waikīkī and surrounding residential communities. The variation in carbamazepine and caffeine concentrations measured in Waikīkī storm drains over a 1 year period generally correlate with daily visitor arrivals to O‘ahu.

Keywords: sewage exfiltration, Hawaii, Waikiki, pharmaceutical tracer, storm drain contamination.

1 INTRODUCTION

An average of 394 million liters per day (mld) of sewage is conveyed through O‘ahu’s 3,380 km web of underground sewer lines. The majority of sewer lines in urban Honolulu are over 65 years old with an overall age range distribution on O‘ahu as follows: <25 years; 22.2%, 26–50 years; 18.3%; 51–75 years; 42.7%, 76–100 years; 11.8% and >100 years, 1.2%. In coastal areas on O‘ahu, the sewage conveyance system is largely immersed in the shallow, brackish to saline groundwater aquifer that underlies the coastal plain. The warm climate in Hawai‘i combined with the high sulfate content of the saline groundwater produces corrosive hydrogen sulphide gases that results in constant challenges in maintenance of the aging sewage conveyance system. Thus, there is an ongoing need to replace and upgrade Hawai‘i’s sewer lines and force mains due to both capacity and structural integrity issues [1].

The exfiltration of sewage in coastal settings such as Waikīkī contaminate the surrounding shallow brackish aquifer, which then enters leaking pipe joints and cracks in the portions of the aging storm water conveyance system that conveys tidal water inland from either the Ala Wai Canal or the Pacific Ocean during the upper part of the tidal cycle. One study by the United States Environmental Protection Agency reported between 12% and 49% of wastewater flows are lost due to leaking infrastructure in United States cities [2]. A recent

WIT Transactions on The Built Environment, Vol 208, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/FRIAR220061

survey completed by the Water Environment Foundation in Milwaukee (315 outfalls, n = 1,500 samples) estimated that 30% of stormwater outfalls show high and consistent levels of untreated wastewater and 8% had very high levels of wastewater.

The system-wide amount of wastewater exfiltration from O‘ahu's sewage system is unknown. A rough, upper-limit estimate of the magnitude of exfiltration can be made by comparing the average daily groundwater withdrawals on O‘ahu by the island-wide water utility, the Honolulu Board of Water Supply (BWS), during the wet winter months of January to March 2021 (127.6, 124.8 and 121 mgd, respectively) with the daily average volume of wastewater treated at the nine Waste Water Treatment Plants (WWTP) operated by the City and County of Honolulu (CCH) on O‘ahu during 2021 (103.7 mgd). The difference in the volume of groundwater pumped by the BWS during these wet months (when use of water for irrigation purposes is at a minimum) and the volume of wastewater is around 20 mgd. It is likely that at least half (10 mgd) of this difference is used during these wet winter months for purposes (residential irrigation, small-capacity private WWTP, wash cars, fill pools, etc.) that doesn't result in a return of the spent water to the sewer system. By comparison, the average daily groundwater withdrawal by the BWS during the dry summer months of June, July and August 2021 were 150, 151 and 150 mgd, a difference of around 45 mgd from the volume of water processed at the nine CCH WWTPs. This simple analysis suggests that the system-wide exfiltration rate on O‘ahu is somewhere in the order of 10%, with the majority of exfiltration likely occurring in the older sections of pipes present in urban Honolulu.

One of the major barriers for municipalities responsible for mitigation of sewage exfiltration is locating grossly leaking sections of the sewage conveyance system in a time-, labor- and cost-efficient manner. The City and County of Honolulu sewers are currently monitored and rehabilitated through extensive CCTV inspection of sewer lines, and a semi-automated computer algorithm to evaluate the CCTV results [1].

The primary objective of the study was to determine whether mapping of the spatial distribution of the maximum pharmaceutical (carbamazepine and caffeine) concentration levels measured in the storm drain systems in the vicinity of Waikīkī can be used to identify areas of on-going sewage exfiltration from the aging sewer conveyance systems in these areas. Ideally, this type of study would utilize shallow groundwater data collected from a dense network of monitoring wells within the study area. Unfortunately, no such monitoring network exists. So, in this study, samples were collected between November 2020 and January 2021 from the dense network of storm water manholes present in this coastal tourist destination and the adjacent, inland McCully-Moiliili residential areas. In these areas, wastewater contaminated groundwater seeps into the stormwater conveyance pipes and mixes with the tidally driven water that enters the storm drain system from the Ala Wai Canal or the ocean (dependent on which side of Waikīkī is sampled). A secondary objective of the study was to measure the temporal variations in caffeine and carbamazepine concentrations measured in three Waikīkī storm drains and at two Ala Wai Canal locations between February 2021 and December 2021, when the number of tourists visiting Hawai‘i varied greatly due to COVID pandemic travel restrictions to the islands.

1.1 Caffeine and carbamazepine

Carbamazepine and caffeine are known as emerging contaminants, which describes pollutants that have been detected in water bodies, may have ecological or human impact, and typically are not regulated under current environmental laws. These compounds are also known as micropollutants because they are typically present in trace quantities (part per trillion to billion levels) in the environment. These micropollutants enter the environment during our daily routines when we consume, flush away, or wash these compounds down the sink. As a result, these compounds are increasingly being used as anthropogenic (human) markers of sewage contamination. Carbamazepine and caffeine were the first and second (62.3% and 56.1%, respectively) most commonly active pharmaceutical ingredients detected in 1,052 river samples collected from 104 countries worldwide in a recently published global-scale study [3]. Caffeine was detected in river samples collected from every continent while carbamazepine was detected in rivers on all continents except Antarctica. The detection frequency of caffeine and carbamazepine in rivers were similar across all six continents where both pharmaceutical compounds were detected.

Caffeine is a naturally occurring stimulant found in coffee, soda, tea, chocolate and energy drinks. The daily consumption rate of caffeine varies worldwide. Northern European countries tend to consume higher daily doses of caffeine (190 to 260 mg/day/person) compared to warmer Southern European countries (80 to 120 mg/day/person). The average daily consumption of caffeine in the United States is 165 mg per person per day [4]. Caffeine is extensively metabolized by humans during consumption, with less than 5% excreted unchanged in the urine [5].

Carbamazepine is a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug. The dosage range for carbamazepine for those on the medication is between 400 to 1,200 mg/day. Daily per capita consumption rates of carbamazepine range from 0.03 to 0.44 mg/day/person [6]. Following consumption, up to 10% of CBZ is excreted from the human body [7].

Caffeine is effectively removed (> 95%) by conventional treatment at WWTPs while carbamazepine is poorly removed (typically less than 10%). Caffeine was found to undergo significant microbial degradation in the Jamaica Bay estuary near New York City while little evidence for removal of carbamazepine was observed [8]. These findings suggest that carbamazepine behaves as a conservative tracer in the environment whereas caffeine is comparatively labile. The persistence of carbamazepine in conventional treatment processes leads to its widespread occurrence in water bodies, especially on the mainland United States where WWTPs commonly discharge treated effluent into nearby surface water bodies [9]. The stability of carbamazepine upon release to the environment enables detection at larger distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage or grey-water, given its ephemeral nature and higher initial concentration levels in untreated wastewater.

1.2 Caffeine and carbamazepine concentration levels in sewage in Hawaiʻi

Researchers at the University of Hawaiʻi monitored the variation in sewage flow and caffeine concentration in the main sewer line exiting Manoa Valley on Oʻahu by collecting composite samples over 3 hour periods during two, week-long dry-weather monitoring periods [10]. They found that the concentration of caffeine showed reproducible daily patterns with the highest concentrations being observed in the mornings and at end of the day (i.e., 8–11 AM and 5–8 PM composite samples), which also corresponded to periods of generally higher sewage flow exiting Manoa Valley. The measured concentration of caffeine in the sewage ranged from 5,000 to 103,400 parts per trillion (ppt, ng/L), with the highest flux of caffeine (2.4 mg/sec) exiting the valley between 8 and 11 AM. The authors associated the primary source of caffeine with the preparation and consumption of coffee and tea, which is secreted to the sewer system by the regular daily metabolic activities of the residents in the valley.

The Safe Drinking Water Branch of the State of Hawaiʻi Department of Health (HDOH) conducted two rounds of sampling of raw wastewater influent at four WWTP and also collected thirteen samples of treated wastewater effluent generated at thirteen WWTP facilities that produce reclaimed water throughout the State of Hawai‘i [11]. The HDOH samples were analyzed using LC-MS-MS methods. Carbamazepine was not detected in the wastewater influent; likely due it being masked by the chromatographic peaks of higher concentration analytes. During the current study, a total of twenty samples were collected from septic tanks at various beach parks on the island of O‘ahu and analyzed for caffeine and carbamazepine using an ELISA immunoassay method. Table 1 summarizes the caffeine and carbamazepine concentrations measured. The median concentration of caffeine and carbamazepine is around 100,000 ppt and 500 ppt, respectively.

Table 1: Caffeine and carbamazepine concentrations measured in septic tanks and WWTP effluent and influent in Hawai‘i.

Source	Caffeine (parts per trillion)				
	Mean	Median	Max. Detect	Count	Detect Frequency
Septic Tanks	19,925	11,600	83,200	11	100%
WWTP Influent[1]	96,238	108,000	150,000	8	100%
WWTP Effluent[1]	152	33	1,200	23	96%
Source	**Carbamazepine (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	682	552	1,735	20	100%
WWTP Influent[1]	ND	ND	ND	8	0%
WWTP Effluent[1]	113	110	220	23	65%
ND = Not Detected					
[1]Oahu WWTP Influent/Efffluent Data from HDOH [11]					

2 DESCRIPTION OF STUDY AREA

This study was conducted on the island of O‘ahu in the 4 km^2 tourist center of Waikīkī and the coastal portion of the adjacent residential communities of McCully-Moiliili, which are comprised of a mix of high rises, low rises and single-family residential homes. Roughly 75% of the State of Hawai‘i’s population of 1.44 million people reside on O‘ahu. Waikīkī means “spouting water” in the Hawaiian language in reference to the rivers and springs that flowed into the area during historic times. The original marsh and swamp lands were considered a health hazard and drained during construction of the Ala Wai Canal in the 1920s, which directs streamflow and storm runoff from the Manoa and Palolo watersheds to the Pacific Ocean and separates Waikīkī from the inland McCully-Moiliili communities. During development of the McCully-Moiliili areas in the 1940s, inland stream flow, spring flow and storm runoff through these areas were routed into lined channels known as the Hausten and Makiki Ditches, which empty into the Ala Wai Canal.

Waikīkī became a major tourist destination in the 1950s with the advent of long-distance air travel to the islands from the mainland United States which prompted the beginning of the construction of the numerous high-rises and resort hotels that dominate today’s skyline. As a result, most of the sewer and storm-drain infrastructure in the Waikīkī area is between 50 and 70 years old. Visitor arrivals reached one million for the first time in 1968, filling approximately 15,000 hotel rooms. From 1990 to 2013, between 4 and 5 million visitors arrived annually on the island of Oʻahu [12], and the number of hotel rooms in Waikīkī had expanded to 30,000 rooms. Between 2013 to 2019, annual tourist arrivals to Oʻahu increased to between 5 and 6 million visitors. Peak visitor arrivals tend to occur during the months of December and July and international visitors (largely from Japan) contribute around one-third of the travelers to Hawaiʻi. Travel restrictions imposed due to the COVID-19 pandemic caused the annual visitor arrivals to Oʻahu to plummet to 1.5 million in 2020 followed by a partial rebound of 3.3 million annual visitor arrivals in 2021.

The sampling effort presented in this study was conducted between November 2020 and December 2021, roughly 6 to 20 months into the global pandemic. The spatial distribution of sewage exfiltration in the Waikīkī and inland McCully-Moiliili areas was based on sampling conducted between November 2020 to January 2021 while temporal variations in caffeine and carbamazepine concentrations were monitored in three Waikīkī storm drain and two Ala Wai Canal locations between February 2021 and December 2021.

3 STUDY METHODOLOGY

A total of 70 storm drain and canal sampling locations were established within Waikīkī, the inland residential McCully-Moiliili communities and along the Ala Wai Canal which separates these two areas. The Ala Wai Canal receives input from the storm drain systems that underlie both the Waikīkī and the inland residential McCully-Moiliili communities. Samples were collected directly from the storm drains by inserting a 1.3 cm diameter PVC pipe through the vent hole in the storm drain manhole cover to the bottom of the storm drain, capping the top of the pipe, withdrawing the pipe from the manhole, and directly transferring the collected sample to a labelled sample container. A PVC pipe was also used to collect samples from the Ala Wai Canal, which allowed a vertical composite sample from the entire depth of the canal (~0.5 to 1.7 m) to be collected. Three rounds of sampling were conducted from this monitoring network between November 2020 and January 2021 under mid- to high-tide conditions to evaluate the spatial distribution of sewage exfiltration in the Waikīkī and inland McCully-Moiliili areas. Additional sampling was conducted between February 2021 and December 2021 from three Waikīkī storm drains and two Ala Wai Canal locations to monitor the temporal variation in concentration levels of these compounds. Samples were collected during the global COVID pandemic, when the number of tourists staying in Waikīkī greatly fluctuated due to travel restrictions imposed by the State of Hawaiʻi. Fig. 1 shows the location of the five repetitively monitored sites along with two canal and groundwater monitoring locations in Waikīkī previously sampled in 2018 for pharmaceuticals [13].

The samples were analyzed for general water quality parameters (temperature, specific conductance, salinity, dissolved oxygen, pH and turbidity) in the field and frozen shortly after collection. Enzyme Linked Immunosorbent Assay (ELISA) test kits manufactured by Eurofins were used to measure the concentration of caffeine and carbamazepine, typically in batches of 80 samples at a cost of less than $8 per sample.

3.1 Pathway of sewage contamination entering coastal storm drain systems

Water levels were measured during this study using transducers under dry weather conditions in the Ala Wai Canal and in the coastal storm drain network underlying Waikīkī and the coastal portion of McCully-Moiliili. Water level fluctuations were identical in amplitude and timing as the tidal changes measured at the National Oceanic and Atmospheric Administration (NOAA) gauge in Honolulu Harbor (NOAA Station ID: 1612340).

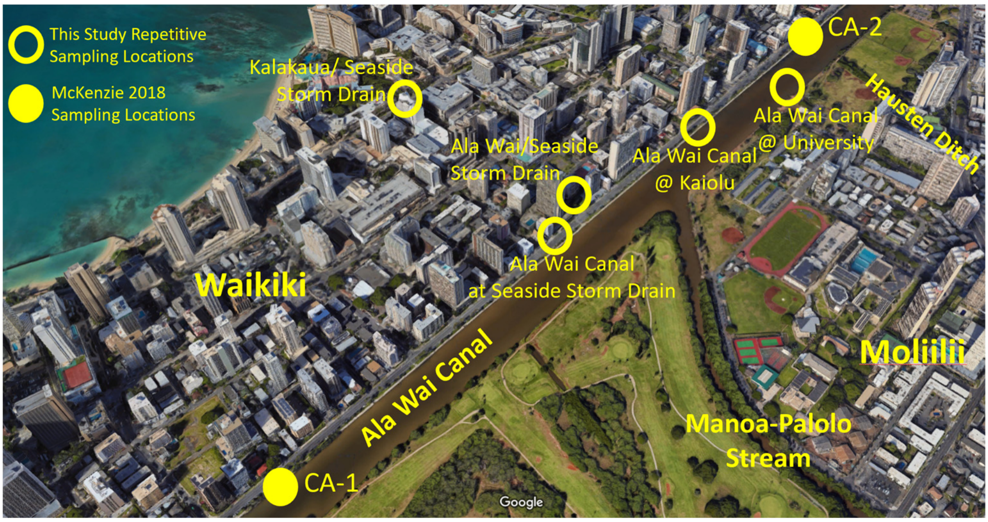

Figure 1: Repetitively sampled locations in Waikīkī during this study (open circles) and two 2018 monitoring locations (closed circles) [13].

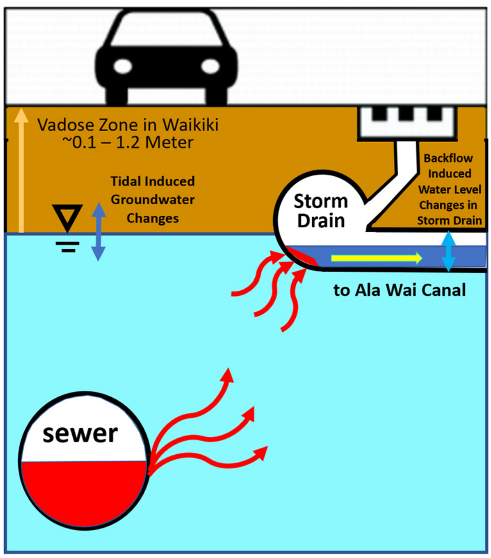

Figure 2: Depiction of mechanism of how sewage exfiltration enters storm drain system in tidally influenced coastal areas on O‘ahu.

Previous studies have shown that leaking sanitary sewers can directly contaminate nearby leaking storm drains with untreated sewage during dry weather conditions [14]. Discharges can also enter the storm drain system indirectly, when groundwater contaminated by leakage from a nearby sewer enters the stormwater system. Fig. 2 depicts how leaks in sewer lines in coastal areas contaminate the surrounding brackish aquifer which can then enter cracks in the storm drain conveyance system during the lower portions of the tidal cycle when the groundwater levels are above the tidally driven water levels in the storm drain pipes. In Waikīkī, wastewater leaking outward from cracked pipes (exfiltration) in the study area migrates into the stormwater system, which acts as a very effective conduit to deliver leaking wastewater into the Ala Wai Canal. Based on the pattern of human consumption of caffeine (breakfast and dinner) and carbamazepine (taken orally twice per day), the concentration levels of these compounds in sewage tend to peak in mid-morning and early evening [10]. However, the caffeine and carbamazepine concentrations that leak into nearby storm drains have likely reached a quasi-steady state concentration in the contaminated groundwater during advective transport between the leaky section of sewer line and the cracks in the storm drain lines through which the contaminated groundwater enters.

Fig. 3 compares the salinities measured in the storm drain located at the intersection of Seaside and Kalakaua Boulevard in central Waikīkī with the salinities present in a storm drain located at the intersection of Seaside and Ala Wai Boulevard, directly adjacent to the Ala Wai Canal. The salinity in both the Waikīkī storm drain and the Ala Wai Canal increased by about 50% during high tide, as salt water from the Pacific Ocean is pushed landward into the storm drain with the tide. As the tide drops, the impact of brackish groundwater entering the storm drain system is seen in the falling salinities observed at both monitoring locations.

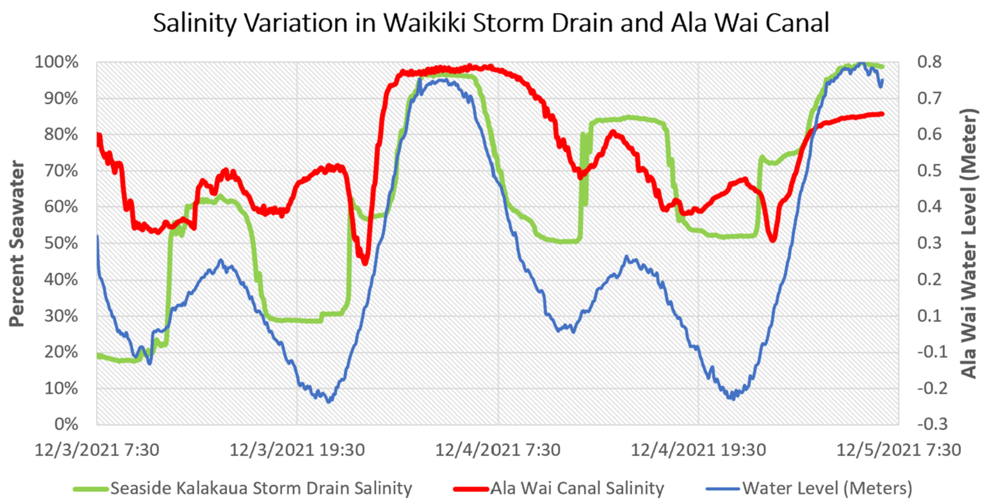

Figure 3: Variation in Salinity and water levels measured in storm drains located in the middle of Waikīkī and adjacent to the Ala Wai Canal.

Fig. 4 shows the change in water levels measured in two connected storm drains located 410 m apart in central Waikīkī and adjacent to the Ala Wai Canal during a large winter rainfall event. The annual rainfall in Waikīkī is around 635 mm per year. A total of 180 mm of rainfall fell in Waikīkī between 30 December 2021 and 3 January 2022 (weather underground station KHIHONOL275 located in central Waikīkī along the Ala Wai Canal).

As can be seen in this graph, the water levels in the storm drains in central Waikīkī quickly rise as much as 0.9 m above the water levels in Ala Wai Canal during intense rainfall events, producing a gradient hydraulic gradient of as much as 0.0022 m/m that drives runoff from the center of Waikīkī towards the canal.

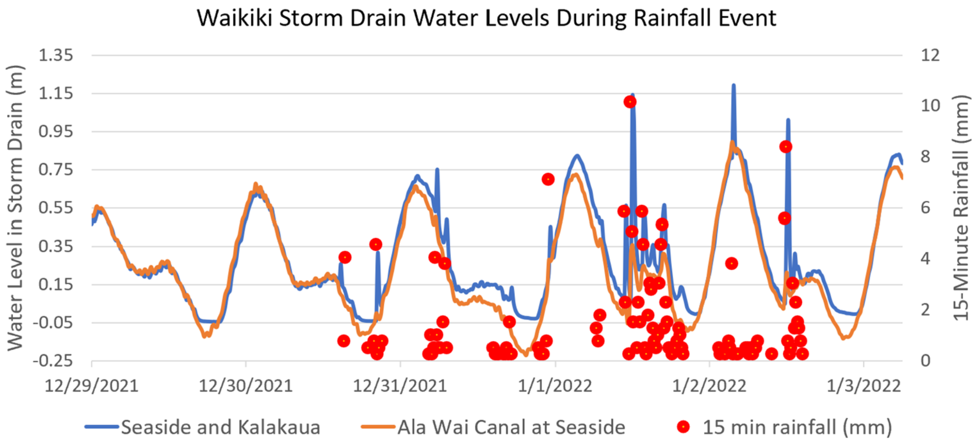

Figure 4: Water level variations in Waikīkī storm drains during a large rainfall event.

The average surface elevation of the majority of land in Waikiki is less than 1 m. Sea-level rise (SLR) is currently predicted to rise between 0.18 to 0.24 m from 1994 to 2014 sea levels by 2050 [15]. Groundwater inundation flooding of the coastal areas in this study area will occur contemporaneous with SLR related flooding as groundwater levels are lifted [16]. Fig. 4 illustrates how vulnerable Waikīkī is to future flooding events should a high-intensity rainfall event hit the area during a high or king tide. At high-tide, much of the capacity of the storm drain system in these coastal areas is filled with tidal water rendering the system unable to convey storm runoff towards the Ala Wai Canal or the Pacific Ocean.

4 SAMPLING RESULTS

The monitoring network of 70 manholes established in the Waikīkī and McCully-Moiliili areas were sampled a minimum of three times between November 2020 and January 2021 under upper mid- to high-tide conditions (typically greater than 0.55 m water levels) when tidal backflow partially fills the underlying storm drain conveyance system. Immunoassay methods were used to quantify the concentration levels of caffeine and carbamazepine present in the storm drain system and in Ala Wai Canal. Fig. 5 shows the storm drain and canal sites sampled (red dots), the layout and age of the sewer system in the area, the location of on-site sewage disposal systems in the area and the maximum carbamazepine concentration measured in the storm drain and canal samples (minimum of three samples) collected from each sampling site between November 2020 and January 2021.

Ponded water was present along the street curb under dry weather conditions near the storm drains sampled on Kaio’o Drive and Namahana Street during the 3 month sampling period (Fig. 5). The dry weather ponded water at these two sites had disappeared by April 2021 suggesting that the water present on the street was related to either a sewage line or water line leak at these locations. The elevated carbamazepine concentrations measured in samples collected from the Hausten ditch were likely related to work undertaken for the Moiliili Area Sewer Reconstruction project [17]. During the sampling work, contractors hired by the City and County of Honolulu (CCH) were replacing a section of deteriorated cast iron sewer line from 808 to 828 Hausten Street that was originally installed in 1935 and located adjacent to the inland end of the Hausten Ditch. According to a press release, CCH intended

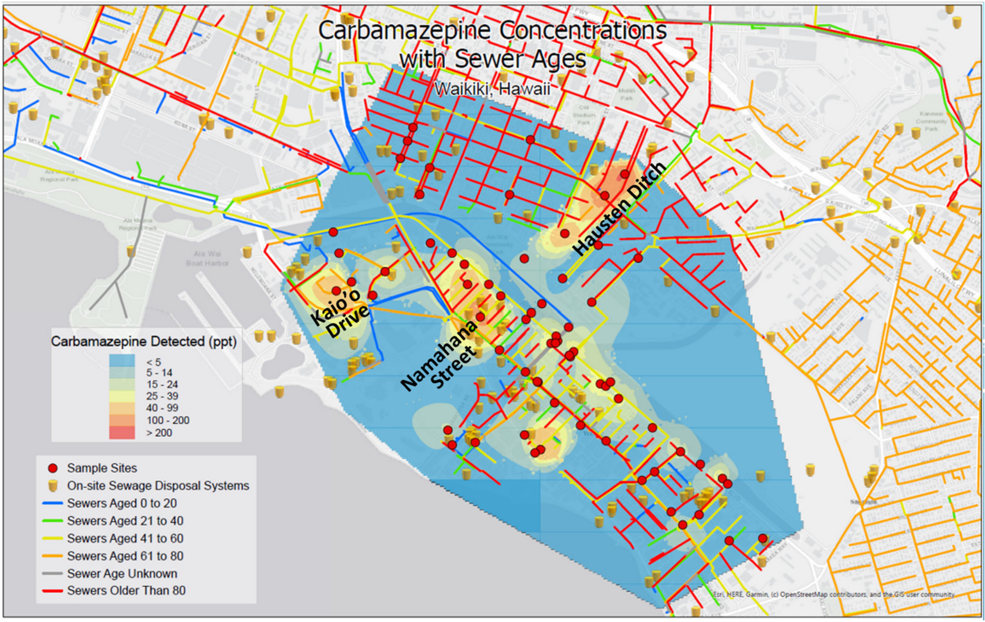

Figure 5: Spatial distribution of the maximum carbamazepine concentration measured in Waikīkī and Moiliili-McCully storm drains between November 2020 and January 2021.

to bypass the sewer line continuously, for 24 hours, 7 days a week during construction using pumps and generators. Based on the elevated carbamazepine concentrations measured in the Hausten Ditch between November 2020 and January 2021, the sewer line being repaired was not successfully bypassed. A follow-on sample collected from the Hausten Ditch in early February 2021 after the sewer repair work was completed did not contain detectable levels of carbamazepine.

4.1 Time variation in caffeine and carbamazepine concentrations

The COVID pandemic had a dramatic impact on the Hawaiian tourist industry. Annual visitors to O'ahu plummeted from over 6 million annual visitors between 2017 and 2019 to 1.5 million visitors in 2020 and 3.3 million visitors in 2021. The decline in the number of tourists was reflected in the volume of wastewater generated. The Sand Island WWTP processes roughly 60% of the wastewater generated on O'ahu and covers the metropolitan Honolulu area, including the Waikīkī and McCully-Moiliili areas. The average daily sewage flow processed at the Sand Island WWTP declined about 12% from a 2017 average daily volume of 260 mld to an average daily volume of 228 mld in 2021.

Five monitoring locations (Fig. 1) (three in Waikīkī storm drains and two in the Ala Wai Canal) were repeatedly sampled at both low and high tide from February 2021 to December 2021. This time series sampling was conducted to evaluate whether the caffeine and carbamazepine concentrations present in Waikīkī storm drains and in the adjacent Ala Wai Canal varied: (1) as a function of the tidal cycle (i.e., high versus mid to low tide) and; (2) over the sampling period, when the 7 day average daily number of visitors to Waikīkī varied from around 6,000 to 30,000 visitors per day as a result of varying travel restrictions related to the COVID pandemic.

Table 2 summarizes the mean, median and maximum concentration levels of caffeine and carbamazepine along with the average salinity measured in the three monitored storm drain locations in Waikīkī and in the two monitoring locations in the Ala Wai Canal between February and December 2021 along with data collected from two canal and groundwater monitoring locations (CA-1 and CA-2, Fig. 1) previously sampled in 2018 [16]. The storm drain located inland of the intersection of Ala Wai and Seaside was impacted by significant intrusion of brackish groundwater as reflected by the low average salinity measured in this storm drain (roughly one quarter of the salinity measured at the nearby the Ala Wai Canal monitoring locations). The presence of significant groundwater at this location is believed to be due to the greater degree of submersion of this storm drain (bottom depth of –1.15 m) than the other two storm drains monitored (Seaside/Ala Wai drain at the canal and Seaside/ Kalakaua bottom depths of –0.24 and –0.45 m). The median caffeine and carbamazepine concentrations measured in the two interior Waikīkī storm drains indicate a sewage or greywater component presence of between 1.3% and 6.4% in the storm drain system.

Table 2: Caffeine and carbamazepine concentrations measured in Waikīkī storm drains and Ala Wai Canal during current study (2021) and previous 2018 study [13].

Waikīkī Repetitive Sampling Locations	Caffeine (ppt)					
	Mean	Median	Max. Detect	Count	% Detect	% Seawater
Storm Drain: Kalakaua/Seaside	4,347	3,269	11,562	24	100%	58%
Groundwater Impacted Storm Drain: Ala Wai / Seaside	1,690	1,273	7,580	27	100%	21%
Storm Drain: Ala Wai Canal at Seaside	677	398	2,793	27	81%	74%
Ala Wai Canal at Kaiolu	543	207	1,735	25	88%	80%
Ala Wai Canal at University	287	82	1,439	24	71%	79%
CA-1 and CA-2 Surface Water[1]	1,091	1,010	2,700	8	75%	NR
CA-1 and CA-2 Groundwater[1]	986	1,045	1,600	8	88%	NR
Source	**Carbamazepine (ppt)**					
	Mean	**Median**	**Max. Detect**	**Count**	**% Detect**	**% Seawater**
Storm Drain: Kalakaua/Seaside	28	12	136	29	93%	58%
Groundwater Impacted Storm Drain: Ala Wai / Seaside	35	32	102	33	100%	21%
Storm Drain: Ala Wai Canal at Seaside	7	2	27	31	67%	74%
Ala Wai Canal at Kaiolu	6	0	44	30	37%	80%
Ala Wai Canal at University	6	0	36	29	48%	79%
CA-1 and CA-2 Surface Water[1]	44	0	150	8	75%	NR
CA-1 and CA-2 Groundwater[1]	83	105	130	8	75%	NR
NR = Not Reported						
[1]Surface and Groundwater Samples Collected in 2018 [13]						

The highest mean/median caffeine concentrations were measured in the storm drain in central Waikīkī while slightly higher carbamazepine concentrations were measured in the groundwater impacted storm drain at the intersection of Ala Wai and Seaside. The caffeine concentrations measured in the storm drain along the Waikīkī side of the Ala Wai Canal and at the canal monitoring location at Kaiolu Street were higher than the caffeine concentrations measured at the inland monitoring location across the canal at the end of University Avenue.

The median caffeine concentrations measured in the groundwater impacted storm drain in 2021 were similar to caffeine levels measured in groundwater in 2018 (1,273 versus 1,045 part per trillion (ppt)) while the caffeine concentrations measured in the Ala Wai Canal in 2021 were significantly lower than 2018 levels (82-398 versus 1,100 ppt). The median carbamazepine concentrations measured in the groundwater impacted storm drain in 2021 were less than a third of the carbamazepine levels measured in groundwater in 2018 (32 versus 105 ppt). This difference in concentration levels measured in 2018 and 2021 is consistent with the higher throughput of sewage in the Waikīkī area (and corresponding exfiltration) in 2018 from the 6 million annual visitors to Oʻahu that year compared to the 1.5 to 3.3 million visitors in 2020 and 2021.

The median concentration of caffeine measured in the storm drains at Seaside/Kalakaua and the groundwater impacted storm drain at Seaside/Ala Wai (Fig. 1) were higher at low tide than high tide (4,160 versus 2,750 ppt and 1,850 versus 790 ppt, respectively). The median concentration of carbamazepine measured in the groundwater impacted storm drain at Seaside/Ala Wai was higher at low tide than high tide (41 ppt versus 20 ppt) while the carbamazepine concentrations measured at the Seaside/Kalakaua storm drain at low and high tide was similar (12 ppt versus 15 ppt). It is important to note that the trace levels of carbamazepine detected during this study are significantly lower than ecotoxicological levels such as the predicted no-effect concentration of 25,000 ppt and the critical environmental concentration of 349,496 ppt determined for this pharmaceutical compound [3].

Fig. 6 shows the variation in caffeine concentrations measured in the storm drain at Seaside/Kalakaua (yellow dots) and in the groundwater impacted storm drain at Seaside and Ala Wai (red dots) along with the average 7 day daily arrival of visitors to Oʻahu in 2021.

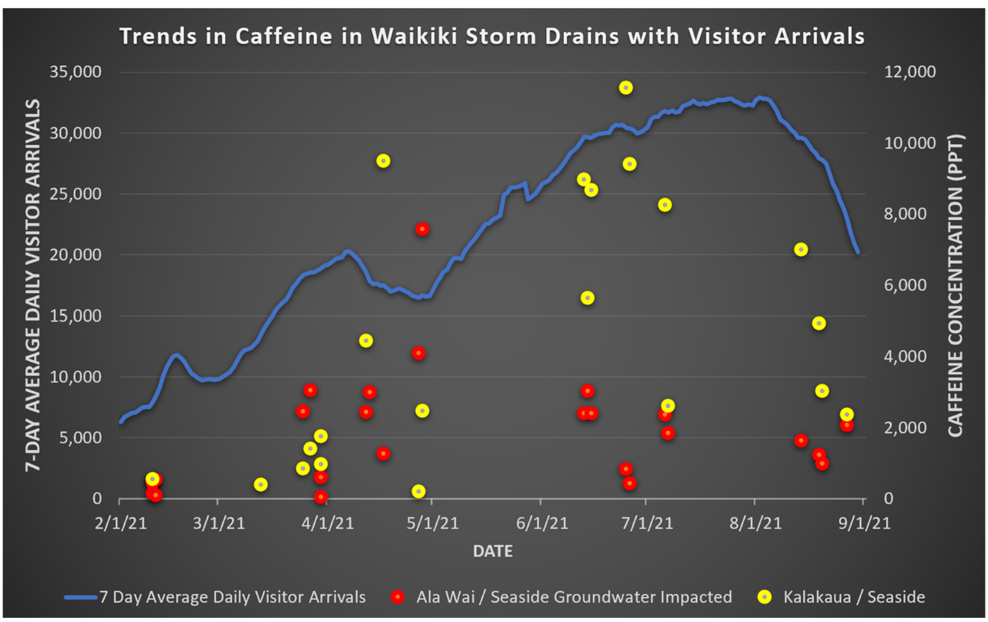

Figure 6: Trend in caffeine concentrations in Waikīkī storm drains and visitor arrivals to Oʻahu.

The caffeine concentrations measured at the Seaside/Kalakaua monitoring locations increased in the middle of the year as tourist arrivals rose then started to decline at the end of the summer as tourist arrivals declined. The trend in caffeine concentrations at the groundwater impacted storm drain at Seaside/Ala Wai are broadly similar but more variable and at overall lower concentrations suggesting the existence of additional input of caffeine to the storm drain at Seaside/Kalakaua than is present in the sewage contaminated groundwater underlying Waikīkī.

5 CONCLUSIONS

This study has shown that sampling of storm drains in low-elevation coastal portions of urban areas such as the city of Honolulu offers an attractive, inexpensive alternative for locating general areas of sewage exfiltration to the traditional exfiltration location methods used. The immunoassay methods used to quantify the concentration of caffeine and carbamazepine present in water in the storm drains and in Ala Wai Canal cost less than $8 per analysis when samples are run in baches of 80 samples. In this study, the pharmaceutical compounds caffeine and carbamazepine were used to identify areas of sewage exfiltration in the Waikīkī and McCully-Moiliili areas in urban Honolulu. Alternative pharmaceutical compounds or artificial sweeteners such as sulfamethoxazole or sucralose would also likely be effective at delineating areas of sewage exfiltration in urban coastal settings.

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IMPACT TO STREAM WATER QUALITY FROM SEWAGE EXFILTRATION AND LEGACY ON-SITE DISPOSAL SYSTEMS ON THE ISLAND OF O‘AHU, HAWAII

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ABSTRACT

The concentration of pharmaceutical compounds and nutrients present in perennial streams, springs and a lake on the island of O‘ahu, Hawai‘i were measured under drought conditions between 2020 and 2022. The combined island-wide daily release of wastewater to the environment on O‘ahu from the continued use of legacy On-Site Sewage Disposal Systems (OSDS) and from exfiltration from the 3,400-kilometer network of underground sewer lines has been estimated to be about 80 million liter per day (mld), or around 3.9% of the total island-wide groundwater flux to the ocean. The 36 streams and 11 springs sampled were located down-gradient of areas with varying densities of OSDS and sewage lines while the lake sampled (Lake Wilson) receives direct input from the wastewater treatment plant that serves Central O‘ahu.

Average pharmaceutical and nutrient levels in streams and springs sampled in areas with high densities of OSDS and sewer lines were slightly higher, but not statistically different than concentration levels measured in streams and springs in areas with low densities of OSDS and low sewer line densities. The average sulfamethoxazole and carbamazepine levels measured in Lake Wilson, the only water body on O‘ahu where treated wastewater is discharged into fresh water, are three to four times higher than average levels measured in the island’s streams and springs. The presence of elevated concentrations of nitrate and silica in some streams and springs on O‘ahu predominately reflects the impact of the historical use of up-gradient lands for sugarcane cultivation rather than wastewater input.

The trace levels of pharmaceuticals detected in O‘ahu streams and springs under baseflow conditions suggest that the actual combined input of wastewater to the environment from legacy OSDS and exfiltration from sewer lines is less than 20% the wastewater flux previously estimated.

Keywords: baseflow, cesspools, Hawaii, Oahu, OSDS, pharmaceutical tracer, septic tanks, sewage exfiltration, springs, streams, wastewater contamination

1 INTRODUCTION

Hawai`i was the last state in the United States to ban the construction of new cesspools. The construction of new cesspools was banned in 2015 due to concerns about water quality threats to human and coral reef health. Legislation was passed in 2017 to replace all existing cesspools in the state by 2050.

A survey completed in 2009 found that 14,600 On-Site Disposal Systems (OSDS) exist on the most densely populated Hawaiian Island, O‘ahu, mostly within one-kilometer of the coast and in residential neighborhoods [1]. These OSDS include cesspools, which account for 77 percent of the surveyed total, along with septic tanks and aerobic treatment units. Cesspools provide minimal treatment of wastewater before it percolates to the underlying groundwater aquifer. This survey estimated that 38 million liters per day (mld) of wastewater are released to the environment island-wide from OSDS, with the majority of the released sewage reaching underlying groundwater. High densities of OSDS are found throughout O‘ahu. Estimates of OSDS density and daily wastewater release volumes range from 60 units/kilometer^2(km^2) and 1.5 mld in leeward urban O‘ahu (Makiki), 27 units/km^2 and 2.3 mld in windward O‘ahu (Waimanalo) and 20 units/km^2 and 3.3 mld on the north shore of O‘ahu (Waialua). The

ISSN: 2398-2640 (paper format), ISSN: 2398-2659 (online), http://www.witpress.com/journals
DOI: 10.2495/EI-VX-NX-1-19

authors of the OSDS survey asserted that the sheer numbers of OSDS in some communities on O‘ahu produces a cumulative effluent volume that is comparable to that of municipal wastewater treatment plants (WWTP) [1].

Groundwater quality on O‘ahu is also impacted by exfiltration of sewage from the island's 3,400-kilometer web of sewer lines that convey an average of 394 mld sewage to WWTP operated by the City and County of Honolulu. The age range distribution of the sewage conveyance system is as follows: <25 years; 22.2%, 26–50 years; 18.3%; 51–75 years; 42.7%, 76–100 years; 11.8% and >100 years, 1.2%. In the urban areas surrounding Honolulu, the majority of the sewage conveyance system is over 65 years old and is beset by leaking joints and pipes due to the presence of corrosive hydrogen sulphide gasses produced by the combination of a warm tropical climate and the high sulfate content of the shallow groundwater surrounding the pipes and joints in the coastal portions of the conveyance systems. Maintenance of this aging and deteriorating sewage conveyance system is a challenge, and there is an ongoing need to replace and upgrade Hawai‘i's sewer lines and force mains due to both capacity and structural integrity issues [2].

The United States Environmental Protection Agency (USEPA) reported between 12 and 49% of wastewater flows are lost due to leaking infrastructure in United States cities [3]. The system-wide amount of wastewater exfiltration from O‘ahu's sewage system is unknown. A rough estimate of 10% system-wide exfiltration is based upon the difference in average monthly groundwater withdrawals by the water utility and the average monthly volume of wastewater treated at the WWTPs operated by the City and County of Honolulu [4]. A 10% loss suggests around 40 mld of wastewater is released to the environment from exfiltration from the sewage conveyance system, roughly the same amount of wastewater that is estimated to be released from the ongoing use of OSDS. Evidence of exfiltration from the sewage conveyance system has been observed in two coastal areas in urban Honolulu, Waikiki and Mapunapuna, based on the presence of pharmaceutical compounds in storm drains in these areas and in the Ala Wai Canal, which receives input from Waikiki storm drains [4].

The United States Geological Survey (USGS) estimates that the mean island-wide groundwater flux entering the ocean is around 2,050 mld [5]. The combined estimated island-wide release of wastewater due to the continued use of legacy OSDS and from exfiltration from the sewage conveyance system is around 80 mld, or roughly 3.9% of the total island-wide groundwater flux to the ocean. The simulated groundwater flux along O‘ahu's shoreline varies from less than 4 mld/km in the drier and narrower portions of the island to maximum values of around 76 mld/km along the shoreline bordering Pearl Harbor [5]. Based upon these previous estimates of wastewater input, chemical evidence of wastewater should be readily detected in groundwater that underlies and streams that flow through areas on O‘ahu with high OSDS and sewer line densities. The focus of the paper is to evaluate whether the combined environmental impact from legacy cesspools and sewage exfiltration can be estimated by measuring the pharmaceutical and nutrient concentrations in island streams and springs under baseflow conditions, when the water present in the streams almost exclusively originated from groundwater discharge from the surrounding watershed. Sampling was also conducted under low water-level conditions in Lake Wilson, which is the only location on O‘ahu that receives direct wastewater input from a WWTP servicing Central O‘ahu.

1.1 Characteristics of Hawaiian streamflow

Streams on O‘ahu are typically short (<6 km long) and have relatively steep gradients [6]. Rainfall runoff to O‘ahu streams tends to be flashy due to the high intensity of rainfall that often falls in the island's interior combined with the small size of the steep drainage basins and limited channel storage present within the island's watersheds. The permeable nature of the island's volcanics and upland soils allow rapid infiltration of water to underlying aquifers resulting in very few streams on O'ahu being perennial over their entire reach. The two largest perennial streams on O'ahu, Kahana and Waikele streams, have annual median streamflow of around 1.05 cubic meters per second (cms). The majority of perennial streams on O'ahu have annual daily median flows of less than 0.1 cms. The flashy nature of runoff and the paucity of large perennial streams precludes large-scale development of surface-water on O'ahu and leads to near-total reliance on groundwater for water supply for the island's roughly 1 million residents [6].

Perennial streamflow occurs on O'ahu in watersheds that receive significant groundwater discharge. These include areas where erosion has incised valleys into rift zones and the stream course intersects the elevated water tables created by the nearly impermeable dikes within the rift zones of the volcano, in upland areas, and near sea level where the stream course intercepts shallow perched or basal groundwater.

Groundwater discharge to streams is known as baseflow, which becomes the dominant component of streamflow during periods of dry weather. Dike impounded groundwater is the dominant contributor to baseflow in streams on O'ahu. Perched groundwater also contributes to stream baseflow, especially in alluvium and rocks associated with the post-erosional phase of activity encountered in valleys in the Honolulu area and in windward O'ahu. Basal groundwater can also enter the coastal sections of streams where the bottom of the stream intercepts the top of the basal lens between streambed elevations of 0 to 7.6 meters above sea level in areas where no coastal confining layer exists. Groundwater can also enter streams through springs. Springs form when a geologic structure (e.g., fault or fracture) or topographic feature (e.g., side of a hill or a valley) intersects groundwater either at or below the water table. This can discharge groundwater onto the land surface, directly into the stream, or into the ocean [7]. Under drought conditions, streamflow in windward O'ahu streams, where flow is dominated by dike impounded groundwater discharge, can decrease to about half the median flow, while flow in perennial streams in leeward O'ahu can decline to between 10 and 25% the stream's median flow [8].

Streams in Hawai`i gain water along some reaches and lose water along other reaches depending on local geohydrologic conditions [7]. A gaining stream is simply one in which groundwater flows into the stream and adds to the discharge of the stream.

During periods of low flow, the quality of the groundwater controls surface-water quality. A vertical profile of samples was collected from two deep monitoring wells located in Central O'ahu and analyzed for solutes and isotopes [9]. The upper 100 meters of the basal aquifer in Central O'ahu was composed of water recharged from local rainfall and irrigation return water that fell or was applied over the previous few decades. Wastewater released due to the continued use of OSDS and from sewage exfiltration would also impact the upper portion of the underlying perched or basal aquifers encountered as wastewater percolates through the vadose zone. This upper portion of the basal and perched groundwater bodies is the zone that contributes groundwater to streams in their lower reaches where samples were collected during this study.

Figure 1 shows the increase in specific conductance measured in four streams in leeward O'ahu as they flow from the mountains toward the sea. This increase in specific conductance reflects the higher concentration of dissolved chemicals (anions, cations, nutrients, pharmaceuticals, etc.) present in groundwater that discharge to these streams at lower elevations compared to the levels present from water discharging from the dike impounded rift zones, which serves as the source of baseflow in the upper reaches of the streams.

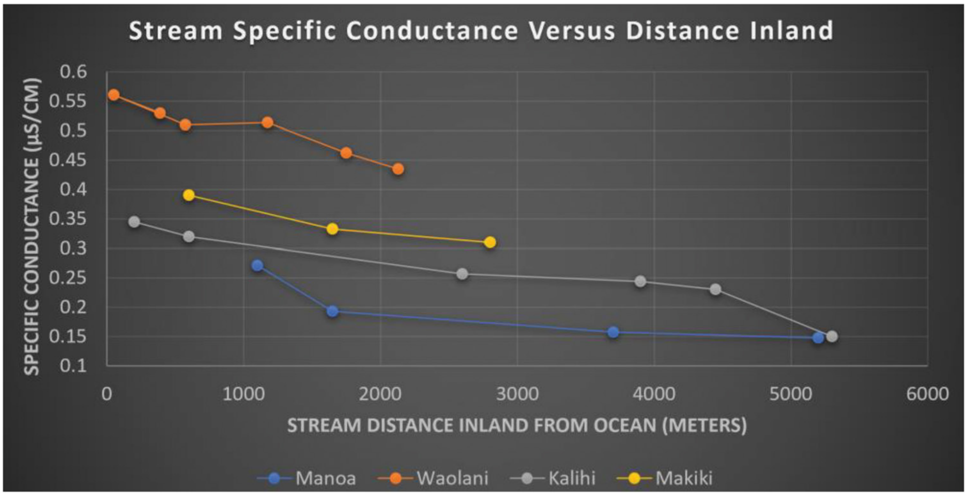

Figure 1: Increase in Stream Specific Conductance During Flow Through Urban O'ahu.

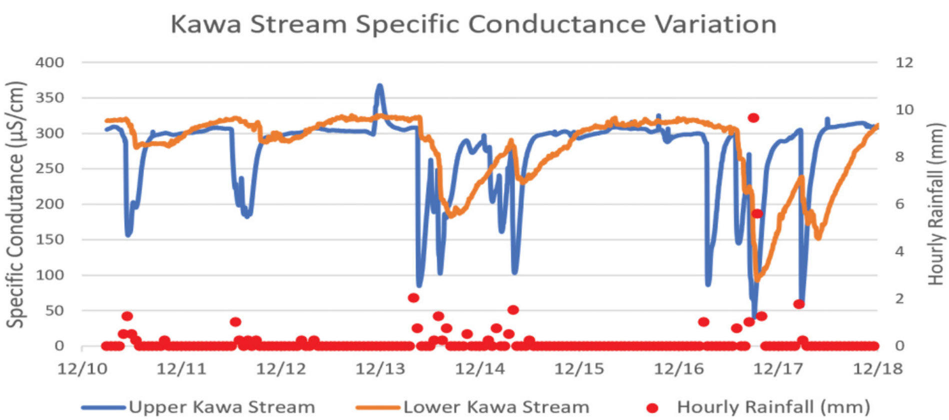

Figure 2: Variation in Specific Conductance in Kawa Stream in Response to Rainfall.

Figure 2 shows the variation in specific conductance measured in Kawa stream as a result of rainfall over an eight-day period in 2021. Kawa stream is a small (0.08 cms average annual flow), perennial spring fed stream in windward O'ahu. The upper monitoring site was located just downstream of the upper springs which supply baseflow to the stream, while the lower monitoring site was located one-kilometer downstream. Flow in this stream becomes dominated by groundwater input within a day or two after moderate rainfall events based on the rapid recovery in specific conductance to spring conductance values (~300 µS/cm).

1.2 Anthropogenic markers of sewage contamination-carbamazepine, sulfamethoxazole and caffeine

Carbamazepine, sulfamethoxazole and caffeine are known as emerging contaminants, which describes pollutants that have been detected in water bodies, may have ecological or human impact, and typically are not regulated under current environmental laws. These compounds are also known as micropollutants because they are typically present in trace quantities (part per trillion to billion levels) in the environment. These micropollutants enter the environment during our daily routines as we consume, flush away, or wash these compounds down the sink. Carbamazepine, caffeine and sulfamethoxazole represent the most frequently detected pharmaceuticals in treated wastewater [10]. As a result, these compounds are increasingly used as anthropogenic markers of sewage contamination.

Carbamazepine is a commonly prescribed anticonvulsant, pain relief and bipolar disorder treatment drug. Sulfamethoxazole is an antibiotic prescribed to treat common bacterial infections including urinary tract infections, middle ear infections, bronchitis and diarrhea. Caffeine is a naturally occurring stimulant found in coffee, soda, tea, chocolate and energy drinks. Carbamazepine, caffeine and sulfamethoxazole were the first, third and sixth (62.3%, 56.1%, 40.7%) most commonly detected pharmaceutical compounds in 1,052 river samples collected from 104 countries worldwide in a recently published global-scale study [11]. Caffeine was detected in river samples collected from every continent while carbamazepine was detected in rivers on all continents except Antarctica and sulfamethoxazole on all continents except Antarctica and Oceania (Australia and New Zealand). The common detection of carbamazepine and sulfamethoxazole is attributed to their conservative behavior in the environment with carbamazepine being somewhat more persistent. The common detection of caffeine is due the high levels and ubiquitous nature of its consumption. The average concentrations of carbamazepine, sulfamethoxazole and caffeine measured in streams worldwide were 85, 262 and 1,510 nanograms per liter (ng/L), respectively [11].

The relative stability of carbamazepine and sulfamethoxazole enables detection at larger distances from sewage release sites while caffeine serves as a better tracer for detecting recent, proximal releases of sewage or grey water, given its ephemeral nature and higher initial concentration levels in released untreated wastewater.

1.3 Pharmaceutical concentrations in sewage in Hawai‘i

Researchers at the University of Hawai‘i measured the concentration of caffeine in sewage in the main sewer line exiting Manoa Valley on O‘ahu to range from 5,000 to 103,400 parts per trillion (ppt, ng/L), with the highest flux of caffeine (2.4 milligrams/second) exiting the valley between 8 and 11 AM [12]. The Safe Drinking Water Branch of the State of Hawai‘i Department of Health (HDOH) conducted two rounds of sampling of raw wastewater influent at four WWTP and also collected 13 samples of treated wastewater effluent generated at 13 WWTP facilities that produce reclaimed water throughout the State of Hawai‘i [13]. LC-MS-MS methods were used to analyze these samples. Carbamazepine was not detected in the wastewater influent; likely due it being masked by other constituents present in the wastewater during analysis.

During the current study, samples were collected from septic tanks at various beach parks on the island of O‘ahu and analyzed for carbamazepine (26 samples), caffeine (20 samples) and sulfamethoxazole (10 samples) using an Enzyme Linked Immunosorbent Assay (ELISA) immunoassay method. Table 1 summarizes the carbamazepine, sulfamethoxazole and caffeine concentrations measured in the septic tanks along with levels measured by HDOH in influent and effluent to Hawai‘i WWTPs. Using the average concentrations of carbamazepine measured in septic tanks and the average of the sulfamethoxazole and caffeine concentrations measured in the septic tanks and in WWTP influent, the mean concentration of carbamazepine, sulfamethoxazole and caffeine in Hawai‘i wastewater is around 745, 1,300 and 61,000 ppt, respectively. The mean concentration of ammonia, nitrate (NO_3-N) and total phosphate measured during this study in wastewater collected from septic tanks (eight samples) located at a busy public beach park used by a representative cross section of island residents and tourists was 80, 13 and 47 milligrams per liter (mg/l), respectively.

Table 1: Carbamazepine, Sulfamethoxazole and Caffeine concentrations in Septic Tanks and WWTP Effluent and Influent in Hawai'i.

Source	Carbamazepine (parts per trillion)				
	Mean	Median	Max. Detect	Count	Detect Frequency
Septic Tanks	745	707	1,735	26	100%
WWTP Influent[1]	ND	ND	ND	8	0%
WWTP Effluent[1]	113	110	220	23	65%
Source	**Sulfamethoxazole (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	1,630	1,550	4,240	10	100%
WWTP Influent[1]	986	940	2,200	8	100%
WWTP Effluent[1]	1,068	395	5,400	16	100%
Source	**Caffeine (parts per trillion)**				
	Mean	**Median**	**Max. Detect**	**Count**	**Detect Frequency**
Septic Tanks	23,614	13,250	83,200	16	100%
WWTP Influent[1]	98,238	108,000	150,000	8	100%
WWTP Effluent[1]	152	33	1,200	23	96%
ND = Not Detected due to dilution of sample during analysis and peak interference.					
[1]Oahu WWTP Influent/Efffluent Data from HDOH [11]					

1.4 Pharmaceutical levels measured in coastal urban settings of Honolulu

A 2022 study measured the spatial distribution of carbamazepine and caffeine concentrations present in the dense network of storm water manholes located in the coastal tourist destination of Waikiki and in the adjacent inland McCully-Moiliili residential areas between November 2020 and December 2021 [4]. Samples were also collected from storm drains in the coastal industrial area of Mapunapuna. In the coastal areas sampled, wastewater contaminated groundwater seeps into the stormwater conveyance pipes and mixes with the tidally driven water that enters the storm drain system from the Ala Wai Canal, which separates the tourist and residential areas in Waikiki. The concentration levels and spatial distribution of detection of these two anthropogenic biomarkers were successfully used to identify areas of ongoing sewage exfiltration in Waikīkī and surrounding residential communities [4]. The impacted groundwater aquifers in the coastal Waikiki and Mapunapuna areas are composed of calcareous and volcanogenic sediments locally referred to as caprock which confine the water in the underlying volcanic rock aquifers. The flux of groundwater through these caprock aquifers is significantly less than fluxes in the underlying basal aquifers, which contributed baseflow to the streams sampled during this study. Figure 3 shows the contoured maximum carbamazepine concentrations measured in storm drain and canal sites sampled (red dots) in the Waikiki and McCully/Moiliili areas while Fig. 4 shows the maximum carbamazepine and caffeine concentrations measured in storm drains (yellow dots) in the industrial area of Mapunapuna. The average carbamazepine and caffeine concentrations measured in Waikiki and Mapunapuna storm drains was 31.7 and 2,940 ppt, and 20.0 and 196 ppt, respectively. The concentrations of carbamazepine and caffeine indicate an average wastewater fraction of up to 4.8% to 2.7% in Waikiki and Mapunapuna storm drains, respectively.

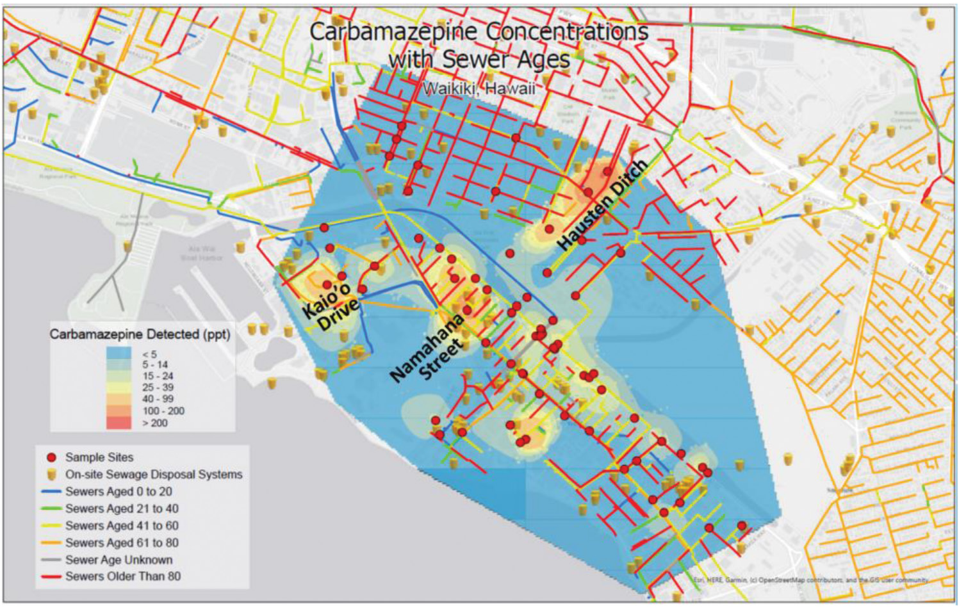

Figure 3: Contoured Maximum Carbamazepine Concentrations in Storm Drains in the Tourist and Residential Waikiki and McCully/Moiliili Areas.

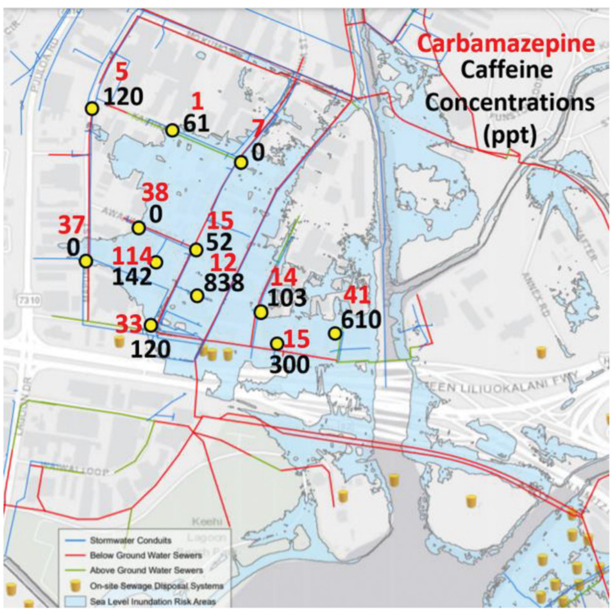

Figure 4: Carbamazepine and Caffene Concentrations in Storm Drains in the Industrial Mapunapuna Area.

2 STUDY METHODOLOGY

Thirty six streams and 11 springs on O'ahu were sampled under low baseflow conditions between November 2020 and September 2022 during periods of extended drought. Streamflow was typically less than the 10th percentile of daily discharge recorded for the sampled stream by the USGS on the day of sampling. Low flow conditions were considered optimal for detection of a wastewater signature from OSDS use and sewage exfiltration to minimize dilution from baseflow entering the streams from the undeveloped, uncontaminated mountainous interior of the island. Samples were collected from the lower reaches of the streams to maximize the amount of groundwater contribution to the stream from the surrounding urban portions of the watershed in the mid- to lower reaches of the stream course.

Two initial rounds of sampling were conducted island-wide in November 2020 and November 2021 during which each stream and spring were sampled twice roughly one week apart. The November 2020 round of samples were analyzed for carbamazepine while the November 2021 round samples were analyzed for carbamazepine and caffeine. Carbamazepine was detected at trace and estimated levels in three springs (Waimanalo Seep, Ulupo Heiau spring and Waimano spring) during the November 2020 sampling. As a result, these springs were repetitively sampled up to August 2022 to determine whether these compounds' presence was persistent or transient in these springs.

The island of O'ahu experienced pronounced drought-like conditions between early January 2022 to September 2022. Stream and spring samples collected during 2022 were analyzed for all three pharmaceutical compounds (carbamazepine, caffeine and sulfamethoxazole) and for nutrients (ammonia, nitrate and phosphate) and silica. An initial round of sampling from Lake Wilson was conducted in November 2021 followed by additional sampling in March and April 2022 when water levels in the lake had reached near record lows due to the ongoing drought in the first half of 2022. Figure 5 shows the location of the stream, spring and lake samples collected during this study in relation to OSDS density and the island sewer network.

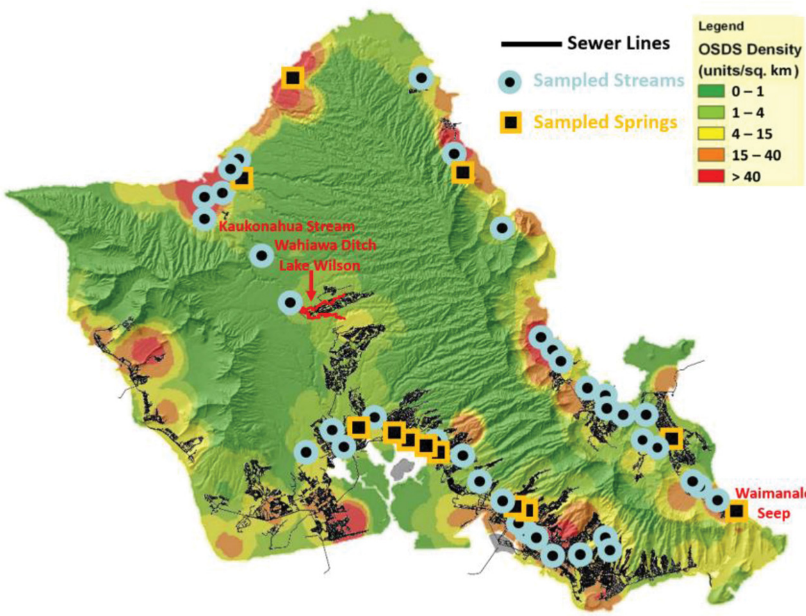

Figure 5: Location of Streams, Springs and Lake Samples Analyzed During this Study.

The streams and springs sampled were located down-gradient of areas with varying densities of OSDS and sewage lines while Lake Wilson receives direct wastewater input from the WWTP that serves Central O‘ahu. Areas of varying densities of OSDS on O‘ahu were divided into four OSDS density range categories: less than 4 units per km^2; 4 to 15 units per km^2; 15 to 40 units per km^2; greater than 40 units per km^2. The USEPA has designated areas with an OSDS density of greater than 15 units per km^2 as regions where there is a significant potential for causing unacceptable groundwater contamination [1]. Areas with OSDS densities of greater than 40 units/km^2 are shaded in orange and red in Fig. 5 along with the location of the island's sewer conveyance system (black lines).

The stream, spring and lake samples were analyzed for general water quality parameters (temperature, specific conductance, salinity, dissolved oxygen, pH and turbidity) in the field using a Hydrolab Quanta and frozen shortly after collection. ELISA test kits manufactured by Eurofins were used to measure the concentration of carbamazepine, sulfamethoxazole and caffeine, typically in batches of 80 samples. The concentrations of the pharmaceutical compounds were classified as either detected, estimated, trace or non-detect. Detected concentrations were above the concentration of the lowest calibration standard (25 ppt for carbamazepine and sulfamethoxazole and 175 ppt for caffeine). Estimated concentrations were between roughly half the lowest calibration standard (12 ppt for carbamazepine and sulfamethoxazole and 85 ppt for caffeine) and the lowest calibration standard. Trace concentrations were between the zero-calibration standard and half the lowest calibration standard. Non-detect samples had measured absorbances greater than the zero standards.

Nitrate, ammonia, phosphate and silica concentrations were determined using colorimetric methods on unfiltered samples. Nitrate concentrations were measured using the cadmium reduction method while ammonia concentrations were measured using the Nessler method. Phosphate concentrations were measured using an adaptation of the Ascorbic Acid method. Silica concentrations were measured using an adaptation of USEPA Method 370.1.

3 SAMPLING RESULTS

Thirty six streams and 11 springs located down-gradient of areas with varying densities of OSDS and sewage lines on the island of O‘ahu were sampled over a two-year period. A minimum of four samples were analyzed for pharmaceuticals and nutrients from all streams and springs. Caffeine was present in 80% and 94% of the streams and springs sampled above detected (175 ppt) and estimated (80 ppt) concentration levels, respectively. Sulfamethoxazole was present in 6%, 15% and 15% of the streams and springs sampled above detected (25 ppt), estimated (12 ppt) and trace (>1 ppt) concentration levels, respectively. Carbamazepine was present in 3%, 5% and 42% of the streams and springs sampled above detected (25 ppt), estimated (12 ppt) and trace (>1 ppt) concentration levels, respectively. Trace levels of caffeine (>80 ppt), carbamazepine and sulfamethoxazole (12 ppt) were measured in 70%, 23% and 6% of the samples collected, respectively.

Table 2 summarizes the average pharmaceutical and nutrient concentrations measured in streams and springs located in the following four categories of contributory land use: (1) areas with high densities of cesspools and high densities of sewer lines; (2) areas with high densities of cesspools and low densities of sewer lines; (3) areas with low densities of cesspools and high densities of sewer lines; and (4) areas with low densities of cesspools and low densities of sewer lines. Table 2 also includes the pharmaceutical and nutrient data collected from Lake Wilson and its two outlets (Kaukonahua Stream and Wahiawa Ditch).

Table 2: Pharmaceutical and nutrient concentrations in O‘ahu Streams, Springs and Lake Wilson.

# Pharm Analysis	Caffeine (ppt)	Sulfamethoxazole (ppt)	Carbamazepine (ppt)	Nitrate (mg/L)	Ammonia (mg/L)	Phosphate (mg/L)	Silica (mg/L)
Stream and Springs: High Density Cesspool / High Density Sewer Contributory Area							
268	398 ± 502	1.5 ± 7.0	2.1 ± 7.2	0.63 ± 1.26	0.12 ± 0.18	0.42 ± 0.29	25 ± 13
Stream and Springs: High Density Cesspool / Low Density Sewer Contributory Area							
79	129 ± 155	0.0 ± 0.0	0.2 ± 0.5	0.31 ± 0.74	0.06 ± 0.11	0.42 ± 0.30	35 ± 18
Stream and Springs: Low Density Cesspool / High Density Sewer Contributory Area							
167	248 ± 678	0.4 ± 2.3	0.5 ± 1.3	0.63 ± 0.88	0.06 ± 0.03	0.73 ± 0.64	34 ± 16
Stream and Springs: Low Density Cesspool / Low Density Sewer Contributory Area							
50	181 ± 188	1.7 ± 5.0	0.0 ± 0.0	0.19 ± 0.73	0.09 ± 0.11	0.24 ± 0.24	29 ± 7
All Stream and Spring Samples Combined							
564	298 ± 524	1.0 ± 5.1	1.3 ± 5.3	0.54 ± 1.10	0.08 ± 0.15	0.52 ± 0.49	30 ± 15
Samples from Lake Wilson and Outlet Streams (Kaukonahua) and Ditch (Wahiawa)							
142	250 ± 420	2.4 ± 6.1	5.7 ± 9.1	0.01 ± 0.05	0.08 ± 0.10	0.30 ± 0.77	8 ± 3

Figure 6 shows the average caffeine concentrations measured in the streams and springs sampled during this study in relation to areas of high OSDS and sewer line densities.

Three springs (Waimanalo seep, Ulupo Heiau and Waimano spring) contained trace or estimated concentration levels of carbamazepine during the two rounds of reconnaissance sampling conducted in November 2020. The Waimanalo seep had the most consistently detectable concentrations levels of carbamazepine and caffeine of the three springs repetitively sampled. Figure 7 shows the persistent nature of and variability in concentration levels of carbamazepine and caffeine in the Waimanalo Seep over the 23-month period sampled. Waimanalo Seep is located in a narrow portion of the island with relatively low coastal groundwater flux rates.

Nitrate, ammonia and phosphorus can be indicators of the presence of wastewater since these nutrients are enriched in wastewater. The average concentration of nitrate, ammonia and total phosphate measured in wastewater collected from septic tanks was 13, 80 and 47 mg/l, respectively. However, nitrate is not unique to wastewater and on O‘ahu its presence in groundwater fed streams may reflect historical use of fertilizers, especially in areas formerly used for sugarcane cultivation [14]. High concentrations of nitrate (30 to 80 mg/kg) are adsorbed on positively charged iron and aluminum oxide particles in the subsoil and saprolite beneath pineapple and sugarcane cultivation areas of central O‘ahu at depths between 6 to 20 meters [15]. Infiltration percolating through the soils and saprolite underlying lands formerly used for sugar cultivation provides a continuous input of nitrate to the underlying basal groundwater aquifers.

The historic use of phosphorus fertilizers has not significantly affected groundwater quality on O‘ahu because phosphate is retained in the aluminum and iron minerals in the soils [7]. Most of the silica in stream water is derived from leaching of volcanic rocks and soil. Rainfall has silica concentrations of less than 1 mg/l and infiltrating water will dissolve the silica present in volcanic rocks and soils leading to silica concentrations in the basal aquifer of between 15 to 40 mg/l [16]. Groundwater concentration levels of above 40 mg/l silica are associated with areas impacted by return irrigation water [14].

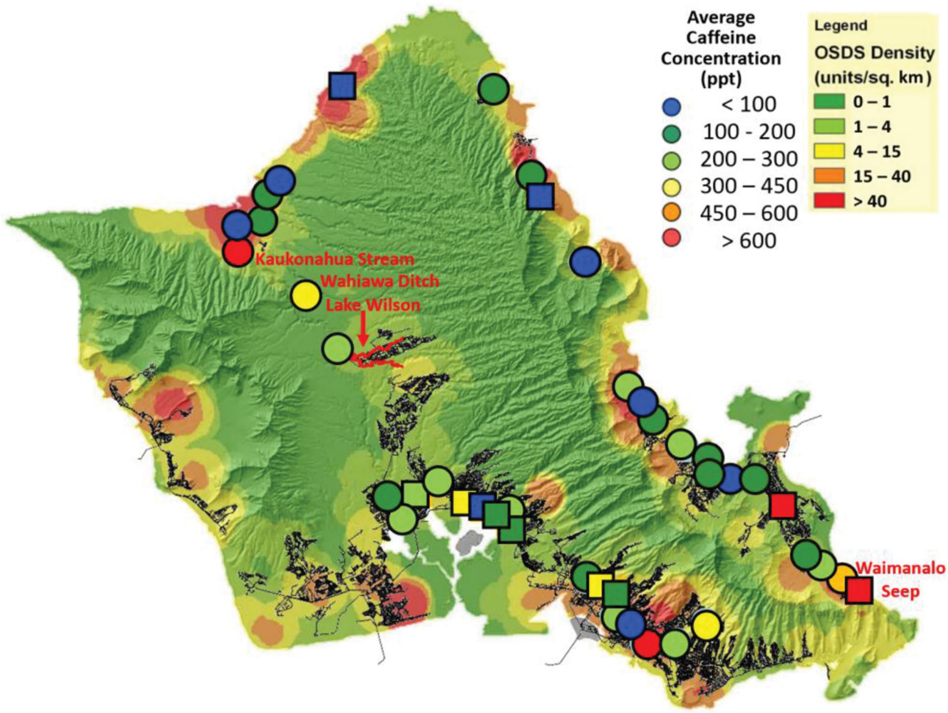

Figure 6: Average Caffeine Concentrations Measured in Streams and Springs.

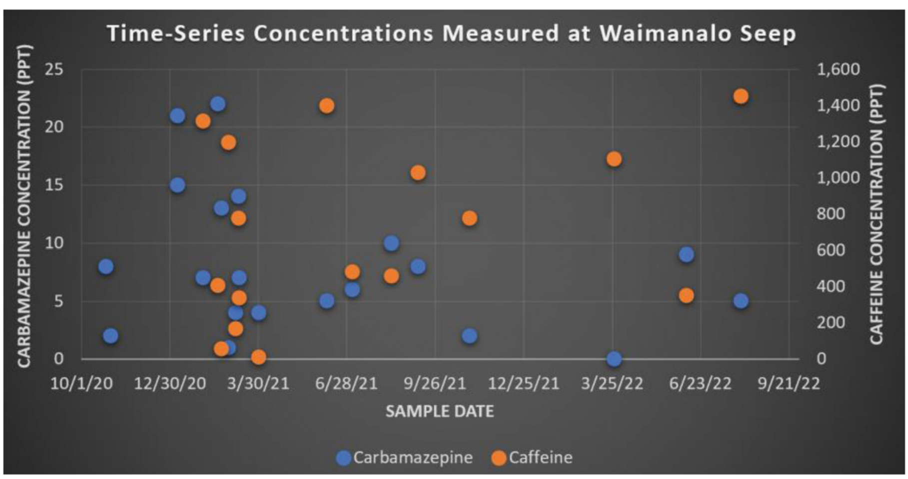

Figure 7: Carbamazepine and Caffeine Concentrations in Waimanalo Seep.

The spatial distribution of nitrate and silica concentrations measured in streams and springs during this study is shown in Figs. 8 and 9. These figures show the general spatial correlation between nitrate and silica level with areas currently or historically used for large-scale agriculture. During this study, the average concentration of nitrate and silica in streams and

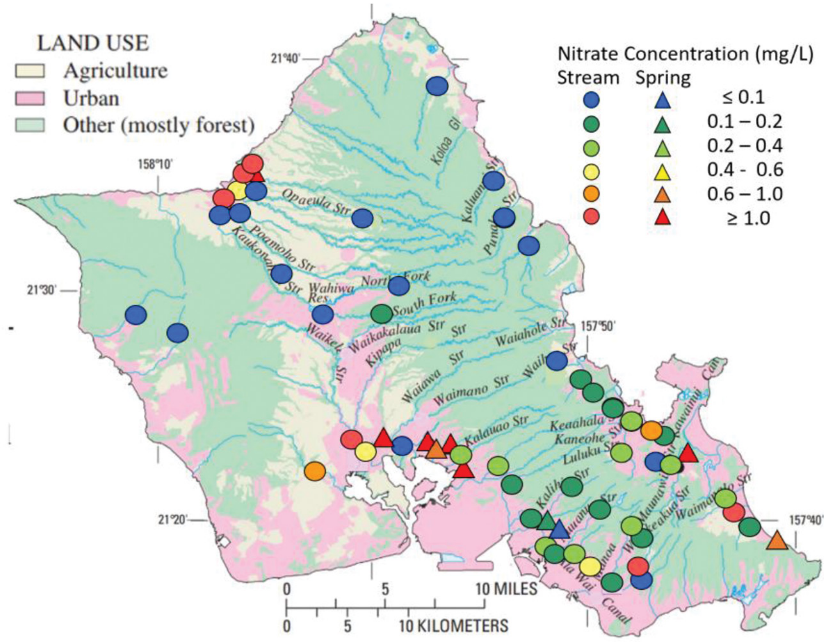

Figure 8: Nitrate Concentrations Measured in O‘ahu Streams and Springs.

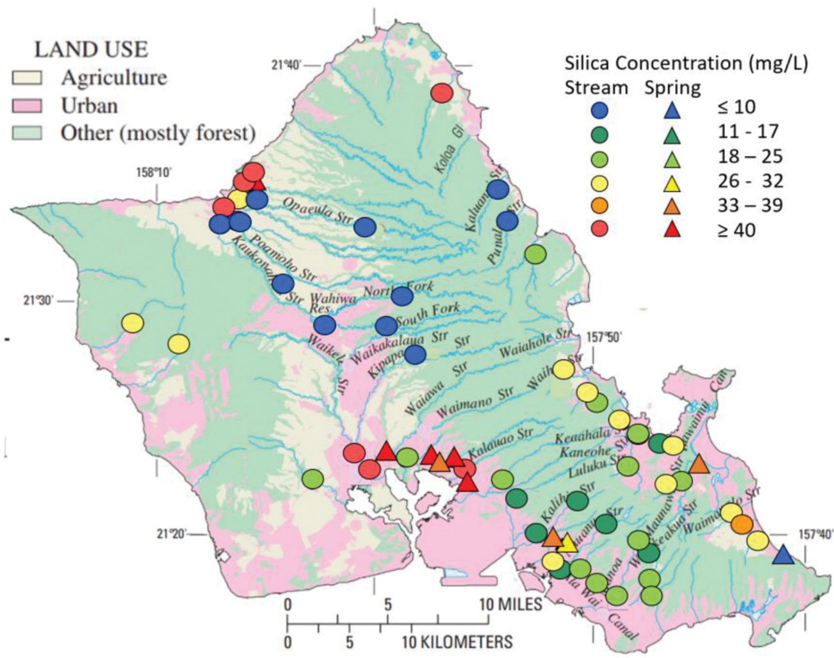

Figure 9: Silica Concentrations Measured in O‘ahu Streams and Springs.

springs located in watersheds where large-scale agricultural activities were conducted was 0.78 and 40 mg/l, compared to concentration levels of 0.40 and 24 mg/l measured in streams and springs located in areas where no large-scale agricultural activity occurred.

4 DISCUSSION

The concentrations of pharmaceutical compounds measured in O‘ahu streams and springs are very low. The mean concentrations of carbamazepine, sulfamethoxazole and caffeine measured in O‘ahu streams and springs (1.3, 0.9 and 298 ng/L, Table 2) were five to three hundred times lower than average levels measured in streams worldwide (85, 262 and 1,510 ng/L) [11]. Many of the streams sampled during the worldwide sampling effort receive direct input of either treated or untreated sewage. Direct release of wastewater to surface water does not occur on O‘ahu except in Lake Wilson which receives around 5.4 mld of tertiary-level treated wastewater from the Wahiawa WWTP. This direct input of wastewater to the lake led to slightly higher average levels of carbamazepine and sulfamethoxazole being present in the lake (5.7 and 2.4 ng/L, Table 2) than average levels measured in O‘ahu streams and springs. Samples were collected from Lake Wilson and its two outlet streams when water levels were quite low, but the volume of water in the lake at the time of sampling was still around 4.5 billion liters. The large volume of water in the lake explains the relatively low concentration levels of pharmaceutical compounds measured in the lake.

Figure 10 compares the carbamazepine and caffeine concentrations (in log-log scale) measured in wastewater collected from septic tanks on O‘ahu, in Waikiki storm drains, in the Ala Wai Canal, in Lake Wilson and in O‘ahu streams and springs to the worldwide average measured in 1,052 streams sampled in 104 countries on all seven continents [11].

The measured concentration of pharmaceuticals and nutrients in streams and springs were not statistically different in contributory watersheds with high densities of OSDS and sewer lines from watersheds with low densities of OSDS and sewer lines (Table 2). The OSDS

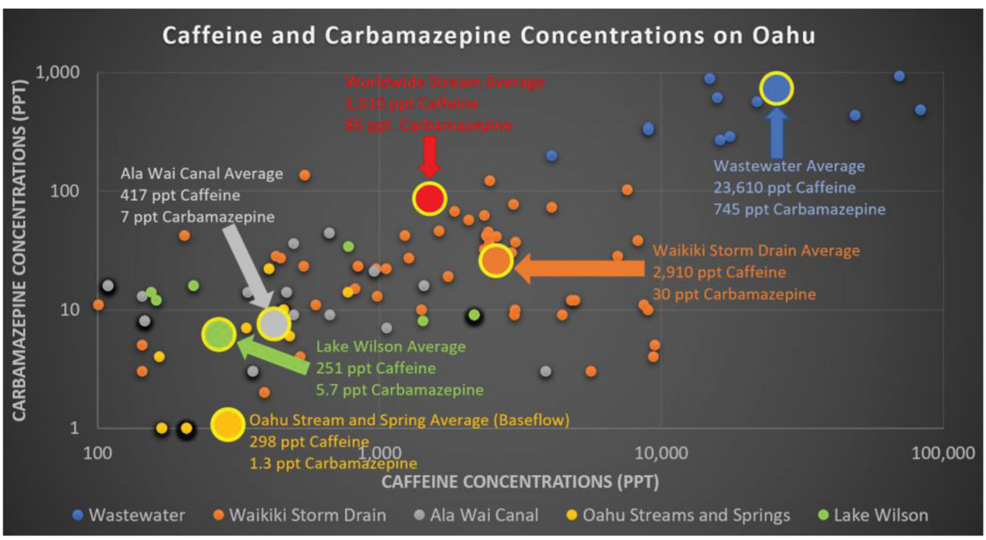

Figure 10: Caffeine and Carbamazepine Concentrations on O‘ahu. Note the log-log scale.

survey estimated wastewater flux in various areas on Oʻahu ([1], Table B-1). The estimated wastewater flux in four areas on Oʻahu where streams were sampled (Makiki, Haleiwa, Waimanalo and Waialua) were 1.25, 1.55, 1.94 and 2.77 mld. The USGS recently prepared a steady-state numerical groundwater-flow model of Oʻahu that simulated groundwater discharge along the coastline of Oʻahu [5]. Based on the simulated coastal groundwater flux in the Makiki, Haleiwa, Waimanalo and Waialua areas, the percentage of wastewater in the groundwater in these areas should be 4.6%, 2.2%, 12% and 4%, respectively. However, based on the average pharmaceutical levels in the streams and springs in these areas, the fraction of wastewater in the streams in the Makiki, Haleiwa, Waimanalo and Waialua areas is estimated to be around 2.6%, 0.7%, 3.2% and 0.7%, respectively. These calculations suggest that the actual environmental impact from cesspools in these areas is between 20 to 50% of the wastewater flux estimated based on the assumptions used in the OSDS survey, not including any impact from sewage exfiltration that may be occurring in these areas. The spatial relationship between elevated nitrate concentrations in streams and former sugar lands (Fig. 8) indicate the elevated nitrate levels originated from legacy agricultural activities rather than from cesspools and sewage exfiltration. This conclusion is supported by the elevated silica levels measured in streams that flow through former sugar lands.

Figure 11 is a generalized map of simulated groundwater discharge to the ocean in the calibrated numerical groundwater model produced by the USGS [5]. The eight streams and springs that had an average caffeine concentration greater than 300 ppt (based on a minimum of six analyses) are also shown on this figure. Kaukonahua Stream and Wahiawa Ditch

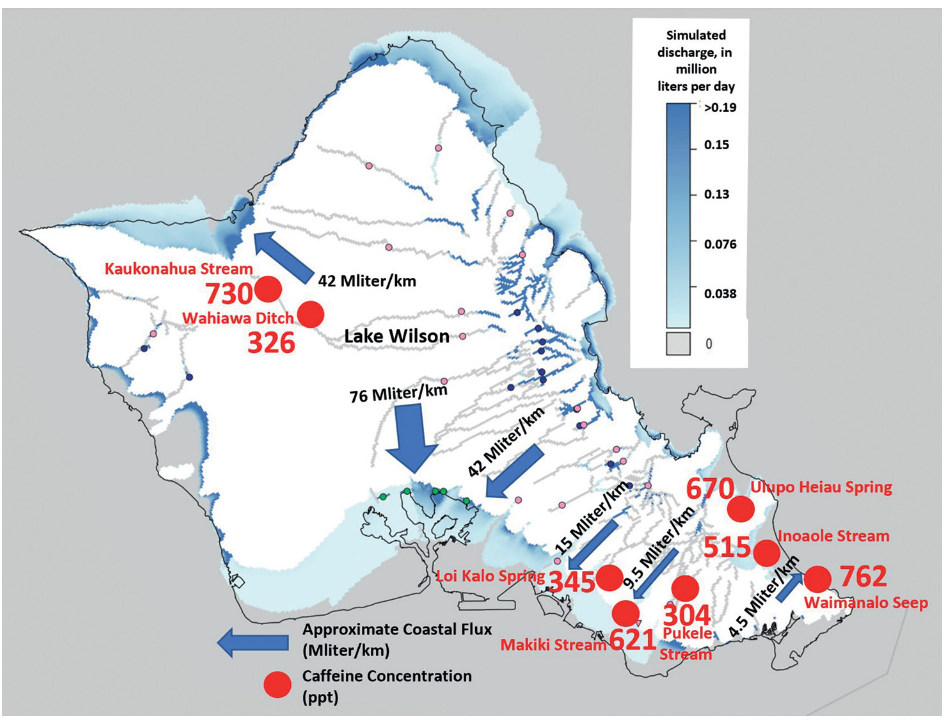

Figure 11: USGS Modeled Island-Wide Groundwater Flux and Streams and Springs with Highest Average Measured Caffeine Concentrations.

samples reflect discharge from Lake Wilson. This figure clearly shows the large differences in groundwater flux simulated to discharge along the shoreline of O‘ahu. The streams and springs where the highest average concentration levels of caffeine were detected during this study were located in areas with relatively low simulated coastal groundwater fluxes, suggesting that in portions of the island with high groundwater fluxes to the coast, wastewater entering the groundwater from cesspools and from exfiltration from sewage conveyance lines is effectively diluted to very low or non-detectable concentration levels.

These findings are consistent with results obtained by HDOH in a community on the island of Hawai`i with high OSDS densities (up to 440 OSDS/square kilometer) and high groundwater flux [13]. Despite the high density of OSDS in the area, the average nitrate concentration measured in groundwater was low (0.2 mg/L) and the measured nitrate levels did not show the expected increase along the groundwater flow paths toward the ocean. The authors suggested that that the actual wastewater contribution from cesspools may be lower than the 750 liter per day per bathroom flux used in the state-wide OSDS assessment [1].

5 CONCLUSIONS

This study found that the current impact to water quality on O‘ahu from legacy cesspools and from wastewater exfiltration from the sewage conveyance systems is significantly less than previously estimated based on OSDS density and estimates of system wide sewage exfiltration. The average concentration of caffeine measured in streams and springs under baseflow conditions was 18% the average measured in streams worldwide, while the levels of carbamazepine and sulfamethoxazole were only 1.4% and 0.6% of the worldwide average. The presence of elevated nitrate concentrations in some streams and springs on O‘ahu is predominately related to legacy agricultural activities rather than from ongoing wastewater releases.

DATA AVAILABILITY STATEMENT

Appendix A contains the average pharmaceutical (caffeine, sulfamethoxazole, carbamazepine), nutrient (nitrate, ammonia, phosphate) and silica concentrations measured in the streams, springs, lake and septic tanks sampled during this study. The streams and springs are ordered based on the estimated density of cesspools and sewer lines present in the contributory watershed of the stream or spring sampled. The last column in the appendix describes whether the contributory watershed was historically used for large-scale agricultural purposes.

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APPENDIX A

Average Pharmaceutical (Caffeine, Sulfamethoxazole and Carbamazepine) and Nutrient Concentrations in Septic Tanks and Lake Wilson and in Streams and Springs Located in Areas of Varying Densities of Cesspools and Sewer Lines

Location	# of Immuno-Assay Analyses	Caffeine (ppt)	Sulfa. (ppt)	Carb. (ppt)	Nitrate (NO3-N) (ppm)	Ammonia (NH4) (ppm)	Phosphate (ppm)	Silica (ppm)	Large-Scale Ag?
Wastewater Source									
Septic Tanks	26	23,614	1,630	745	13.1	85.5	44.9	NM	NA
High Density Cesspool / High Density Sewer Contributory Area									
Waimanalo Seep	42	762	0.0	7.1	0.7	0.22	0.41	4	NO
Makiki Stream	18	621	18.0	1.4	0.4	0.08	0.75	22	NO
Inoaole Stream	8	515	0.0	1.8	0.0	0.42	1.57	–	YES
Loi Kalo Spring	16	345	0.0	0.0	0.0	0.08	0.34	39	NO
Waolani Stream	31	256	0.0	5.3	0.6	0.11	0.54	23	NO
Kalauao Stream	9	238	0.0	0.2	0.3	0.03	0.37	48	NO
Heeia Stream	4	236	0.0	–	0.4	0.03	0.12	29	YES
Manoa/Palolo Stream	26	232	4.7	0.3	0.2	0.08	0.34	20	NO
Kahawai Stream	26	200	0.0	0.1	2.6	0.15	0.30	36	YES
Ie Ie Park Spring	18	198	0.0	0.0	0.8	0.06	0.46	48	NO
Kalihi Stream	21	196	0.0	2.2	0.5	0.05	0.40	17	NO
Kunawai Spring	8	157	0.0	0.3	0.0	0.07	0.65	30	NO
Ahuimanu Stream	10	130	0.0	0.0	0.1	0.03	0.17	25	NO
Kahaluu Stream	11	63	0.0	0.0	0.2	0.03	0.22	27	NO
Nuuanu Stream	5	0	0.0	0.0	0.1	0.08	0.30	15	NO
Pauoa Stream	7	–	–	0.0	0.0	0.05	0.70	20	NO
Waialae Nui Stream	4	–	–	0.0	0.2	0.62	0.19	–	NO
Kaupuni Stream	0	–	–	–	0.0	0.03	0.31	–	YES

Appendix A: (*Continued*)

Location	**# of Immuno-Assay Analyses**	**Caffeine (ppt)**	**Sulfa. (ppt)**	**Carb. (ppt)**	**Nitrate (NO3-N) (ppm)**	**Ammonia (NH4) (ppm)**	**Phosphate (ppm)**	**Silica (ppm)**	**Large-Scale Ag?**
High Density Cesspool / Low Density Sewer Contributory Area									
Waihee Stream	4	272	0.0	–	0.0	0.02	0.24	27	YES
Anahulu Stream	12	168	0.0	0.0	1.2	0.06	0.43	37	YES
Paukauila Stream	9	167	0.0	0.0	0.5	0.20	0.67	45	YES
Waimanalo Stream	17	141	0.0	0.2	0.2	0.06	0.23	31	YES
Loko Ea Fishpond	12	70	0.0	0.0	2.9	0.04	0.30	48	YES
Kiikii Stream	9	0	0.0	0.0	1.5	0.25	0.66	35	YES
Haaula Seep	4	–	–	0.0	–	–	–	–	NO
Kaunala Seep	12	–	–	0.3	0.0	0.49	0.29	2	NO
Anahulu River Spring	0	–	–	–	2.5	0.03	0.92	69	YES
Low Density Cesspool / High Density Sewer Contributory Area									
Ulupo Heiau Spring	17	670	0.0	2.5	1.2	0.03	1.96	33	NO
Pukele Stream	4	304	0.0	0.0	0.8	0.16	0.40	19	YES
Waimano Stream	30	295	3.0	2.2	0.4	0.08	0.45	43	NO
Waipahu Spring	23	235	0.0	0.2	0.7	0.08	0.78	47	YES
Kapakahi Stream	26	215	0.0	0.3	0.3	0.11	0.82	52	YES
Kaneohe Stream	8	173	0.0	0.3	0.8	0.03	0.22	22	NO
Waikele Stream	8	172	0.0	0.0	1.0	0.02	0.66	48	YES
Kalauoa Spring	9	128	0.0	0.0	0.0	0.01	0.78	43	NO
Keaahala Stream	14	128	0.0	0.3	0.1	0.02	0.25	28	NO
Kawa Stream	23	88	2.3	0.5	0.7	0.04	0.53	17	NO

Appendix A: (*Continued*)

Location	**# of Immuno-Assay Analyses**	**Caffeine (ppt)**	**Sulfa. (ppt)**	**Carb. (ppt)**	**Nitrate (NO3-N) (ppm)**	**Ammonia (NH4) (ppm)**	**Phosphate (ppm)**	**Silica (ppm)**	**Large-Scale Ag?**
HECO Spring	5	86	0.0	0.0	0.0	0.00	0.70	–	NO
Moanalua Stream	0				0.1	0.11	0.51	22	NO
Maunawili Stream	0	–	–	–	0.4	0.05	0.29	23	NO
Low Density Cesspool / Low Density Sewer Contributory Area									
Waiawa Stream	11	228	0.0	0.0	0.0	0.16	0.21	21	YES
Kapaa Stream	19	168	2.1	0.0	0.1	0.21	0.51	27	NO
Kahana Stream	18	0		0.0	0.1	0.03	0.02	22	NO
Kahuku Stream	2	–	–	0.0	0.0	0.03	0.86	48	YES
Honouliuli Stream	0	–	–	–	0.7	0.07	0.30	25	YES
Kahana Iki Stream	0	–	–	–	0.0	0.05	0.21	31	NO
Samples from Lake Wilson and Outlet Streams (Kaukonahua) and Ditch (Wahiawa)									
Kaukonahua Stream	16	730	9.7	1.5	0.0	0.13	2.63	7	NO
Wahiawa Ditch	22	326	2.8	4.9	0.0	0.09	0.22	8	NO
Lake Wilson	104	214	1.9	10.9	0.0	0.08	0.19	8	NO
COMBINED	142	251	2.4	5.7	0.0	0.08	0.30	8	NO

OCCURRENCE AND PERSISTENCE OF THE HERBICIDE GLYPHOSATE IN A SUBURBAN TROPICAL WATERSHED

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ABSTRACT

Stream, streambed sediment and suspended sediment sampling for the herbicide Glyphosate was conducted in a small, 4.05-square kilometer suburban watershed on the island of Oahu, Hawaii between December 2017 and April 2020. Over this 2.5-year study period, a total of 188 stream samples (142 runoff conditions, 46 baseflow conditions), 81 streambed sediment samples, and 9 suspended sediment samples were collected and analysed for glyphosate and a subset of sediment samples were analysed for its degradation product aminomethylphosphonic acid (AMPA).

The glyphosate concentration levels measured during stormwater runoff conditions within Kawa stream were significantly higher than levels measured under groundwater dominant baseflow conditions. The mean and median glyphosate concentrations (μg/L) and the frequency of glyphosate detection (reporting limit 0.075 μg/L) measured in Kawa stream under runoff and baseflow conditions were 0.98/0.51/92% and 0.10/0.035/28%, respectively. The glyphosate concentrations measured in this small suburban tropical stream were significantly higher than mean levels measured by the USGS between 2014 and 2020 in streams that drain small urban watersheds throughout the continental United States. The glyphosate concentration levels measured in riverbed and suspended sediments in Kawa stream were generally two to three orders of magnitude higher than levels measured in stream-water.

The majority of glyphosate (>90%) was transported to Kaneohe Bay in the dissolved phase and originated from residential areas within the contributory watershed. The mean mass flux of glyphosate measured entering the near coastal environment under baseflow conditions was around 0.16 mg/min, while the mean mass flux during runoff conditions was 106 mg/min. The estimated median half-lives of glyphosate and AMPA measured in streambed sediments during this study were 4.7 and 6.2 days, respectively. This short half-life (4.7 days) along with the high-frequency (92%) of glyphosate detection in Hawaiian streams under runoff conditions illustrates the steady, unceasing input of glyphosate to Hawaiian streams.

Keywords: glyphosate, AMPA, environmental half-life, transport mechanism, streams, stream bed sediment, suspended sediment, urban mass flux.

1 DESCRIPTION OF STUDY AREA

Kawa stream is a perennial, 4.2-kilometer long stream (including a 0.6-km long tributary, Kawa Ditch) located in Kaneohe on the windward side of the island of Oahu, Hawaii. The main branch of the stream starts in the Hawaii Memorial Park cemetery and runs in a generally north/northeasterly direction through residential areas before discharging along the southern shoreline of Kaneohe Bay. Baseflow to the stream originates from small, perched groundwater seeps and springs within the watershed that range in elevation from 15 to 70 m above mean sea level. The United States Geological Survey (USGS) began continuous streamflow monitoring of Kawa stream on 9/29/2016. The mean and median streamflow measured in Kawa stream between September 2016 and July 2020 was 0.11 and 0.03 cubic meters per second (cms), respectively.

The major land uses within the 4.05 square kilometer Kawa stream watershed are single-family residential (35.5%), forest land (34%), cemetery land (11.5%), golf course (6%), school (6%), highways and streets (4%), commercial (2%) and park areas (1%) [1]. The residential portion of the watershed is known as the Pikoiloa neighborhood and has a population

ISSN: 2398-2640 (paper format), ISSN: 2398-2659 (online), http://www.witpress.com/journals
DOI: 10.2495/EI-V4-N2-141-156

of around 4 000. The houses in the watershed range in age from 20 to 80 years old and are highly sought after for their large lot sizes by Hawaiian standards (average lot size of 750 square meters). The southwestern headwaters of the watershed contain two separate cemeteries, the private Hawaiian Memorial Park and the Hawaii State Veterans Cemetery. The watershed also contains an elementary school (Kaneohe Elementary) and high school (James B. Castle High). The coastal section of the watershed contains the 18-hole Bayview Golf Course.

Urbanization of the watershed has altered the stream's natural hydrologic and hydraulic features [2]. Concrete drop structures constructed within the stream during urban development of the area reduced stream slopes and concrete channel linings stabilized the stream banks. Rainfall generated stormwater that falls on the residential portions of the watershed are conveyed to Kawa stream through a network of approximately 260 inlets (catch basins and grated inlets), 120 manholes, and nearly 13 700 linear meters of ditches, drainage pipes and box culverts [1]. The increase of impervious surfaces and installation of an efficient storm drain system during development of the residential subdivisions, cemeteries and schools within the watershed increased peak flows in the stream since storm generated runoff within the urbanized portions of the watershed can travel at greater speeds through the conveyance systems as well as through the hardened channelized sections of the stream. The resultant increased energy of flow within the stream during runoff events has led to downcutting within the unlined sections of the stream bed and undermined some of the constructed stabilizing structures within the stream [2].

Kawa stream is currently in violation of State of Hawaii water quality standards and is included in the 1998 Clean Water Act §303(d) list of impaired water bodies in the State of Hawaii. Total Maximum Daily Load (TMDL) standards, which reflect the maximum pollutant loads a waterbody (in this case, Kaneohe Bay) may receive, were previously established for nutrients (nitrogen and phosphorous) and total suspended solids (TSS) present in Kawa stream. A TMDL study of Kawa stream concluded that the nutrients leaving the watershed could enhance unwanted algae growth within the stream and Kaneohe Bay [3].

2 GLYPHOSATE PROPERTIES AND USAGE

Glyphosate and AMPA are non-volatile, polar and very soluble in water (11.6 g L^{-1}, 25 °C for glyphosate). However, these compounds strongly adsorb to soil particles, which bind them in the upper soil layer reducing their ability to leach into deeper soil layers and into groundwater [4]. Both compounds are very hydrophilic and practically insoluble in organic solvents and thus are assumed to be non-bioaccumulative in living organisms [5].

Previous half-life values measured for glyphosate range from 2 to 215 days in soils and from 2 to 91 days in waters [6]. The wide range of observed half-lives for glyphosate is a result of variable environmental conditions at the various previous study sites including soil characteristics (i.e. extent of soil-binding), pH and endogenous microbial populations and activity. Degradation of glyphosate in soils is mainly a biological process accomplished by different microorganisms, but bacteria, in particular members of the genus *Pseudomonas*, seem to be the most important [7]. The degradation product AMPA is believed to be somewhat more persistent than glyphosate in the environment, with measured half-lives in soil ranging from 60 to 240 days [8,9]. The decay of glyphosate and AMPA under laboratory conditions was fastest under warm and moist soil conditions and slowest under cold and dry conditions [10]. For instance, glyphosate was found to decay 8.4 times faster at 30°C than at 5°C under laboratory conditions.

Table 1: Glyphosate Use in the United States (Benbrook, 2016).

Annual glyphosate usage (1 000 kg)	1974	1982	1990	1995	2000	2005	2010	2014
Agricultural usage	363	2 268	3 359	12 465	35 699	71 481	106 941	113 347
Non-agricultural usage	272	1 270	2 402	5 679	8 980	10 025	11 357	12 037

Glyphosate is the most widely used herbicide, both in terms of mass applied and geographic distribution, in the United States. By comparison, the annual mass of the second-most used weed killer herbicide applied to agricultural crops in 2016 in the United States (atrazine) was roughly one quarter the mass of glyphosate applied. Historical usage data compiled by Benbrook [11] show that glyphosate use in the United States has increased roughly 200-fold since 1974 (Table 1). The increases in glyphosate usage in the United States and world-wide resulted mainly from widespread adoption of Roundup Ready crops that were genetically engineered to be tolerant to glyphosate in the early 1990s [12].

In the United States, it is estimated that over 12 million kilograms of glyphosate are currently used for non-agricultural purposes annually, including application by municipalities and homeowners to streets, parks, lawns, backyards and along waterways in urban and suburban settings [13,14]. The upward trend in glyphosate use has contributed to significant incremental increases in environmental loadings and human exposures to glyphosate, AMPA, and various surfactants and adjuvants used in formulating end-use glyphosate-based herbicides [11].

A previous water quality study conducted in Hawaii found widespread glyphosate contamination within surface waters and stream bed sediment on the islands of Oahu and Kauai [15]. Either glyphosate or AMPA was detected in 100% of the 32 stream bed sediment samples collected from multiple streams sampled on these two islands during this study. The present-day mean concentration levels of glyphosate measured in Hawaiian stream waters are roughly an order of magnitude higher than the next most commonly detected pesticide (the atrazine degradation product, 2-hydroxy-4-isopropylamino-6-ethylamino-s-triazine (OIET), with a mean concentration of 59 ng/l and 67% detection frequency) measured by the USGS in 32 stream waters collected on the islands of Oahu and Kauai from November 2016 to April 2017 [16]. In addition, the current mean glyphosate stream and sediment concentrations are seven and ten times higher than concentration levels of persistent organic pollutants (α-chlordane in sediment and pentachlorophenol in streams) measured in the mid-1970s on Oahu [17].

3 STUDY METHODOLOGY

Stream, suspended sediment and streambed sediment samples were collected from Kawa stream for glyphosate analysis between December 2017 and April 2020. The stream samples were also analysed for total suspended solids (TSS) and specific conductance. A total of 188 stream samples were collected in order to quantify the variation in glyphosate concentration present in the stream throughout the year under both baseflow and runoff conditions and over the duration of individual runoff events. A total of nine suspended sediment samples were collected during nine separate runoff events during this 2.5-year monitoring period. In addition, a time series of 81 increment streambed sediment samples were collected from three monitoring locations within the stream between February 2019 and April 2020. Stream and suspended sediment samples were collected at the USGS Gaging Station while the streambed sediments were collected at the Upper Dam, Lower Dam and Kawa stream Mouth sampling locations depicted in Fig. 1.

A multi-incremental sampling approach was used to collect the streambed sediments in order to produce representative temporal glyphosate concentration data. Traditional discrete sampling methodologies often produce a large variability of measured concentrations between and within individual discrete sediment samples collected at a given site. Sampling theory [18] and field experiments [19,20] have determined that a representative concentration for an analyte present in a heterogeneous matrix is best achieved by a multi-increment sampling approach which involves the collection of an adequate sample mass from an adequate number of locations within a delineated area of interest known as a Decision Unit (DU). Three DUs were established along different reaches of Kawa stream during this study which were repetitively sampled. The largest sampled DU was 250 square meters in size and established in the estuary where Kawa stream discharges into Kaneohe Bay. The two other DUs were both 20 square meters in size and were located just upstream of concrete drop structures installed to reduce the natural slope of the stream. The sampled DUs correspond to the upstream areas behind these drop structures where sediments transported in the stream tend to accumulate and the segment of stream where the stream enters the bay. A total of 50 increments of approximately 5 grams of sediment per increment were collected from each DU to create an individual

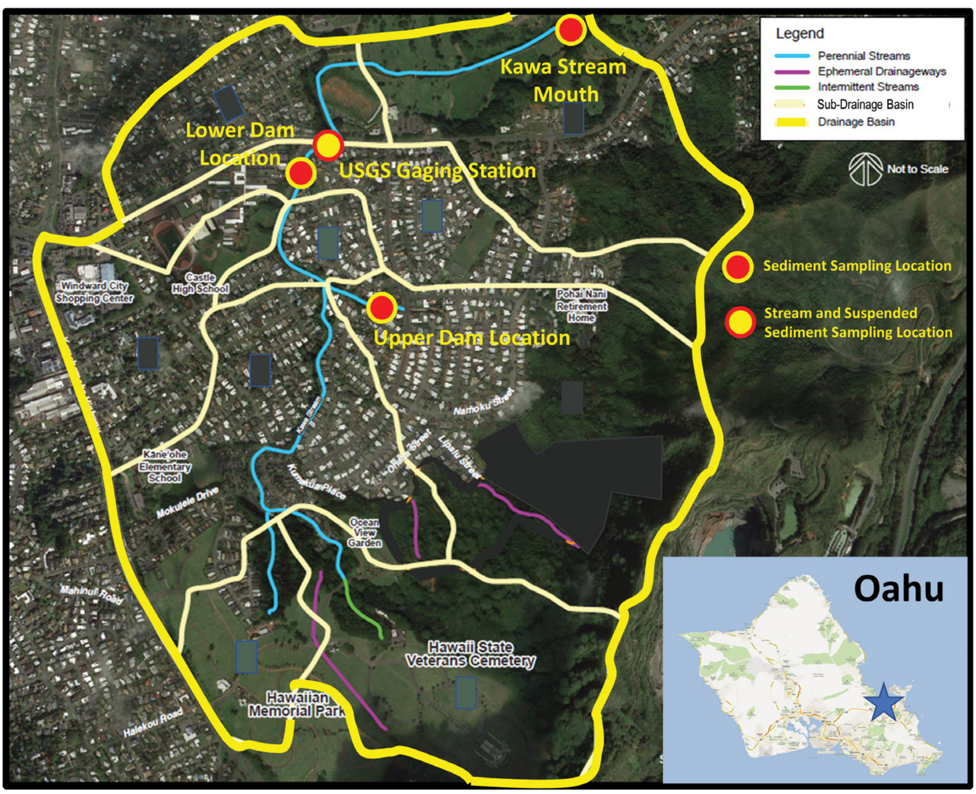

Figure 1: Kawa Watershed Kawa stream watershed and locations where stream and sediment samples were collected.

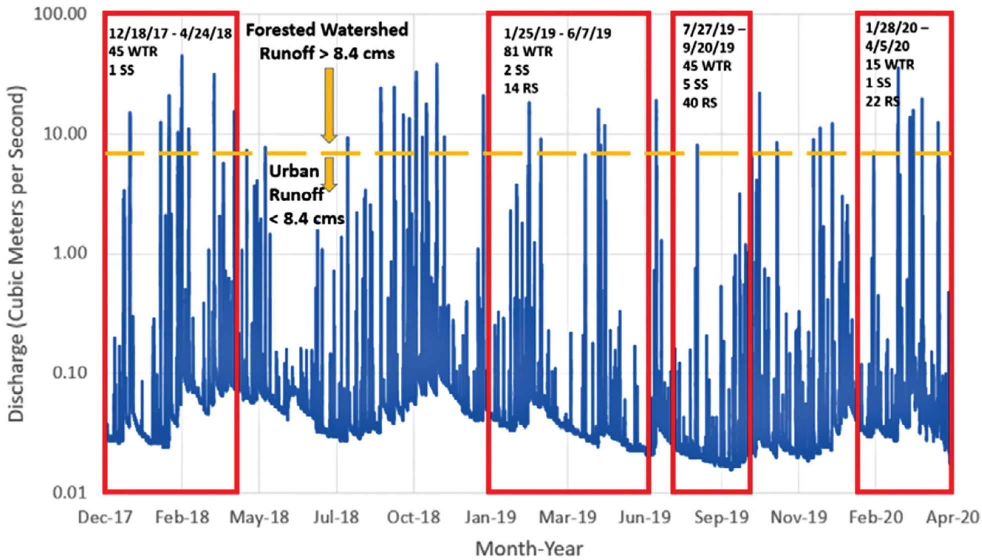

Figure 2: Kawa Stream Hydrograph Kawa stream hydrograph during study period: December 2017 to April 2020.

multi-increment sample that was then analysed for glyphosate content. An attempt was made to collect each sample from roughly the upper 1–2 cm layer of sediment present within each sampled DU. Gravel size particles (>2 mm) were removed by screening the samples prior to analysis. Suspended sediment samples were collected continuously from the stream over time periods of between 15 and 45 minutes during which time three to four coincidental stream samples were collected for glyphosate and total suspended solids analysis.

Figure 2 shows the hydrograph for Kawa stream between December 2017 and April 2020 and the four periods of time (red rectangles) when environmental samples were collected. The number of stream samples (WTR), suspended sediment samples (SS) and streambed sediment samples (RS) collected during each sampling period are also shown in this figure. The yellow dashed line shows the approximate streamflow (~8.4 cms) above which runoff from the forested watershed begins contributing to streamflow within Kawa stream. Glyphosate was not detected in three runoff samples collected from the forested portion of the watershed in early 2018.

4 STREAM, SUSPENDED SEDIMENT AND STREAMBED SEDIMENT RESULTS

Glyphosate concentrations were measured using the Abraxis Glyphosate Enzyme Linked Immunosorbent Assay (ELISA) Plate Kit. The ELISA method was used for this study since it allowed for higher frequency testing while reducing cost and time for analysis as compared to fixed laboratory methods. The Glyphosate ELISA method has a reporting limit of 0.075 and around 18 ppb for water and sediments, respectively. The sediment samples were extracted with 1 M NaOH. A total of 13 split time-series streambed sediment samples collected from the Upper Dam sampling site were submitted to Pacific Agricultural Laboratory for Glyphosate and AMPA analysis by Liquid Chromatography-Fluorescence Detection (LC-FLD). The limit of quantification for Glyphosate and AMPA in sediment with the LC-FLD method is 17 and 50 ppb, respectively. The coefficient of determination (R^2) for the glyphosate concentrations measured in the thirteen splits of sediment samples analysed by both immunoassay and LC-FLD methods was 0.66. Table 2 summarizes the glyphosate concentrations measured in suspended sediment and streambed sediments, and in stream waters under baseflow and ascending/descending runoff conditions during this study.

Stream samples collected under baseflow conditions where shallow perched groundwater was the source of streamflow typically contained undetectable or trace levels of glyphosate (28% detection frequency, 0.075 μg/L detection limit). Stream samples collected under both ascending and descending runoff conditions contained similar elevated mean glyphosate concentrations (around 1.0 part per million) and detection frequencies (around 92%). The variation in stream glyphosate concentration measured during individual runoff events suggests that glyphosate originates from both input to the stream from stormwater runoff from the surrounding residential portions of the watershed as well as from resuspension and release of glyphosate accumulated within streambed or riparian sediments deposited within and along the banks of the stream.

The highest median glyphosate concentration (724 μg/kg) was measured in the suspended sediment samples. The highest median streambed sediment concentrations were measured at the Upper Dam sampling site (573 μg/kg), which receives runoff from the surrounding residential community in the eastern portion of the watershed. The streambed sediment collected from the Lower Dam sampling site, which receives runoff from both the eastern and western portions of the watershed that contains the two cemeteries, elementary and high school, contained less than half the median glyphosate concentration (254 μg/kg) present in the sediment at the Upper Dam sampling site that receives only runoff from the eastern, residential portion of the watershed. This suggests that the residential areas within the watershed contribute higher loads of glyphosate to the stream than the cemeteries and schools within the watershed. The glyphosate concentration measured in the fine grain sediments present in the estuary where Kawa stream discharges into Kaneohe Bay are significantly lower (44 μg/kg) than levels measured in streambed sediments higher up in the watershed. This result may indicate that much of the glyphosate transported via Kawa stream discharges further out in Kaneohe Bay from the sampled DU located at the mouth of the stream during large rainfall runoff events.

Figure 3 depicts the median and range of glyphosate concentrations measured in runoff and baseflow condition stream samples, as well as the suspended sediment and streambed sediments analysed during this study. The median glyphosate concentrations measured in these media vary over five orders of magnitude. The elevated glyphosate concentrations measured in streambed sediments that accumulated at the Upper Dam site (compared to the levels measured down-stream at the Lower Dam site) suggest that the surrounding eastern residential portion of the watershed contributes the majority of the glyphosate measured within the watershed.

The mean and median concentration of glyphosate measured in Kawa Stream between 2017 and 2020, whose contributory watershed consists of residential and suburban land use, are similar to but slightly higher than glyphosate concentrations measured elsewhere on Oahu in Honouliuli Stream (mean 0.76 μg/L, median 0.22 μg/L, 54 samples collected between 2017 and 2020), which flows through the major industrial agricultural watershed on the island of Oahu, where large-scale experiments on genetically modified corn are conducted as well as diversified agriculture practiced. This illustrates the significant importance of urban and residential usage of glyphosate in the overall mass flux of this chemical within the environment.

The measured stream glyphosate concentrations are significantly lower than the U.S. Environmental Protection Agency drinking water Maximum Contaminant Level of 700 μg/L [21], and the chronic aquatic toxicity standards (1 800 μg/L) established by the State of Hawaii

Table 2: Glyphosate concentrations measured in stream and sediment samples.

Condition	**# Samples**	**% Detect glyphosate**	**Median glyphosate[1]**	**Mean glyphosate[1]**	**Maximum glyphosate**	**Minimum Glyphosate**
Stream water samples (µg/L)						
Baseflow conditions	47	27.7%	0.035	0.10	0.91	0.035
Ascending runoff conditions	93	92.5%	0.48	0.99	6.99	0.035
Descending runoff conditions	46	91.3%	0.72	0.96	6.60	0.035
Sediment samples (µg/kg)						
Suspended sediment	9	89%	724	1 056	3 934	< 97
Streambed sediment: upper dam	41	100%	573	701	4 100	51
Streambed sediment: lower dam	8	100%	254	245	418	28
Streambed sediment: stream mouth	32	31%	44	47	87	< 18

[1] Non-detect results were assigned a concentration of 0.035 ug/L.

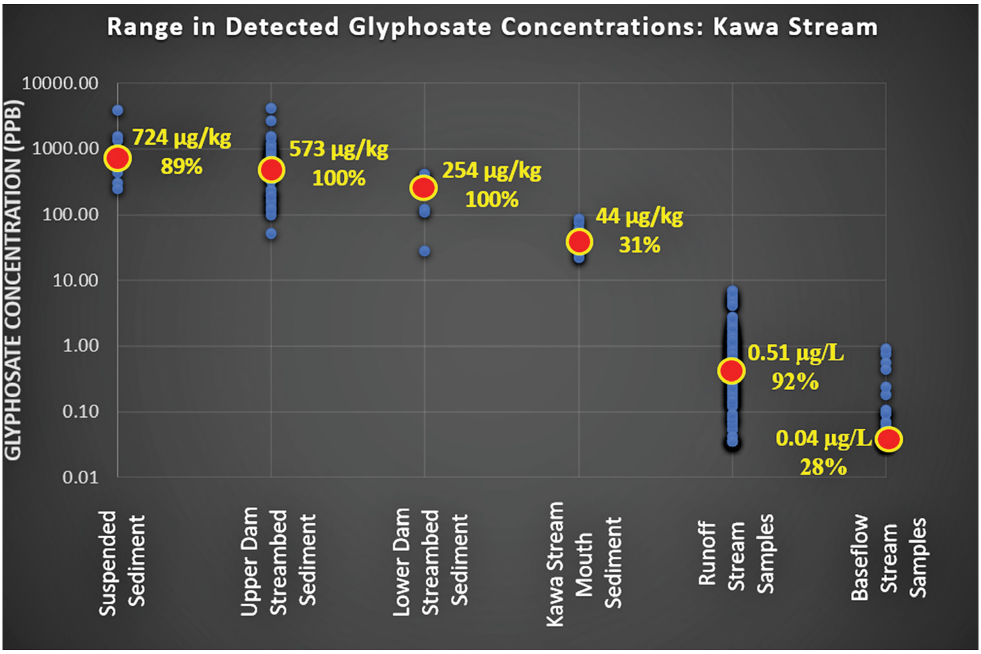

Figure 3: Median concentration and frequency of detection of glyphosate in suspended sediment, streambed sediment, runoff streamflow and baseflow streamflow.

Department of Health [22]. There are no human health or aquatic life benchmarks for AMPA. However, pesticides such as glyphosate and AMPA are often detected in the environment as chemical cocktails composed of multiple pesticides, surfactants and adjuvants. Further research is warranted on potential increased synergistic risks posed by glyphosate combined with other chemicals at the low part per billion levels commonly detected in streams.

The USGS has been conducting periodic monitoring of glyphosate and AMPA in a network of over 70 streams across the contiguous United States since the early 2000s [6,23]. The detection limit achieved by the USGS laboratory since 2009 is 20 ng/L as compared to the 75 ng/L detection limit associated with the immunoassay analysis used during this study. Table 3 compares the glyphosate concentrations measured in Kawa stream between 2017 and 2020 with glyphosate concentrations measured in small, urban watersheds in the mainland United States between 2014 and 2020 by the USGS, listed in order of median streamflow. The mean and median glyphosate concentration measured by the USGS in streams within these ten, small (<10 000 km^2) urban watersheds were 210 and 60 ng/L, respectively. By comparison, the mean and median glyphosate concentrations measured in Kawa stream were 759 and 341 ng/L, respectively, or 3.6 and 6.0 times higher. The only mainland United States stream that had similar glyphosate concentration levels as measured in Kawa stream was the Santa Ana River, which runs through the densely populated suburban metropolis surrounding Los Angeles. The elevated mean and median glyphosate concentrations measured in this small suburban Hawaiian watershed stream is likely due to three factors: (1) the small size of the Kawa watershed and the correspondingly short travel distances required for the glyphosate to enter the stream from the surrounding residential areas; (2) the extensive storm sewer

Table 3: Glyphosate levels in Hawaiian and continental United States urban watersheds.

Stream	**State**	**Median streamflow (cms)**	**% Watershed developed**	**Number of samples**	**Median glyphosate (µg/L)**	**Mean glyphosate (µg/L)**	**Detect frequency**
Kawa (All)	Hawaii	0.032	66.0%	186	341	759	76%
Kawa (Runoff)	Hawaii	0.032	66.0%	139	510	980	92%
Kawa (Baseflow)	Hawaii	0.032	66.0%	47	35	104	28%
Shingle	Minnesota	0.5	87.5%	128	50	95	73%
Swift	N Carolina	0.7	94.1%	128	80	173	96%
Cherry	Colorado	0.8	49.7%	135	130	343	85%
Fanno	Oregon	1.3	99.2%	126	90	135	98%
Sope	Georgia	1.4	99.1%	120	35	93	72%
Santa Ana	California	6.3	49.6%	85	320	800	99%
White Rock	Texas	2.6	97.8%	115	210	467	91%
Clinton	Michigan	8	70.8%	133	30	125	59%
Neuse	N Carolina	79	42.8%	97	50	70	79%
Chattahoochee	Georgia	111	66.2%	89	30	57	66%

system and moderately steep watershed topography within the Kawa watershed; and (3) the fact that ground treatment for weeds is required year-round in the tropical environment in Hawaii.

The instantaneous mass of dissolved phase glyphosate present in Kawa stream measured during the 2.5-year monitoring period was estimated by multiplying the measured glyphosate concentration by the streamflow volume at the time the samples containing detectable levels of glyphosate were collected. Under baseflow conditions, separate values were calculated based on just samples with detectable concentrations (13 samples) and for all baseflow samples collected (47 samples, 28% detection frequency). The mean, median and maximum glyphosate mass flux measured in Kawa stream is summarized in Table 4.

The total mass of glyphosate discharged in the dissolved phase from the Kawa watershed over the 2.5-year monitoring period was estimated to be around 4.4 kg (baseflow assumed for streamflow below 0.07 cms) when the median measured glyphosate mass flux under all baseflow and runoff conditions (0.0 and 19.9 mg/min) were applied to the 2.5-year flow data recorded by the USGS.

The annual mass of dissolved phase glyphosate discharging from Kawa stream is compared to the annual mass of glyphosate discharged from the larger, urban watersheds on the mainland United States in Table 5. The annual glyphosate mass for the mainland USGS stations was calculated by multiplying the median glyphosate concentration measured between 2014 and 2020 by the mean streamflow during this same period of time. The annual mass of glyphosate discharged from the Kawa watershed normalized to the urbanized area within the watershed is 7 to 110 times higher than the area normalized glyphosate mass flux measured in mainland streams. The contribution of glyphosate to Kawa stream per person living within the watershed is the second highest of the rivers compiled.

In addition to the dissolved phase, glyphosate is also transported out of the watershed in suspended sediment during runoff events. The percentage of glyphosate present in the suspended sediment load was measured during nine runoff events by continuously collecting suspended sediments over a 15 to 45-minute period as well as three or four contemporaneous stream samples. The total mass of suspended sediment during the sampling

Table 4: Mean, median and maximum glyphosate mass flux measured in Kawa stream.

Condition	# Samples	Mean glyphosate mass flux (mg/min)	Median glyphosate mass flux (mg/min)	Maximum glyphosate mass flux (mg/min)
Baseflow conditions (detects)	13	0.60	0.32	2.5
Baseflow conditions (all)	47	0.16	0.00	2.5
Ascending runoff conditions	86	113.6	19.0	1 006
Descending runoff conditions	42	90.3	26.4	872
All runoff conditions	128	106.0	19.9	1 006

Table 5: Annual and per capita mass of glyphosate mass discharged.

Stream	State	Annual glyphosate mass discharged (kg/year)	Annual glyphosate mass discharged per urban area (kg/year/km^2)	Total/urban watershed area (km^2)	Estimated population within watershed	Glyphosate contribution to stream per person (mg/year/person)
Kawa	**Hawaii**	**1.76**	**0.677**	**4.1/2.6**	**4 000**	**440**
Swift	N Carolina	1.76	0.034	54.4/51	25 000	70
Shingle	Minnesota	0.72	0.011	73.0/63.9	50 000	14
Sope	Georgia	1.49	0.019	80.0/79.0	30 000	50
Fanno	Oregon	3.59	0.044	81.6/80.9	60 000	60
White Rock	Texas	16.86	0.100	172/168	500 000	34
Clinton	Michigan	7.34	0.013	800/567	140 000	52
Cherry	Colorado	3.20	0.006	1 062/528	350 000	9
Santa Ana	California	63.23	0.022	5 858/2 905	1 500 000	42
Chattahoochee	Georgia	104.82	0.025	6 294/4 165	500 000	210
Neuse	N Carolina	125.00	0.042	6 972/2 984	65 000	1 923

interval was calculated by measuring the TSS concentrations in the stream samples collected. The glyphosate concentration in the composite suspended sediment collected and the concurrent stream samples were then measured by immunoassay. The percentage of glyphosate mass present in the suspended sediment compared to the mass present in the dissolved phase ranged from 1.2 to 27.7% during the nine sampled events. The mean/median percentage of glyphosate mass present in the suspended sediment versus the dissolved phase was 8.7% and 5.4%, respectively.

A total of 10 runoff samples collected during a large storm event (~2.3 inches daily rainfall on 3/15/20) were analysed for glyphosate and nutrients to provide insight to the relative amounts of suspended sediment, nutrients and glyphosate produced during a moderately large runoff event. Figure 4 shows the hydrograph for Kawa stream on 3/15/20 and the glyphosate, TSS and total nitrogen/phosphorous concentrations measured during the two periods of runoff that occurred on that day. The yellow dashed line delineates the portions of the hydrograph where runoff from the upland forested watershed contributed to streamflow. Previous sampling found that the forested portion of the watershed contributes no glyphosate but disproportionally large percentages of the suspended solids and nutrient loads that enter Kaneohe Bay during large runoff events.

The total mass of suspended solids, total nitrogen, total phosphorous, nitrate + nitrite and ammonia during the 3/15/20 runoff event was estimated to be 277,600, 2,085, 516, 142 and 19 kilograms, respectively, based upon the analytical results obtained on the ten samples collected. By comparison, the dissolved mass of glyphosate during this runoff event was estimated to be around 100 grams. The water quality data suggests that the watershed became

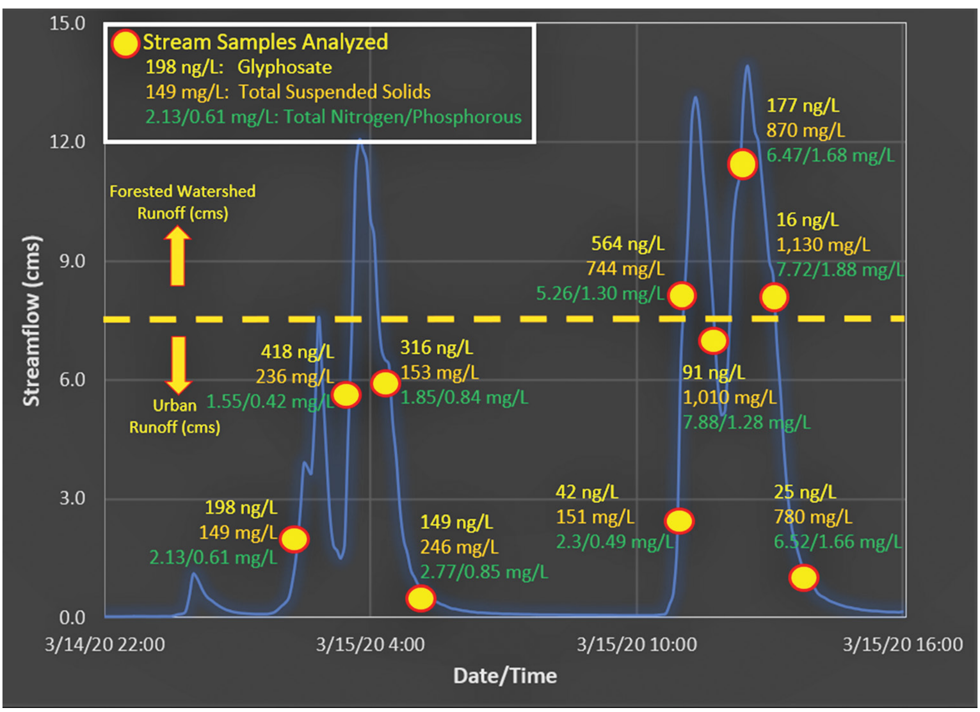

Figure 4: Variation in glyphosate, total suspended solid, nitrogen and phosphorous measured during 3/15/2020 rainfall runoff event.

almost depleted of glyphosate by around 13:00 during this storm event after 100 grams of glyphosate left the watershed since only trace levels of glyphosate were detected in the last two stream samples collected during this runoff event.

The half-life of glyphosate and AMPA in streambed sediments at the Upper Dam monitoring site was estimated by collecting a time-series of increment sediment samples from the DU established just above the concrete drop structure at this site. The decline in glyphosate and AMPA concentrations measured in the time-series of sediment samples collected during dry periods when no runoff occurred was used to derive the half-life values. It was assumed that no additional glyphosate was added to the sampled streambed sediments during these dry periods due to the near absence of glyphosate in stream samples collected under baseflow conditions.

Figure 5 plots the percentage reduction in glyphosate levels measured in sets of sediment samples collected after various durations of dry weather conditions. The degradation curves associated with half-life values of between 1 to 14 days are also shown on this figure. Measured half-lives for glyphosate in sediment ranged from 2.7 days to 7.6 days (12 measurements, median 4.7 days) while the AMPA half-lives (not plotted) ranged from 0.7 to 8.0 days (6 measurements, median 6.2 days). The median half-lives determined for glyphosate and AMPA (4.7 and 6.2 days) in stream sediments in the tropical Kawa watershed are significantly lower than typical literature values for these two compounds in soils (2–215 and 60–240 days, respectively) [6,8,9]. Despite the short persistence of glyphosate in the Hawaiian environment, the current concentration levels are seven and ten times higher than concentration levels of persistent organic pollutants (with longer half-lives on the order of years) measured in waters and sediments in the mid-1970s on the island of Oahu [15]. This attests to the significantly higher present-day mass loading of glyphosate to the Hawaiian environment than historic pesticide loading levels in urban environments.

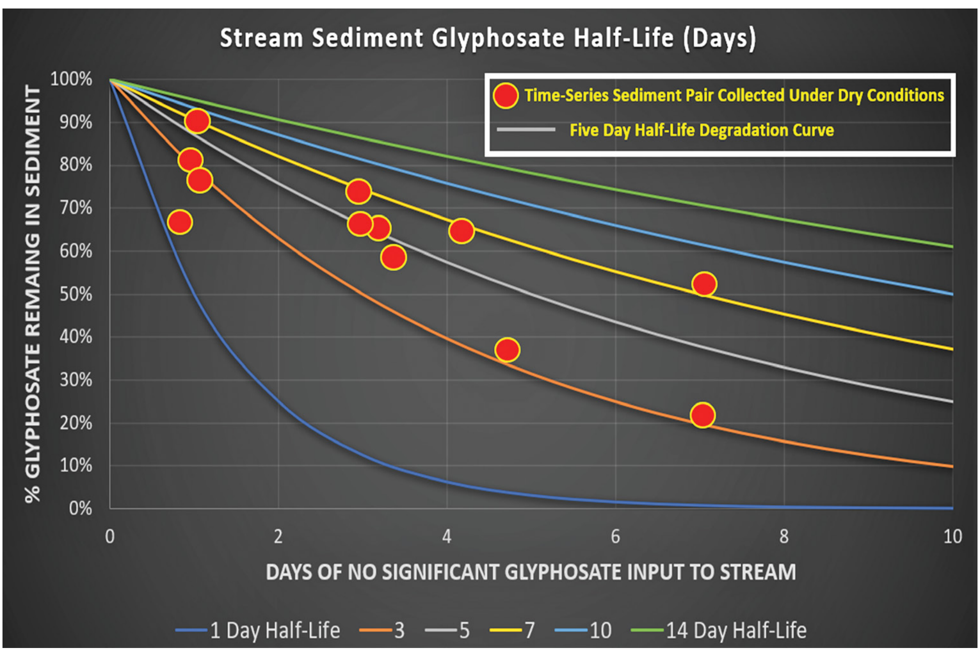

Figure 5: Range of glyphosate half-lives measured in streambed sediments.

5 CONCLUSIONS

Elevated glyphosate concentrations were measured in a stream that drains a small suburban tropical watershed in Hawaii compared to concentration levels measured in small streams in urban watersheds on the mainland United States. The present-day mean concentration of glyphosate in Hawaiian streams is an order of magnitude higher than mean concentrations levels of the next most commonly detected pesticide (the atrazine degradation product OIET, [16]) and seven and ten times higher than concentration levels of persistent organic pollutants measured in streams and sediments in the mid-1970s on Oahu [17]. Residential areas within the Kawa watershed (as opposed to golf courses, cemeteries and schools) were found to contribute the majority of glyphosate to the stream during large rainfall runoff events based on the spatial distribution of glyphosate concentrations measured in streambed sediments in Kawa stream.

The annual mass of glyphosate discharged from the Kawa watershed on Oahu normalized to the urban acreage within the watershed is 7 to 110 times higher than the area-normalized mass of glyphosate measured in mainland streams by the USGS. The small size, moderately steep topography, and extensive network of storm sewers and impervious surfaces within the watershed as well as year-round use of glyphosate for treatment of weeds likely contribute to the higher measured glyphosate fluxes in Kawa stream. The estimated mass of glyphosate (0.1 kg) discharged in Kawa stream during a well monitored runoff event on 3/15/20 was a small fraction (0.004%) of the mass of nutrients (total nitrogen and phosphorous, 2 601 kg) discharged during the same runoff event. Less than 10% of the annual glyphosate flux out of the Kawa watershed is transported in suspended sediments.

The median half-life of glyphosate and AMPA measured in streambed sediments during this study were 4.7 and 6.2 days, respectively. This short half-life combined with the ubiquitous detection of glyphosate in streams and sediments collected in Hawaiian streams during this and previous studies illustrate the unceasing nature of glyphosate input to the environment in the Hawaiian Islands. The most effective approach to reducing the mass flux of glyphosate entering the environment in the future would involve a combination of implementing governmental polices that promote reduction of nutrient, pesticide and sediment loads to urban storm drains systems and working with local health departments to provide guidance to the general public on the proper application of pesticides for homeowners.

ACKNOWLEDGEMENTS

The Pacific Islands Water Science Center (Mr. Travis Hylton) of the USGS graciously provided splits of stream samples collected by their autosampler on Kawa stream during the March 15, 2020 runoff event. The authors analysed the split samples for glyphosate while the USGS analysed the primary samples for TSS and nutrient content.

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SB-426-HD-1
Submitted on: 3/17/2023 4:22:47 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Gerard Silva	Individual	Oppose	Written Testimony Only

Comments:

We will not Comply to this Communist Control !!!!!

SB-426-HD-1
Submitted on: 3/18/2023 11:51:21 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Virginia Tincher	Individual	Support	Written Testimony Only

Comments:

Members of the Consumer Protection and Commerce Committee,

Cesspools have been a concern for years and now due to increasing storm intensity which washes undigested cesspool contents into waterways the negative health impacts are increasing and action is critical.

I strongly support the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversions, or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be upgraded, converted, or connected before 1/1/2030, and priority level 2 cesspools to be upgraded, converted, or connected before 1/1/2035.

I urge you to pass SB426 SD1 HD1.

Virginia Tincher, Oahu

SB-426-HD-1
Submitted on: 3/19/2023 7:36:50 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Pieter Meinster	Individual	Oppose	Written Testimony Only

Comments:

Opposition to SB-426

I wish to express my opposition to this bill and explain my position below.

What we have here are three distinct issues;

1. This bill itself, attempting to accelerate the compliance dates. The study that this bill is based on was conducted without any community impact consideration or outreach and took absolutely no account of the large number of extraneous sources of contamination to our nearshore waters. Basically misidentifying cesspools as the sole/primary source.
    1. The conclusions reached in this study don't even stand up to peer review, see testimony by Dr. Spengler.
2. The cost of such system that will be shouldered by the majority lower income group of affected people, without realistic financial aid options in place, this would create an unbearable hardship.
    1. As far as the grant is concerned, to put things in perspective; on Oahu alone, there are approximately 29,000 properties that are listed in the tabulation of properties that are eligible for the grant (https://health.hawaii.gov/wastewater/files/2023/02/EligibleTMKList_Honolulu.pdf).
    2. These properties are within that classification of high priority, per the recommendations from the report (https://health.hawaii.gov/wastewater/files/2022/01/priortizationtoolreport.pdf).
    3. However, the number of grants are currently capped at only 225 Statewide. That is less than 1% of qualifying TMKs on Oahu alone (0.7% actually), significantly less if taken Statewide! If these grants are to be even remotely effective in offsetting the financial hardship that this measure is going to impose on communities Statewide, we would need to see a 99% or more increase in funding availability.
    4. There is talk of a tax credit. A tax credit would only be effective for those that have the money to install a septic system to start with and that have a large existing tax liability (high income), scanning that bill it appears this tax credit applies to one tax year only. Exceptionally few people in this demographic have the State tax liability to make use of a one time credit. Additionally, if this is

modeled after the first tax credit that was made available some years back, it only applied to a specific list of Tax Map Keys (TMK) that were eligible.

3. Current legislation dictating that any alternate private wastewater management system be abandoned, within 90 days of notification of city & county sewer availability.
    1. Located in Chapter 14 of the Revised Ordinances of Honolulu, under Article 1. "Use of public sewers. Sec. 14-1.6 (a) When Required. Every lot that has sanitary facilities requiring sewage disposal which is accessible to a public sewer and is not connected shall be connected to the public sewer within 90 days after the owner or person legally responsible has been notified to do so. The director may grant an owner or person legally responsible a 30- day extension of time to connect to the public sewer upon a showing of extenuating circumstances and a good faith effort by such owner or person to make the connection. Under no circumstances shall the director grant more than three, 30-day extensions of time."
    2. Ruling should be altered. When a household installs a septic tank (or alternate acceptable system), such system be universally accepted as the de facto primary and sole means of wastewater handling for that property and further mandates to subsequently connect to sewer be removed. This requires a change in legislation.

I appreciate your review of my testimony.

Mahalo

Pete Meinster - resident Makaha

SB-426-HD-1
Submitted on: 3/19/2023 1:43:33 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Kevin McClintock	Individual	Comments	Written Testimony Only

Comments:

Issue 1; Cesspool Pilot Grant Program (CPGI). Program Effective qualification date of 1 July 2022 "disqualifies" Individual Wastewater Systems (IWS) upgrades (cesspool to septic/ATU) completed between 1 Jan 2021 and 30 June 2022 elimibnating **ANY** and **ALL**incentives to upgrade cesspools in that period. My upgrade cost exceeded $50,000.00 and was completed 6 Apr 2022, 54 days prior to CPGI qualification and after the upgrade tax credit expired and was neccessitated by the Wastewater branch requirement to upgrade IWS's prior to approval of a city/county building permit for home improvements, additions or new construction. This represents a significant financial and public health mandate in the absence of public infrastructure with arbitrary qualification dates for homeowners executing upgrades in aforementioned time period. Additionally there is possibly a group of disenfranchised homeowners who completed cesspool upgrades in the post taxcredit/pre-CPGI period.

Relief Sought: Appropriate agency/body Revise CPGI qualification dates to include cesspool upgrade post tax credit period (1 Jan 2021 thru 1 July 2022)

Issue 2: Due to the high cost of Cesspool upgrades to septic systems (with a multi-decade life expectancy and by design contaminant containment), a **sewer connection exemption** (thru bill language) should be made for "mandated sewer connection" in the event sewer infrastructure becomes available to the upgraded property. Typically cesspool upgrades are amortized over extended periods and with a sewer connection mandate a significant financial burden would imposed on homeowners with the amortized upgrade financing and the addtional monthly sewage charges once connected.

Relief Sought: Insert "sewer connection exemption" language in bill for appropriate time period for upgraded properties.

3/20/2023

CPC Committee
Hawai‘i State Capitol
Honolulu, Hawai‘i 96813

Dear Chair Nakashima, Vice Chair Sayama, and Members of the Committee on Consumer Protection & Commerce,

Position: Support SB426 SD2 HD1

The Surfrider Foundation is a national nonprofit organization dedicated to the protection and enjoyment of our ocean, waves, and beaches. Surfrider maintains a network of over 150 chapters and academic clubs nationwide, including 4 chapters in the Hawaiian Islands. The Surfrider Foundation focuses on many aspects of the environment such as coastal protection, plastic pollution, and water quality.

The Surfrider Foundation, Hawai‘i region, is testifying in **strong support of SB426 SD2 HD1**, which would implement the recommendation of the cesspool conversion working group to accelerate the dates for required upgrades, conversions, or connections for priority one and two cesspools.

With an estimated 83,000 cesspools, Hawai‘i has one of the highest per capita number of cesspools in the nation. The cesspool conversion working group recommends the removal of the 14,000 worst (“priority one”) cesspools by 2030; removal of the 12,000 “priority two” cesspools by 2035; and removal of the remaining “priority three” 55,000 cesspools by the current 2050 deadline. Targeting the worst polluting cesspools first will help reduce sewage pollution, protect groundwater and coastal ecosystems, and ensure clean water for the people of Hawai‘i. **This is the most important bill to implement the recommendations of the working group.**

Surfrider Foundation maintains a citizen-science water quality monitoring program called the Blue Water Task Force (BWTF) on Kaua‘i, Maui, and O‘ahu that tests for enterococcus, a fecal indicator bacteria. Since 2018, the O‘ahu BWTF has been monitoring water quality in Kāne‘ohe bay at Kahalu‘u due to the high concentration of coastal cesspools in this area. Due to these cesspools, the water near and around Kahalu‘u regularly exceeds state public health standards (see 2021 annual results). Without policies requiring a faster phase out of the cesspools with the greatest environmental threat, we will continue to pollute our coastal and freshwaters, threatening both environmental and public health.

Thank you for your consideration of this testimony in support of SB426 SD2, submitted on the behalf of the Surfrider Foundation’s 4 Chapters in Hawai‘i and all of our members who live in the state and visit to enjoy the many coastal recreational opportunities offered by all of the islands’ coastlines.

Sincerely,

Lauren Blickley
Hawai‘i Regional Manager
Surfrider Foundation

SB-426-HD-1
Submitted on: 3/20/2023 10:21:20 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Mark Hixon	Individual	Support	Written Testimony Only

Comments:

Aloha. It is well-documented that the many cesspools in Hawaii leak waste into coastal waters, and nutrients from that waste fertilize seaweeds, allowing them to overgrow and smother corals. No coral = no reef = no fisheries, no ocean tourism, and no coastal protection. We must solve the cesspool issue before we lose our reefs. Please pass this bill. Mahalo.

SB-426-HD-1
Submitted on: 3/20/2023 10:36:54 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Daniel Amato	Individual	Support	Written Testimony Only

Comments:

To: Members of the CPC committee

From: Daniel Amato, PhD

Re: Hearing SB426 SD2 HD1 RELATING TO CESSPOOLS.

Hearing: Thursday March 21, 2023, 2:00 pm, room 329

Aloha Members of the CPC:

As a research scientist and a water quality professional, I strongly support SB426. Decades of research have concluded that wastewater presents a major stressor for the nearshore environment. In addition, the Cesspool Conversion Working Group has concluded that specific cesspools require immediate action. It is very important to begin the process of upgrading cesspools that exist in sensitive locations. We cannot wait 25 more years to begin this process. The reef needs this stress relief now. Please support SB426 in your committee. Mahalo -Dr. Daniel Amato

SB-426-HD-1
Submitted on: 3/20/2023 10:44:42 AM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Mattison Priest	Individual	Support	Written Testimony Only

Comments:

Aloha Committee Members,

My name is Mattison and I live in Liliha. Over 80,000 cesspools are polluting our groundwaters with over 50 million gallons of raw sewage every day. Cesspool nutrients are harming coral reefs and the community at large. We have to start upgrading this outdated infrastructure to protect the health of our community.

Mahalo for the opportunity to testify.

Mattison Priest

SB-426-HD-1
Submitted on: 3/20/2023 12:42:00 PM
Testimony for CPC on 3/21/2023 2:00:00 PM

Submitted By	Organization	Testifier Position	Testify
Helen Cox	Individual	Support	Written Testimony Only

Comments:

Aloha Committee Chair and Members,

Please support SB426. This bill is essential if we are to protect our waters and reefs. It implements the recommendation of the cesspool conversion working group to accelerate the dates for required conversion or connections of priority level 1 cesspools and priority level 2 cesspools by requiring priority level 1 cesspools to be converted or connected before 1/1/2030 with certain exceptions. Priority level 2 cesspools will be converted or connected before 1/1/2035. Both of these new deadlines are before the current deadline of 1/1/2050.

Mahalo for supporting SB426.

Helen Cox, Kalaheo, Kauai