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The influence of wastewater discharge on water quality in Hawai'i: A comparative study for Lahaina and Kihei, Maui

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ABSTRACT

In Maui, Hawai'i, wastewater reclamation facilities (WWRFs) dispose of partially treated effluent into injection wells connected to the nearshore environment. Hawai'i State Department of Health data from 2004–2015 were assessed for qualitative trends in nutrient, turbidity, and Chlorophyll *a* water quality (WQ) impairments for fourteen marine sites on Maui Island. We introduce a novel method, the Qualitative Impact Percentage (QIP), to facilitate a qualitative comparison of disparate factors contributing to WQ impairment. Sites near the Lahaina WWRF in West Maui, which was found in violation of the Clean Water Act in 2014, had fewer exceedances and lower geometric means compared to sites near the Kihei WWRF. Our results suggest that WQ impairments may be a greater concern in Kihei than previously acknowledged. This paper attempts to raise the awareness of policymakers and the public and to encourage further research assessing the effects of the Kihei WWRF on the marine environment.

1. Introduction

1.1. The Clean Water Act and Hawai'i's coral reefs

Hawaiian coral reefs are a hotspot for species diversity with 25% of marine species found nowhere else in the world (Friedlander et al. 2008). Studies in Hawai'i since the 1990s have linked coral reef decline to agricultural runoff, shoreline development, excess nutrients, and macroalgal blooms (Friedlander et al. 2008; Dailer et al. 2012b; DLNR 2012). While there is substantial evidence of coral decline throughout the Hawaiian Islands and globally, management regulations and legislation are decades behind current science and are largely ineffective (Richmond et al. 2007). Reef ecosystems are prominent in traditional Hawaiian culture in a way that cannot be quantified. In addition to their ecological significance, coral reefs are an essential component to Hawai'i's $12 billion annual tourism industry, with their total value estimated at $10 billion. Their decline and subsequent loss may have serious economic and ecological implications (Friedlander et al. 2008; Hawai'i 2010).

1.2. Hawai'i water quality standards

The Clean Water Act (CWA) is the primary federal law regulating anthropogenic sources of water pollutants into the nation's waters, including seas within three miles of land (CWA Federal Water Pollution Control Act, 1972; Secs. 101 & 502). The CWA requires states to set water quality standards (WQS) to protect the designated use of a water body. For some waters in Hawai'i, designated uses include aquatic life propagation, recreation, and preservation of coral reefs for tourism. To monitor WQS, the State of Hawai'i Department of Health (HIDOH) uses: 1) nutrient criteria for nitrogen (N) as total nitrogen (TN = inorganic + organic N), ammonia (NH_4), and Nitrate + Nitrite ($NO_3 + NO_2$), total phosphorous (TP), and turbidity; and 2) biological numeric criteria for Chlorophyll *a*, and two bacterial indicators, *Enterococcus*, and *Clostridium perfringens* to assess risks to human health (Hawai'i Administrative Rules, 2014). Every two years, states must report to Congress any impaired waters not meeting state or federal WQS (HAR 2004, 2014; CWA Federal Water Pollution Control Act, 1972). In 2014, the HIDOH WQ report indicated 85% of Hawai'i's sampled marine waters do not meet one or more WQS and are classified as impaired; 43% of impairments were for nutrients (HIDOH 2014).

1.3. Illegal wastewater discharge: Maui case study

The beaches along the west-facing coasts of Maui are inside a National Marine Sanctuary, classifying them as marine class AA waters and requiring the state to support marine life, conservation of coral reefs, scientific research, and recreation in these areas (HAR 2004, 2014). In addition, two of Maui's largest populations are also located along these same beaches, surrounding Lahaina and Kihei, where two of Maui counties' wastewater reclamation facilities (WWRF) are also located.

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While the WWRFs use some methods of biological N removal, treated wastewater effluent is still about six times higher in dissolved N concentrations than those of groundwater levels (Hunt 2006). The Lahaina and Kihei WWRFs inject approximately 3.4 and 2.5 million gallons of partially treated wastewater effluent per day (Dailer et al. 2010), respectively, into deep shafts that discharge fluids underground, (a.k.a. 'injection wells') (Code of Federal Regulations Chapter 40 Part 144.3). In addition, the Lahaina WWRF injects 63,609–78,274 lbs. of N per year and the Kihei WWRF injects 47,754–71,654 lbs. of N per year (Dailer et al. 2010).

From 1995 to 2012, Maui Island's total coral cover for four sites in West Maui decreased 37%, with two popular tourist sites for snorkeling and diving, Honolua Bay and Kahekili, decreasing 76% and 33%, respectively (DLNR 2012). Concern over the ecological effects on marine ecosystems spurred investigations into whether a hydrological connection between the injection wells and the nearshore environment existed (Hunt and Rosa 2009; Dailer et al. 2010, 2012a; DLNR 2012). Several isotope and tracer studies in recent years confirmed Kahekili Beach Park has freshwater seeps directly connected to the injection wells, which bubble up at about 2 m depth (Hunt and Rosa 2009; Dailer et al. 2010). Due to its lower salinity, the wastewater floats to the surface water where most recreation occurs (Dailer et al. 2012a).

In April 2012, a lawsuit was filed against the County of Maui for being in violation of the CWA. It alleged the county has been discharging wastewater from injection wells into the ocean since the 1980s without permits from the EPA (US District Court, District of Hawai'i 2012). In May 2014, the judge determined that wastewater entering the ocean at Kahekili "significantly affects the physical, chemical and biological integrity of the receiving waters" (Henkin 2015). In January 2015, a federal judge ruled all four injection wells at the Lahaina WWRF were in violation of the CWA (Imada, 2015). In September 2015, a settlement was reached requiring Maui county to pay \$100,000 in penalties, apply for the proper permits for disposal, and invest \$2.5 million to update wastewater projects in West Maui; the county is currently appealing the case (Kelleher, 2015).

1.4. Study goals: sounding the alarm for Kihei, Maui

The Lahaina WWRF and its negative effects on nearby West Maui beaches have received more attention than the other two WWRFs on the island (at Kihei and Kahului). This is largely due to the fact that the EPA regulates discharge for the Lahaina WWRF through an Underground Injection Control (UIC) permit. The Kihei and Kahului WWRFs do not currently have UIC permits. Since the 1990s, many segments along the Kihei coast have been classified as impaired, (HIDOH 2002; Hunt 2006) and over the past several decades, both North and South Kihei sometimes experience increased rates of macroalgal blooms on or near coral reefs, with algae washing up and rotting on popular beaches. This has caused annual economic losses up to \$20 million for clean-up efforts and lost tourism (Van Beukering and Cesar 2004).

Hunt (2006) estimated Kihei's WWRF injects approximately three million gallons per day of tertiary-treated wastewater effluent into injection wells. Wastewater is injected below the groundwater before rising and mixing with surface groundwater, forming a plume about a mile wide along the Kihei coast. The central part of the Kihei WWRF plume is at Kalama Beach Park (hereafter Kalama) and Cove Park where the resurfacing groundwater, estimated to be 60% to 80% effluent, emerges near shore (Hunt 2006; Hunt and Rosa 2009). Cove Park is a central location in the Kihei area for many tourists to learn how to surf, paddle board, or canoe, and is a high demand location for recreational activities. The plume can be seen in aerial images, and on most days can be seen from shore (*personal observations*).

The primary goal of this paper is to qualitatively assess 2004–2015 WQ data from the HIDOH for nutrients (TN, $NO_3 + NO_2$, NH_4, TP), turbidity, and Chlorophyll *a* for fourteen sites near the Lahaina and Kihei WWRFs (five sites north of the Lahaina WWRF, four sites adjacent to the Lahaina WWRF, and four sites adjacent to the Kihei WWRF (Fig. 1). In addition, we also introduce a novel method, the Qualitative Impact Percentage (QIP), to standardize and qualitatively compare WQ data. Fundamentally, this paper aims to inform a larger audience on the current status of WQ impairments in Maui, and to essentially '*sound the alarm*' for concerned citizens, researchers, and state managers to conduct further investigations into what possible effects the Kihei WWRF may be having on the marine environment, and take constructive action as appropriate.

2. Methods

2.1. Dataset and site selection

Nutrient WQ data were compiled for TN (μg N/L), $NO_3 + NO_2$ (μg N/L), NH_4 (μg N/L, TP (μg P/L), Chlorophyll *a* (μg/L), and turbidity (N.T.U.; Nephelometric Turbidity Units) from the HIDOH Clean Water Branch website for 2004–2015 (Teruya and HIDOH 2015). Only fourteen sites had ≥1 year of data available for all nutrient variables in a single year; these sites were included in our QIP assessment (see Table 2 & Fig. 1 for specific site names). Of these fourteen sites, eight sites (four sites near the Lahaina WWRF and four sites near the Kihei WWRF) had nutrient data for ≥4 consecutive years (2009–2015) (see Appendix A for a better understanding of the temporal distribution of water samples). These eight sites were included in our geometric mean (GM) assessment (Fig. 2A–F).

In reports to Congress, the HIDOH sorts data into two year cycles from November 1st to October 31st (e.g. the 2014 report covers data gathered between 11/1/2011 and 10/31/2013) and further breaks data down into wet or dry seasons (based on the amount of fresh water discharge per shoreline mile) (HAR 2004 §11–54–6). However, the available DOH dataset did not indicate whether a given nutrient sample should be considered 'wet' or 'dry' for the purpose of comparing to standards. Therefore we divided samples into 'wet' or 'dry' based on the month the sample was collected (i.e. wet season: November through April; dry season: May through October) similar to HIDOHs' guidelines for inland waterways (HAR 2004 §11–54–2) that drain into these coastal locations. We examined data collected from November 1, 2004 to October 31, 2015 and sorted the data into one-year periods beginning on November 1 and ending on October 31. Appendix A shows the temporal distribution of samples over the course of each year. Partitioning the data in this way allowed for each year's worth of data to contain samples from the wet season, samples from the dry season and provided the opportunity for year-by-year comparisons while still preserving the ability to compare our results to HIDOH reports to Congress (Appendix B).

2.2. Geometric mean assessment

The Geometric mean (GM) was calculated for each wet and dry season per site per year for the reported values. All sites selected for this study happen to be classified as 'coastal' (HAR 2004 §11–54–2); therefore, each GM was compared to applicable standards for coastal sites as given in the Hawai'i Administrative Rules (HAR 2004 §11–54–6(b); Table 1). The number of samples in each grouping that exceeded the Geometric Mean Standard (GMS) were counted, along with all samples exceeding the 10% Statistical Threshold Value (STV), and the 2% STV (HAR 2004 §11–54–6(b)(3); Appendix B).

2.3. Quality impact percentage (QIP)

The traditional statistical methods used to analyze water quality data, such as calculating a mean and standard deviation, require having a "large enough" set of independent samples drawn from sources having a common expectation and variance. Because HIDOH samples