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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

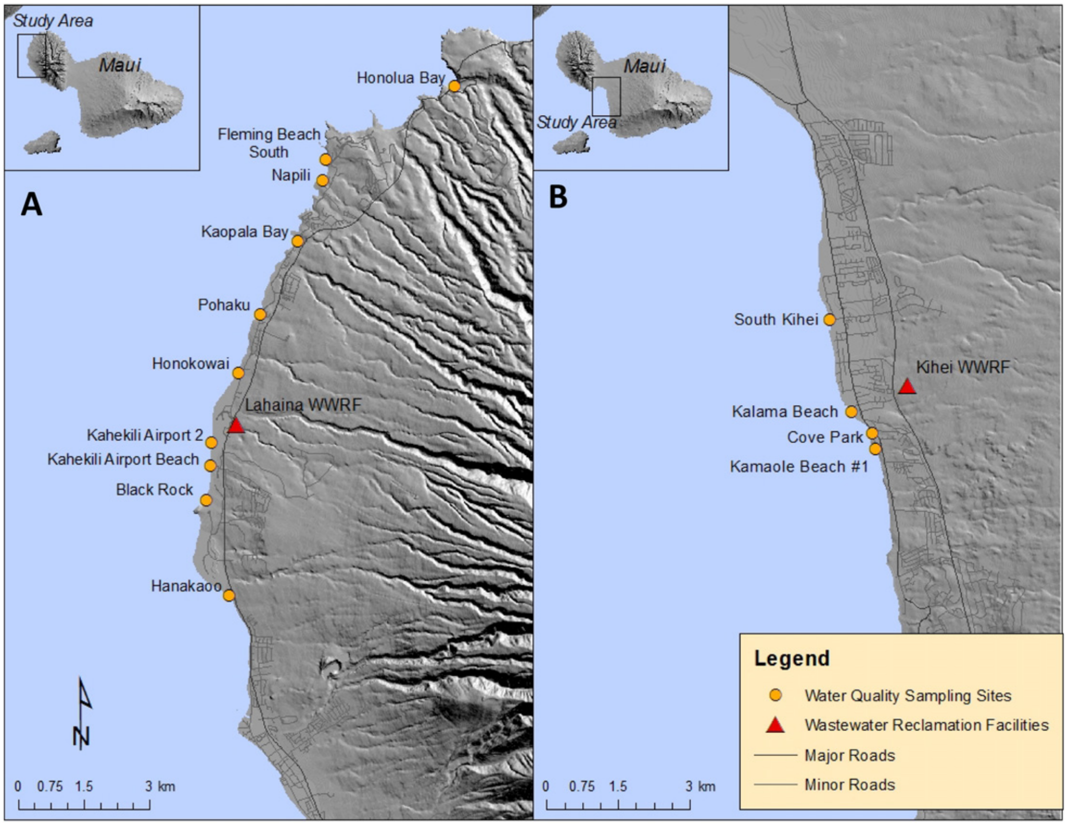


Fig. 1. Map of the ten sample sites near the Lahaina WWRF (A) and the four sites near the Kihei WWRF (B). The wastewater reclamation facilities are indicated by red triangles. Major and minor roads are included for reference. Site names are modified from the Storet site data from the HIDOH. http://health.hawaii.gov/cwb/. Basemap is copyright 2014 Esri, OpenStreetMap contributors.

at a given site are sometimes collected weeks or months apart under conditions which are likely to differ substantially in wind, rain, currents, and wave action, it seems extremely unlikely that the prerequisites of common expectation and variance are met. This precludes any ability to definitively state how impacted a site was on a certain date.

In order to estimate the relative degree of impact of multiple sites along the west facing coasts of Maui, we devised a method for comparing WQ samples relative to their respective standards. Our method makes no assumptions regarding the underlying statistical distribution of the samples. Rather, we compare them to their applicable standard and the implicit normal distribution underlying the standard. We generated a QIP for each WQ variable (TN, $NO_3 + NO_2$, NH_4, TP, turbidity, and Chlorophyll *a*) to facilitate a standardized qualitative comparative assessment estimating which sites were most and least impaired, and which variables had the greatest impact relative to the others. Individual impact percentages were calculated for each variable by averaging four numbers: the calculated GM as a percentage of the GMS (Eq. (1)), the percentage of samples exceeding the GMS (Eq. (2)), the percentage exceeding the 10% STV (Eq. (3)), and the percentage exceeding the 2% STV (Eq. (4)). See Appendix B for a thorough description of QIP calculations with two specific site examples. A brief description is as follows:

$$\text{GM QIP} = 100 * \text{GM}/(\text{GMS}) \tag{1}$$

$$\text{n>GMS QIP} = 100 * (\text{n>GMS})/(0.5 * \text{number of samples}) \qquad (2)^{*}$$

* *If the samples are normally distributed the frequency of values would form a bell shaped curve. The value '0.5' represents a normal bell shape curve with 50% of samples falling on each side of the center of the curve which corresponds to the Geometric Mean Standard (GMS). If more than 50% of the sample values fall to the right of the GMS then this formula will yield a number greater than 100%.*

$$\text{n>10\% STV QIP} = 100 * (\text{n>10\% STV})/(0.10 * \text{number of samples}) \qquad (3)^{**}$$

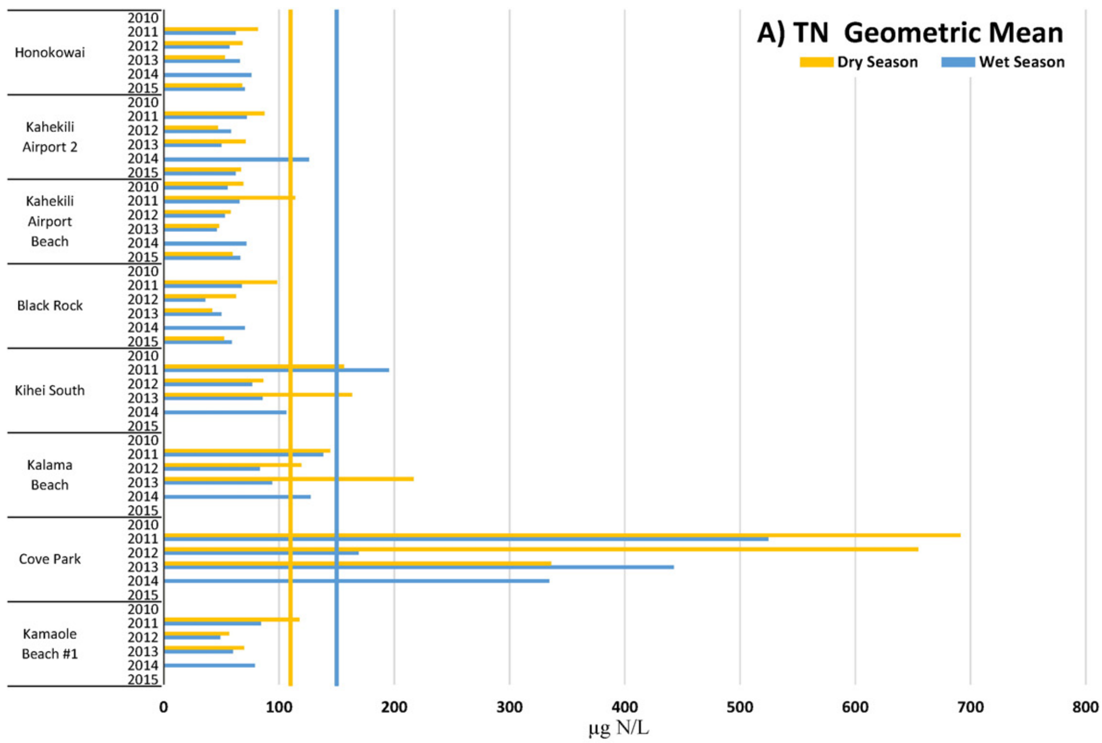
** *The 10% Statistical Threshold Value (STV) is located on the far right of a bell shaped curve where 90% of all sample values would be to the left of that point and 10% would be on the right. If more than 10% of the sample values fall to the right of the 10% STV then this formula will yield a number greater than 100%.*

$$\text{n>2\% STV QIP} = 100 * (\text{n>2\% STV})/(0.02 * \text{number of samples}) \qquad (4)^{***}$$

*** *The 2% STV is chosen so that 98% of samples fall to the left of that point, and 2% fall to the right. If more than 2% of the sample values fall to the right of the 2% STV then this formula will yield a number greater than 100%.*

Taken together, these four formulas yield a composite QIP value which gives us a qualitative idea of how impacted a waterbody is. Since they are unitless, QIPs for different nutrients or pollutants can be compared to one another. In addition, QIPs are merely a crude measure of how well a sparse set of samples conforms to an expected statistical distribution; therefore, they can give a relative impression of which nutrient or pollutant is farthest from meeting its standard, and hence is likely to be the most impactful. The QIP for each WQ variable was calculated for each wet and dry season and for each year. When the individual QIPs are averaged together by year they yield the QIP values shown in Table 2 (see Appendix B for further detail). The goal of this assessment was to qualitatively compare across sites and years using a standardized value. These results are purely comparative in a qualitative context; a detailed statistical assessment was beyond the scope of this paper.

In addition, the QIP values for different sites may be based on samples from non-overlapping years because every site has multiple years where no samples were collected. For example, the TN QIP for Honolua Bay was based on data from August 2006 to December 2007, and February to October 2015, while the TN QIP for Cove Park was based on January 2011 to March 2014 (Figure A1).



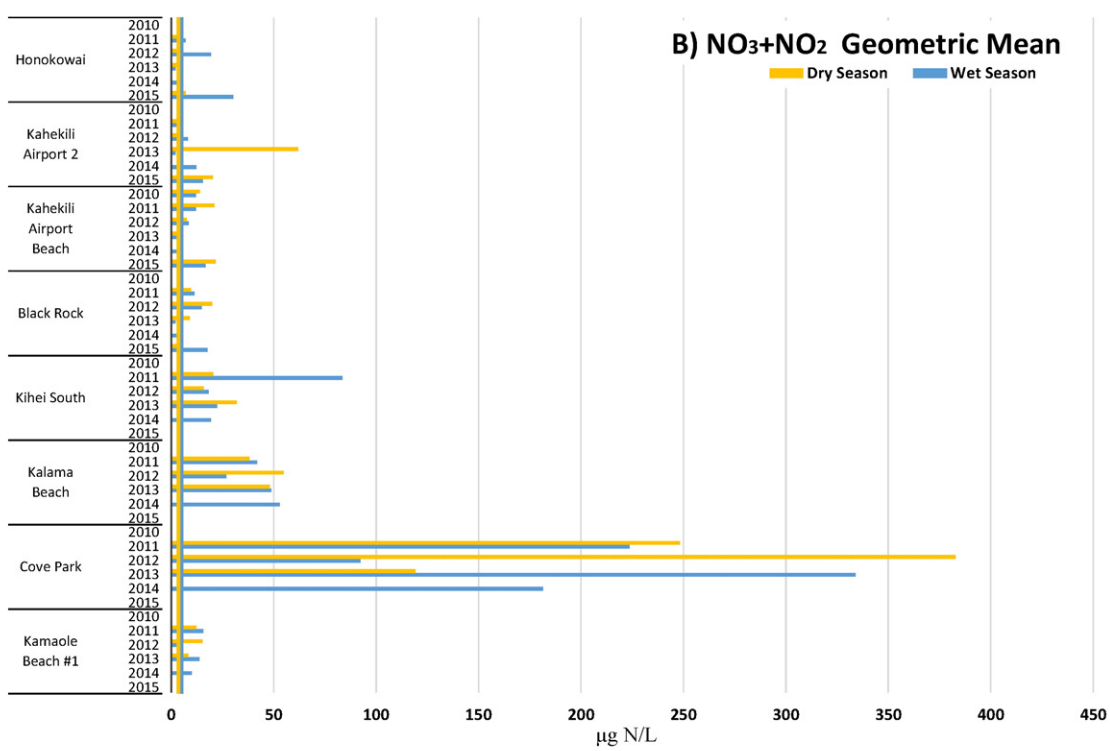


Fig. 2. The geometric means for A) total N (TN), B) $NO_3 + NO_2$, C) NH_4, D) total phosphorus (TP), E) turbidity, and F) Chlorophyll *a*. Bars are divided by season (dry season = light bars; wet season = dark bars) and by year (2010–2015). Sites are ordered from the most northern point to the most southern point of Maui moving from top to bottom. Vertical lines represent the geometric mean standards set by the state of Hawai'i and the Environmental Protection Agency for each criterion*. Bars extending beyond this reference line indicate the site GM exceeded the standard for that season in that year. Light colored vertical lines represent dry standards; dark vertical lines represent wet standards. *See* Table 1 for specific GMS. *HAR §11–54–6(b).

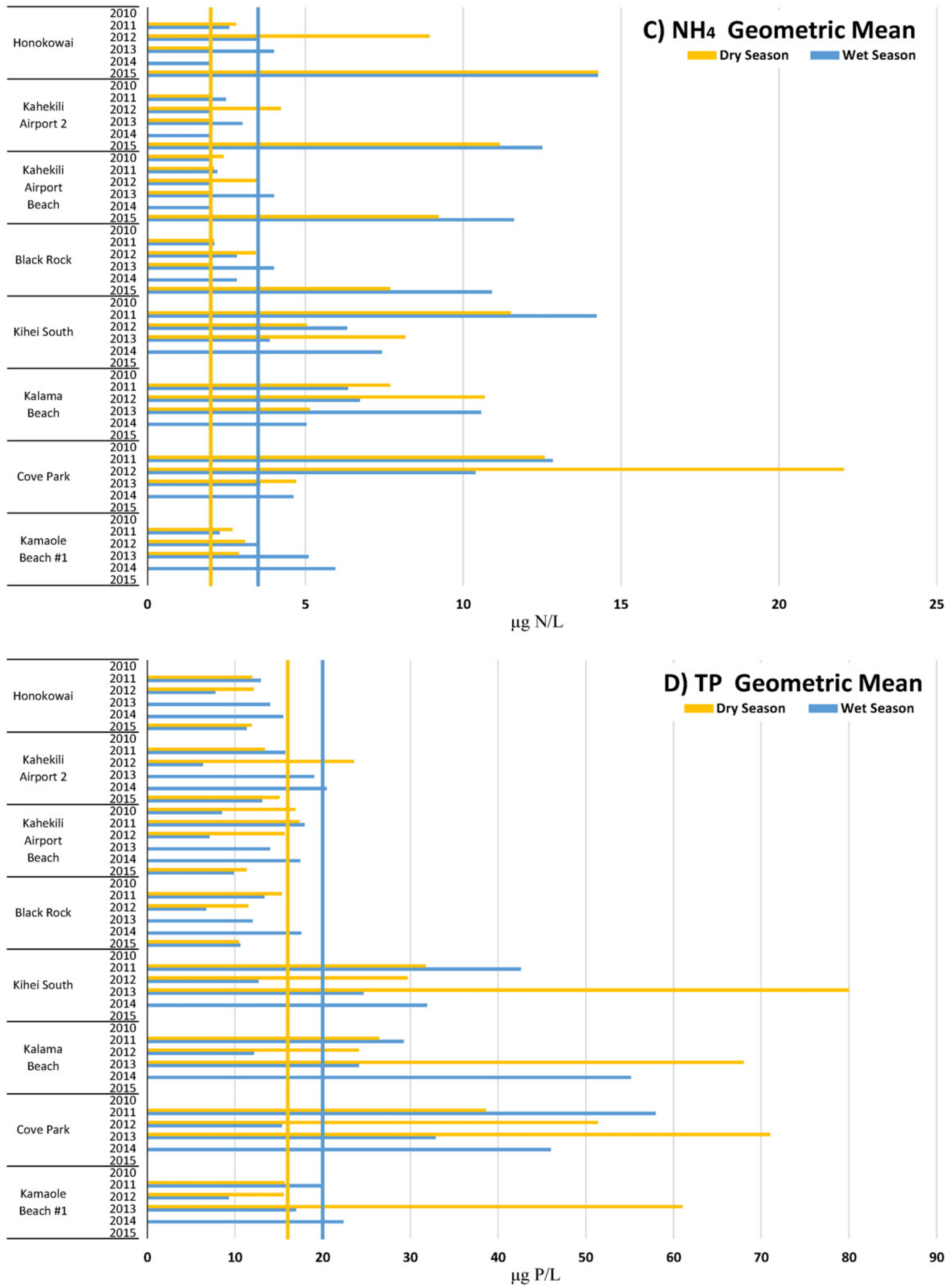


Fig. 2 (*continued*).

3. Results

3.1. Geometric mean comparisons

3.1.1. Total N, $NO_3 + NO_2$, and NH_4

The Kihei WWRF sites had more exceedances of TN, $NO_3 + NO_2$ and NH_4 than the Lahaina WWRF sites (Fig. 2A–C) compared to standards (Table 1). Only NH_4 came close to having the same number of exceedances at both the Lahaina sites and the Kihei sites. Cove Park was noticeably higher in all N concentrations and appeared to be the site of most concern in terms of exceeding GMS. For example, comparing the GMS (Table 1) to Fig. 2A–C, Cove Park was 6.3× higher than the dry season standard in TN (2011 dry season; 691 µg N/L), 109× and 67× higher than the season standards in $NO_3 + NO_2$ (2012 dry

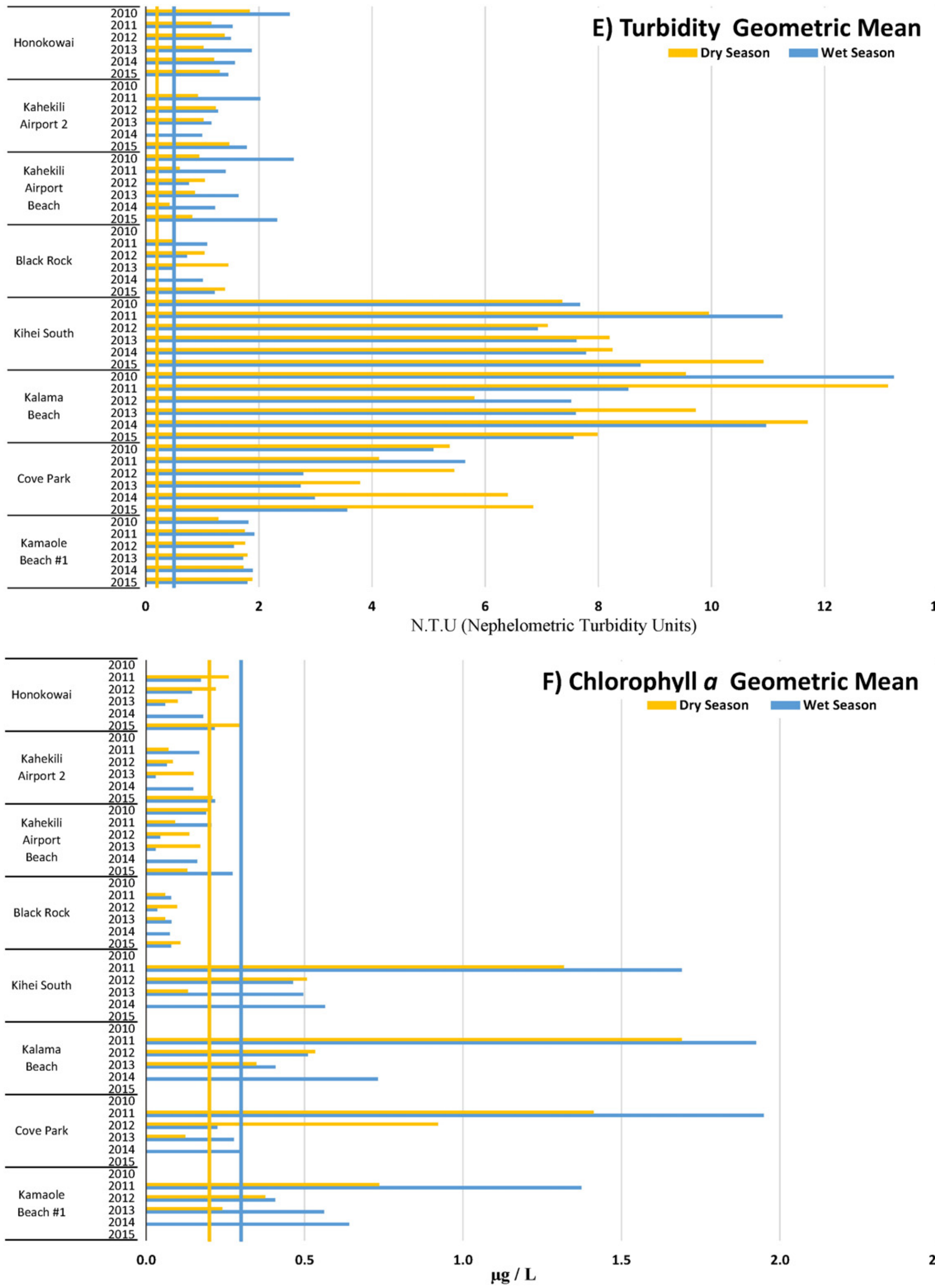


Fig. 2 (*continued*).

season; 383 µg N/L, and 2013 wet season; 334 µg N/L respectively), and 11× higher than the dry standard in NH_4 (2012 dry season; 22 µg N/L).

3.1.2. Total phosphorus, turbidity & Chlorophyll a

Sites near the Kihei WWRF had more exceedances in TP, turbidity and Chlorophyll *a* than sites near the Lahaina WWRF (Fig. 2D–F). Kihei sites exceeded the TP standard by 1.1–5× with a total of 10 exceedances each for both the wet and dry seasons (Fig. 2D); in contrast, there was one exceedance in the wet season and three exceedances in the dry season for Lahaina sites. Turbidity exceeded GMS every year and at every site on the island (Fig. 2E). The sites most impacted by turbidity appeared to be South Kihei, Kalama, and Cove Park which were 22.5×, 26.4× and 11.3× higher than the wet season standard, respectively, and 54.6×, 65.6×, and 34.2× higher than the dry season standard, respectively. In addition, Kihei sites had more Chlorophyll *a* exceedances than Lahaina sites; specifically, wet season measurements ranged from 1.4× to 6.5× the standard (0.41 µg/L at Kamaole Beach #1 to 1.95 µg/L at Cove Park), and dry season

Table 1
The Hawai'i Geometric Mean Standard (GMS) and Statistical Threshold Values (STV) for sites classified as 'coastal segments' according to HAR §11–54–6(b). Total phosphorus (TP) is expressed in μg P/L, total nitrogen (TN), Nitrate + Nitrite ($NO_3 + NO_2$), and ammonia (NH_4) are expressed in μg N/L, turbidity is expressed in N.T.U. (Nephelometric Turbidity Units) and Chlorophyll *a* is expressed in μg/L.

Hawai'i standards	Wet season			Dry season		
	GMS	10% STV	2% STV	GMS	10% STV	2% STV
TN	150.0	250.0	350.0	110.0	180.0	250.0
TP	20.0	40.0	60.0	16.0	30.0	45.0
$NO_3 + NO_2$	5.0	14.0	25.0	3.5	10.0	20.0
NH_4	3.5	8.5	15.0	2.0	5.0	9.0
Turbidity	0.5	1.3	2.0	0.2	0.5	1.0
Chlorophyll a	0.3	0.9	1.8	0.2	0.5	1.0

measurements ranged from 1.2× to 8.5× the standard (0.24 μg/L at Kamaole Beach #1 to 1.69 μg/L at Kalama).

3.2. Qualitative Impact Percentages

The sites with the highest wet and dry season average QIPs for 2004–2015, and therefore the sites of most concern in terms of WQ impairments, were Cove Park, Pohaku, Kaopala Bay, Kalama, and Kihei South (Fig. 3). $NO_3 + NO_2$ and turbidity contributed the most to the high QIP averages at these five sites. Nutrient concentrations appeared to either largely vary by season (TP, NH_4, Chlorophyll *a*) or show little to no difference between seasons (TN, $NO_3 + NO_2$ and turbidity). Overall, the dry season had higher QIPs of Chlorophyll *a*, NH_4, and TP (Fig. 3; Table 2). Interestingly, sites directly next to the Lahaina WWRF had lower QIPs than sites north of the Lahaina WWRF. Black Rock in the wet season came close to meeting nutrient standards (Fig.3; see reference bar).

4. Discussion

The HIDOH has been especially concerned with turbidity in recent years; standards were exceeded in 92% of Maui's marine segments sampled in 2014. Turbidity contributed the most to QIP averages for almost all sites (Fig. 3). Turbidity is caused by excessive sediment altering the amount of light reaching aquatic species. High turbidity can alter primary production, feeding behaviors, reproduction, and survival of species, as well as influence the production and health of phytoplankton and zooxanthellae in corals (Wilber and Clarke 2001). In some cases, turbidity has been directly linked to coral decline (Nemeth and Nowlis 2001). Nutrient loading has negatively affected coastal ecosystems throughout

Table 2
The average Qualitative Impact Percentages (QIPs) for each WQ variable for each site by season (wet vs dry). N = the number of total samples and n = the total number of years sampled included in the average QIP. Sites are arranged from North to South. The Storet Site IDs are consistent with the HIDOH website. http://health.hawaii.gov/cwb/.

Site	Storet site ID	Season	Mean QIP	N (n)	TN	N (n)	TP	N (n)	$NO_3 + NO_2$	N (n)	NH_4	N (n)	Turbidity	N (n)	Chloro-phyll a	N (n)
Honolua Bay		Wet	766	166 (9)	401	26 (3)	391	26 (3)	294	26 (3)	392	26 (3)	1082	36 (9)	280	26 (3)
	707	Dry	1351	249 (10)	759	39 (3)	345	39 (3)	118	39 (3)	1312	39 (3)	1598	54 (10)	757	39 (3)
Fleming Beach South		Wet	700	153 (8)	623	21 (3)	21	21 (3)	1290	21 (3)	363	21 (3)	805	48 (8)	46	21 (3)
	650	Dry	1470	230 (8)	927	35 (2)	100	35 (2)	2428	35 (2)	755	35 (2)	1626	55 (8)	312	35 (2)
Napili		Wet	376	149 (7)	149	27 (3)	19	27 (3)	902	27 (3)	370	27 (3)	567	14 (7)	48	27 (3)
	723	Dry	1302	155 (8)	161	26 (2)	94	26 (2)	1887	26 (2)	726	26 (2)	1508	25 (8)	464	26 (2)
Kaopala Bay		Wet	1537	114 (8)	511	17 (3)	60	17 (3)	2051	17 (3)	260	17 (3)	1978	29 (8)	306	17 (3)
	692	Dry	1905	218 (7)	839	34 (2)	54	34 (2)	2363	34 (2)	890	34 (2)	2212	48 (7)	802	34 (2)
Pohaku		Wet	1428	144 (7)	979	26 (3)	80	26 (3)	2463	26 (3)	250	26 (3)	1750	14 (7)	291	26 (3)
	724	Dry	1760	155 (8)	1293	26 (2)	367	26 (2)	3485	26 (2)	696	26 (2)	1880	25 (8)	767	26 (2)
Honokowai		Wet	467	105 (7)	12	16 (5)	45	16 (5)	414	16 (5)	227	16 (5)	837	25 (7)	15	16 (5)
	725	Dry	996	159 (8)	125	24 (4)	22	23 (3)	161	24 (4)	573	24 (4)	1442	40 (8)	82	24 (4)
Kahekili Airport 2		Wet	205	112 (5)	17	19 (5)	24	19 (5)	388	19 (5)	298	19 (5)	489	17 (5)	11	19 (5)
	733	Dry	481	143 (4)	115	24 (4)	71	23 (3)	803	24 (4)	369	24 (4)	1326	24 (4)	30	24 (4)
Kahekili Airport Beach		Wet	557	219 (10)	10	30 (6)	147	30 (6)	246	30 (6)	169	30 (6)	847	69 (10)	19	30 (6)
	695	Dry	413	257 (10)	100	36 (5)	44	35 (4)	603	36 (5)	291	36 (5)	696	78 (10)	50	36 (5)
Black Rock		Wet	137	94 (5)	9	16 (5)	45	16 (5)	322	16 (5)	225	16 (5)	220	14 (5)	5	16 (5)
	734	Dry	344	137 (4)	115	23 (4)	83	22 (3)	433	23 (4)	312	23 (4)	1029	23 (4)	17	23 (4)
Hanakaoo		Wet	1233	502 (11)	77	16 (3)	27	16 (3)	1357	16 (3)	380	16 (3)	1497	422 (11)	114	16 (3)
	693	Dry	1768	564 (11)	37	21 (2)	85	21 (2)	1433	21 (2)	667	21 (2)	2005	459 (11)	373	21 (2)
Kihei South		Wet	1299	670 (11)	406	42 (6)	246	41 (6)	1138	42 (6)	535	42 (6)	1942	461 (11)	398	42 (6)
	676	Dry	1926	732 (11)	679	47 (5)	626	45 (5)	1208	47 (5)	1109	47 (5)	2544	500 (11)	795	46 (5)
Kalama Beach Park		Wet	1448	137 (8)	37	20 (4)	280	19 (4)	1470	20 (4)	401	20 (4)	2060	38 (8)	382	20 (4)
	679	Dry	2308	126 (9)	437	17 (3)	632	15 (3)	1612	17 (3)	777	17 (3)	2837	44 (9)	737	16 (3)
Cove Park		Wet	1329	131 (7)	778	20 (4)	507	19 (4)	2589	20 (4)	501	20 (4)	1548	32 (7)	304	20 (4)
	703	Dry	1998	115 (8)	1307	17 (3)	1180	15 (3)	3336	17 (3)	1218	17 (3)	2155	33 (8)	773	16 (3)
Kamaole Beach #1		Wet	544	534 (11)	13	19 (4)	68	18 (4)	590	19 (4)	191	19 (4)	712	440 (11)	271	19 (4)
	681	Dry	1183	551 (11)	175	17 (3)	578	15 (3)	644	17 (3)	100	17 (3)	1459	469 (11)	371	16 (3)

Maui with high rates of coral decline and macroalgal blooms occurring next to Maui counties' WWRFs (Dailer et al. 2010; DLNR 2012).

From 1997 to 2008, the County of Maui disposed of approximately 51 billion gallons of partially treated effluent. This effluent, including approximately 3.84 million lbs. of N (Dailer et al. 2010), was pumped into injection wells connected to the nearshore environment. A lawsuit filed in 2012 against the County of Maui focused on the Lahaina WWRF and the subsequent effects on West Maui beaches and ecosystems, particularly the Kahekili Beach Park area. However, the Kihei coast has received less attention despite the fact that it's beaches are also within the same National Marine Sanctuary Boundary, requiring strict federal and state protection of coral reef ecosystems, marine life, and recreational opportunities (US District Court, District of Hawai'i 2012).

We found sites near the Kihei WWRF had more frequent and much greater WQ exceedances than sites near the Lahaina WWRF (Fig. 2). Specifically, Kahekili sites were lower in concentrations for most variables compared to all sites near the Kihei WWRF. In 2012, Kahekili Beach Park was in non-attainment for $NO_3 + NO_2$, turbidity, and NH_4; however, in 2014 it was delisted and is now in attainment for all standards except for turbidity (HIDOH 2012, 2014). In contrast, the sites along the Kihei coast have been listed as impaired for nutrients, turbidity, and Chlorophyll *a* since before 2002 (HIDOH 2002). Of particular concern is Cove Park, directly next to Kalama and at the center of the wastewater plume from the Kihei WWRF. Cove Park was 6.3× higher in TN (2011 dry season), and 109× and 67× higher in $NO_3 + NO_2$ (2012 dry season and 2013 wet season), respectively, than the associated GMS.

Cove Park remains a popular beach for tourists and recreationists who are largely unaware of current WQ impairments. Kalama and Kihei South sites also had much higher concentrations of turbidity, Chlorophyll *a*, and TP concentrations than sites near the Lahaina WWRF. In addition, the Kalama and Kihei South sampling locations reside within a fringing reef, and consequently the reef flat remains relatively shallow for a considerable distance (~100 m) from shore. Because of this, emerging wastewater may be in higher concentrations compared to sites with deeper benthic profiles. Therefore, WQ impairments may be more of a concern in South Maui than previously acknowledged, and perhaps should be given more attention in legislative, management, and policy decisions.

The goal of this paper was to provide a qualitative assessment for West and South Maui WQ concentrations in the context of Hawai'i WQS; however, information on flux estimates or statistical analyses behind the demonstrated trends is beyond the scope of this paper. Detailed assessments of nutrient fluxes on Maui exist elsewhere. Hunt and Rosa (2009) suggested WWRFs are not the only source of nutrient discharge into Maui's nearshore environment; agriculture and forests

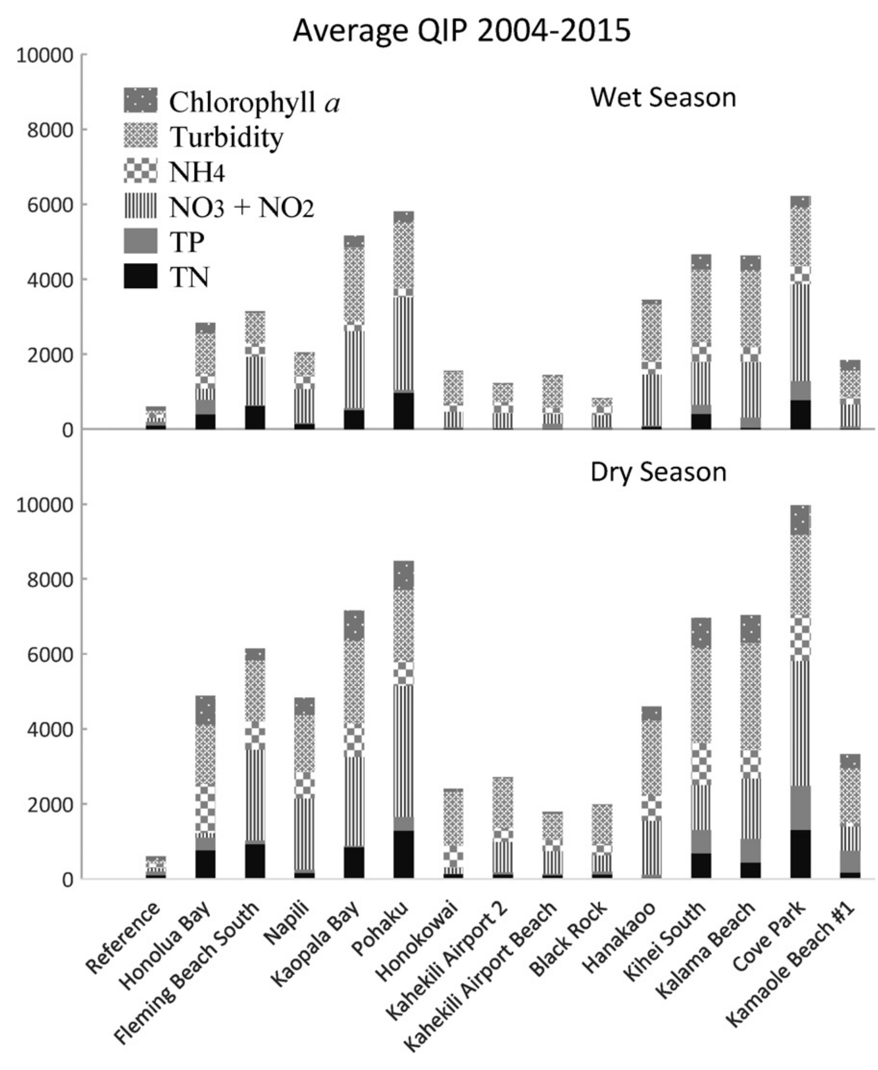


Fig. 3. The QIP factor values averaged across all years (2004–2015) for each site for the wet season (top) and the dry season (bottom). For ease of display, each WQ variable is stacked by site, therefore the y axis is only for scale. The QIP is a standardized way to qualitatively see site impairment but QIP is unitless. The reference QIP bar shows what a site would look like if it was suffering maximum impact yet still attaining water quality standards by the slimmest margin. For example, Black Rock in the wet season is very close to meeting WQS for all variables except for $NO_3 + NO_2$.

are also important nutrient sources. Hunt (2006) reported the total mass of injected nutrients is comparable between both WWRF facilities, but natural or background levels of N flux are 4× higher in Kihei than Lahaina. Because population size and development is similar between the two locations, differences in background N flux are presumably due to higher cover of N-fixing plants in the upland areas of Kihei (Hunt 2006).

Geomorphic and physical mixing differences between locations can also be an important determinant of concentrations. Generally, the fringing reef next to Kihei and Kalama is believed to have poorer water circulation than Kahekili Beach Park which could cause greater accumulation of nutrients on the reef (Storlazzi et al. 2008). Further investigations are necessary to elucidate the reasons behind these trends and allow for the development of more effective management practices.

5. Conclusion

Our results indicate relatively higher nutrient concentrations and more numerous WQ exceedances at sites near the Kihei WWRF. The pending Lahaina WWRF lawsuit will determine civil penalties and the required 'next steps' that the County of Maui will need to take in order to comply with the CWA. An important goal would be for Maui County to take into consideration not only the Lahaina WWRF, but also the Kihei and Kahului WWRFs when updating infrastructure and developing novel Hawai'i practices and procedures for dealing with wastewater disposal. We propose that stakeholders, managers, and scientists conduct further investigations into the influence of the Kihei WWRF on the surrounding marine environment. Coral reefs are a valuable economic and ecological resource and are currently in decline throughout Hawai'i. It is of fundamental importance to use WQ assessments and other methods to quickly assess ecological threats in order to set management priorities and preserve the integrity of coral reefs for future generations.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marpolbul.2015.12.047.

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