RECEIVED
02/18/2025
2:42 pm
STATE OF HAWAII
LAND USE COMMISSION

Mākena Golf & Beach Club
2024 annual water quality monitoring report

January 19, 2025 **_Final_** *AECOS* No. 1535AB

Allen Cattell, Ph.D. and E. B. Guinther
AECOS, Inc.
45-939 Kamehameha Highway, Suite 104
Kāneʻohe, Hawaiʻi 96744
Phone: (808) 234-7770 Email: Cattell@aecos.com

Introduction

This annual report of the water quality monitoring program for Mākena Golf & Beach Club (MG&BC) satisfies a requirement stipulated in Condition No. 10, Declaration of Conditions pertaining to the Amendment of the District Boundary, as imposed by the State Land Use Commission and dated April 17, 1998. The County of Maui, Zoning Ordinance 3613, Condition 19 includes a similar requirement.

The primary goals of the water quality monitoring program are to: (1) assess the degree that fertilizers used on land to enhance golf course turf growth and resort landscaping, as well as any other plant nutrient sources, leach to groundwater and subsequently discharge into nearshore waters off the MG&BC property; (2) establish that delivery of these nutrients into the nearshore zone is occurring; and (3) determine if subsequent water quality has measurable impacts on biological community structure in the nearshore marine environment.

Site Description

Coastal waters south of the mouth of Kapuaikea Stream at the north end of MG&BC property and including Mākena Bay and Maluaka Bay (Figures 1 and 2), are designated as "Class A, open coastal waters" in State of Hawaiʻi, water quality standards (HDOH, 2021). These waters are included on the HDOH 2024 list of impaired waters in Hawaiʻi prepared under Clean Water Act §303(d) and listed as impaired for nitrate+nitrite, ammonium, total nitrogen, and turbidity (HDOH, 2024). The so designated nearshore waters are listed as "Category 3"—meaning that insufficient data and/or information exist to make use-support determinations—and as "Category 5"—meaning that available data and/or information indicate that at least one designated use is not supported or is threatened, and a Total Maximum Daily Load (TMDL)[1] study is needed.

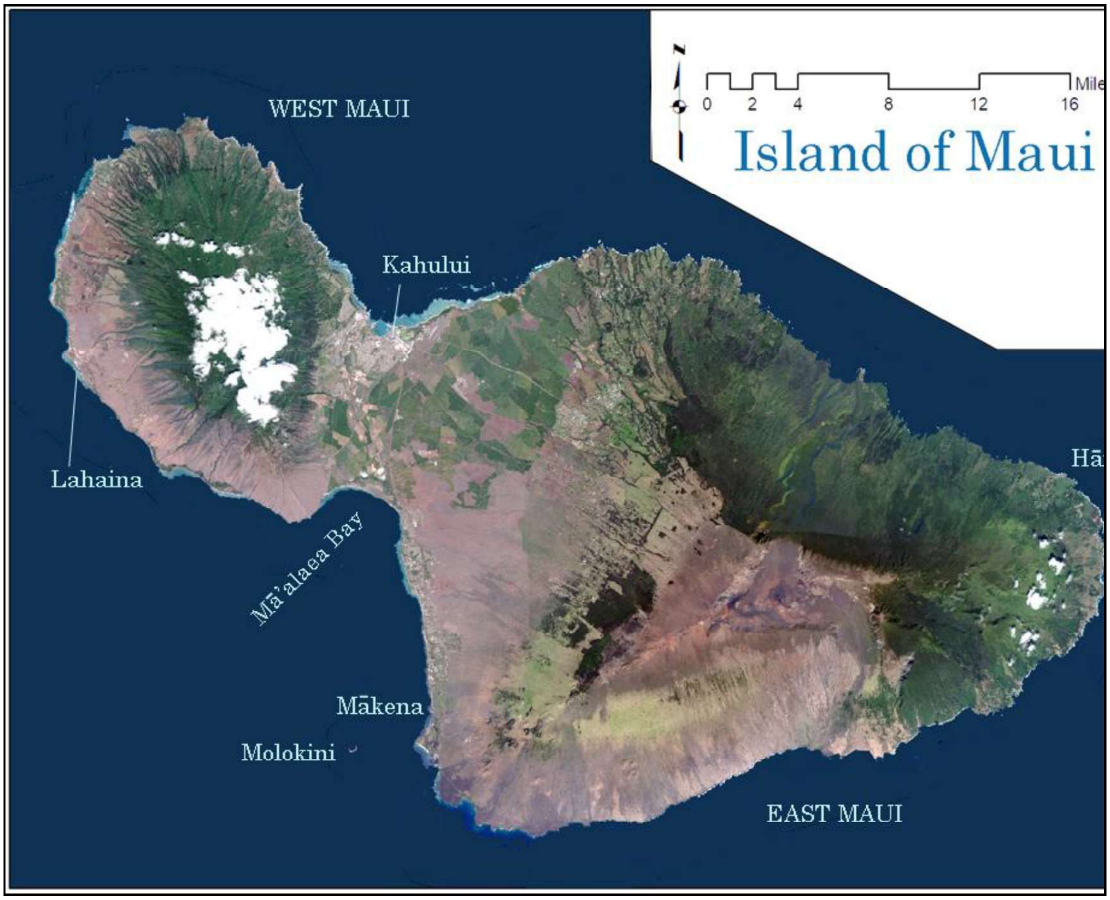

Figure 1. Island of Maui satellite image showing location of Mākena on the western coast of East Maui, south of Ma'alaea Bay.

Coastal waters from Pu'u Ola'i south (Figure 2) are designated as "Class AA, open waters" in state water quality standards (HDOH, 2021). These waters are also included on the list of impaired waters in Hawai'i prepared under Clean Water Act §303(d) for nitrate+nitrite, ammonium, total nitrogen, and chlorophyll α (HDOH, 2024). These nearshore waters are listed as "Category 3" and "Category 5" water areas, and a Total Maximum Daily Load (TMDL) study is needed.

[1] TMDL studies are done to establish limits on point-source discharges of substances causing impairments to water quality of aquatic environments. The term "needed" means "has not been done".

Docusign Envelope ID: 6A06E70E-F032-42F7-A503-24C08DCE14C3

Water quality parameters of particular interest for purposes of the monitoring program are termed plant nutrients[2]. Nutrient enrichment of nearshore coastal waters from groundwater intrusion and storm water runoff can enhance nuisance algae production (HDLNR, 2020) and have a deleterious impact on corals and other biological components in Hawaiian coastal waters (Laws et al., 2004; Fabricius, 2005; MRC, 2011; *AECOS*, 2016, *AECOS,* 2020.).

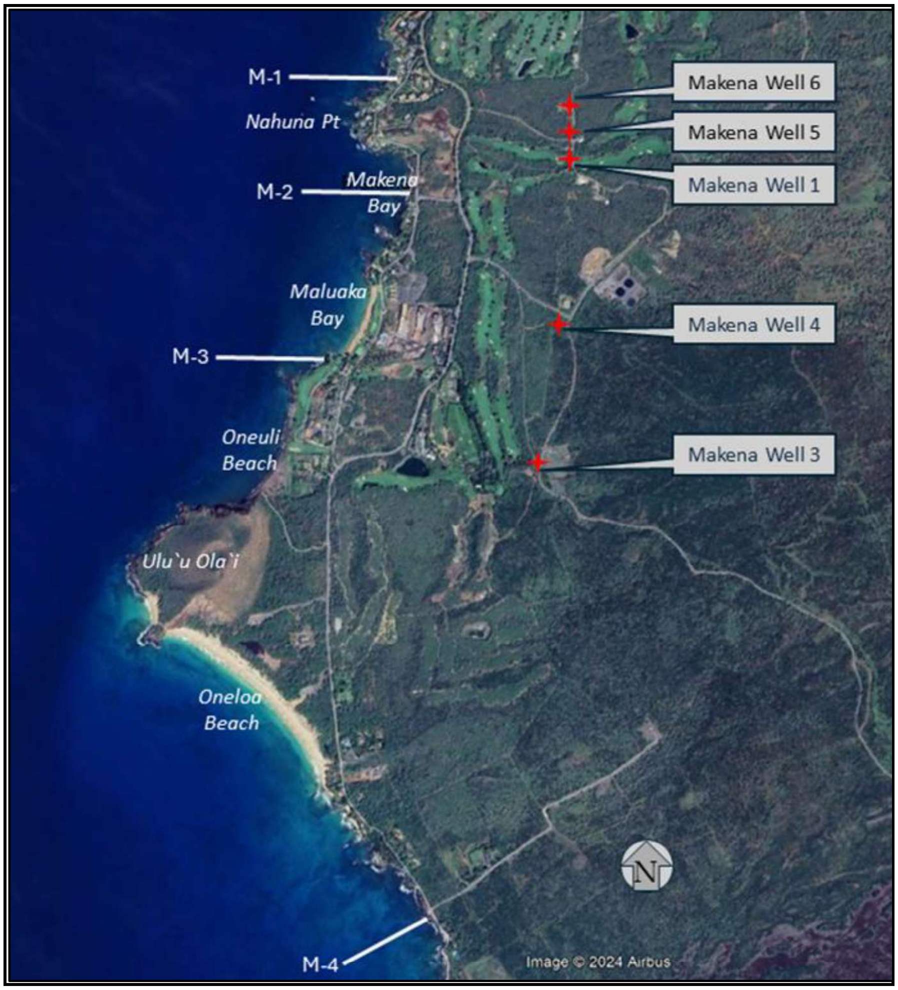

Figure 2. Location of water quality monitoring transects (M-1 through M-4) and resort irrigation wells.

2 "Plant nutrients" are nitrogen and phosphorus chemical compounds that promote plant growth, including algal growth in the marine environment.

Methods

The *AECOS* water quality monitoring program, beginning in June 2018 (*AECOS*, 2018), includes quarterly sampling along three transects in nearshore marine waters adjacent to MG&BC (transects “M-1”, “M-2”, and “M-3”) and a control transect (“M-4”) located far south of the resort (Fig. 2, above) near the northern boundary of ʻAhihi-Kinaʻu Natural Area Reserve in an area of Maui with minimal ongoing land use. Four stations are sampled along each transect at distances of 2 m, 10 m, 50 m, and 100 m from shore for a total of 16 stations.

Water quality samples are also collected at five irrigation wells used for resort golf course and landscaping irrigation: Seibu wells 6, 1, 3, 4 and 5 (Fig. 2). Our program emphasizes monitoring of MG&BC management practices that might influence coastal water quality.

Table 1. Analytical methods and instruments used for water quality analysis.

Analysis	Method	Reference	Instrument
Temperature	SM 2550B	SM (2017)	YSI ProPlus DO meter thermistor
Salinity	SM 120.1	SM (2017)	Accument AB200
pH	SM 4500H+	SM (2017)	pH pHep HANNA meter
Dissolved Oxygen (DO)	SM 4500-OG	SM (2017)	YSI ProPlus DO meter
Turbidity	EPA 180.1	USEPA (1993b)	Hach 2100Q Turbidimeter
Ammonium (NH_4)	EPA 349	USEPA (1997a)	Seal AA3 Auto Analyzer
Nitrate+Nitrite (NO_3+NO_2)	EPA 353.2	USEPA (1993a)	Seal AA3 Auto Analyzer
Silicates	EPA 360.0	USEPA (1997c)	Seal AA3 Auto Analyzer
Total Nitrogen (TN)	EPA 353.4	USEPA (1993a)	Seal AA# Auto Analyzer
Ortho-Phosphate (PO_4)	EPA 365.5	USEPA (1997b)	Seal AA3 Auto Analyzer
Total Phosphorus (TP)	EPA 365.5	USEPA (1997b)	Seal AA3 Auto Analyzer
Chlorophyll α (Chl. α)	SM-10150	SM (1998)	Turner Fluorometer

Temperature, salinity, pH, and dissolved oxygen (DO) are measured *in situ*. Water samples are collected, chilled, and returned to the *AECOS* laboratory for additional analyses. The following parameters are measured from these samples in the laboratory: salinity, turbidity, ortho-phosphate, ammonium, nitrate+nitrite, total nitrogen (total N or TN), total phosphorus (total P or TP), and chlorophyll α. Table 1 (above) lists instruments and analytical methods used for these field and laboratory analyses.

The PacIOOS Regional Ocean Modeling System (PacIOOS, 2024) is used to estimate coastal water currents in the nearshore waters off Mākena at the time of a sampling event.

Results

Water quality results from 27 sampling events conducted between the beginning of the water quality monitoring program in June 2018 and November 2024 are summarized in Tables 2 and 3 by comparing means of "historic" (2018 - 2023) annual program results with 2024 means. Values rendered in italics exceed State of Hawaiʻi water quality standards (HDOH, 2021) for open coastal waters; the standards are shown along the bottom of each table. Note that the state standards include two sets of criteria: (1) so-called "wet" criteria for coastal waters receiving more than 3 million gallons of freshwater discharge per day (mgd) per shoreline mile; and (2) "dry" criteria for waters receiving less than 3 mgd of freshwater water discharge per shoreline mile. Mean annual rainfall in the Mākena area is less than 15-in per year (Giambelluca et al. 2013), so results in these tables are appropriately compared with state "dry" criteria. The dry criteria are more stringent than the wet criteria for most parameters because land runoff (natural) influences are expected to be less off dry coasts.

Salinity means were very slightly higher in 2024 along all four transects compared with historic means and tended to increase with distance from shore. Mean salinity values increased progressively between Transect M-1 and Transect M-3. Water temperatures, on the other hand, showed little change with distance from shore and mean values were slightly lower than historical data. pH means were slightly elevated along all four transects in 2024 compared with historic data. DO saturation mean values were very slightly low compared with historic means on all four transects. Turbidity means were low along all four transects during 2024 and tended to decrease with distance from shore. Chlorophyll α geometric means tended to decrease with distance offshore and were elevated compared with historic data.

Salinity, temperature, pH, and DO saturation met state criteria during both historic and 2024 results at all stations and transects. Turbidity and chlorophyll α geometric mean values exceeded state criteria at all stations along all four transects for both historic and 2024 results.

Table 2. Station by station comparison of historic (2018 - 2023) means (*n* = 27) with 2024 means (*n* = 4) for physical parameters and chlorophyll α.

Transect	DFS† (m)	Salinity (ppt)		Temperature (° C)		pH		DO (% Sat.)		Turbidity‡ (NTU)		Chl. α‡ (µg/L)	
		Historic	2024	Historic	2024	Historic	2024	Historic	2024	Historic	2024	Historic	2024
M-1	2	34.04	33.94	26.5	25.6	8.18	8.42	102	105	*1.48*	*0.91*	*0.73*	*1.17*
	10	34.22	34.59	26.3	25.5	8.21	8.41	105	103	*0.87*	*0.61*	*0.51*	*0.69*
	50	34.32	34.80	26.3	25.6	8.21	8.39	101	95	*0.77*	*0.48*	*0.42*	*0.50*
	Means	**34.27**	**34.57**	**26.3**	**25.6**	**8.20**	**8.38**	**101**	**100**	***0.91***	***0.67***	***0.49***	***0.69***
M-2	2	34.23	34.57	26.4	25.8	8.17	8.37	96	94	*1.86*	*1.08*	*0.46*	*0.58*
	10	34.27	34.90	26.3	25.7	8.19	8.37	95	92	*1.25*	*0.73*	*0.37*	*0.41*
	50	34.35	34.77	26.3	25.7	8.19	8.35	95	91	*0.83*	*0.78*	*0.31*	*0.33*
	100	34.53	35.06	26.3	25.6	8.18	8.36	95	90	*0.54*	*0.43*	*0.25*	*0.32*
	Means	**34.35**	**34.82**	**26.3**	**25.7**	**8.18**	**8.36**	**95**	**92**	***1.12***	***0.75***	***0.35***	***0.41***
M-3	2	34.17	34.81	26.3	25.6	8.18	8.36	103	100	*0.75*	*0.49*	*0.54*	*0.66*
	10	34.40	34.95	26.3	25.6	8.17	8.36	100	93	*0.57*	*0.39*	*0.39*	*0.39*
	50	34.53	34.98	26.3	25.7	8.17	8.36	98	98	*0.42*	*0.31*	*0.29*	*0.30*
	100	34.70	34.89	26.3	25.6	8.17	8.34	95	89	*0.39*	*0.25*	*0.23*	*0.25*
	Means	**34.45**	**34.91**	**26.3**	**25.6**	**8.17**	**8.36**	**101**	**95**	***0.53***	***0.36***	***0.36***	***0.40***
M-4	2	34.31	34.65	25.9	25.0	8.13	8.33	101	99	*1.22*	*0.95*	*0.59*	*0.64*
	10	34.38	34.68	25.9	25.0	8.13	8.33	100	99	*1.01*	*0.81*	*0.48*	*0.68*
	50	34.64	34.73	25.9	25.5	8.12	8.32	98	94	*0.62*	*0.54*	*0.31*	*0.57*
	100	34.78	34.93	26.0	25.2	8.08	8.33	94	91	*0.45*	*0.39*	*0.25*	*0.33*
	Means	**34.53**	**34.75**	**25.9**	**25.2**	**8.12**	**8.33**	**98**	**96**	***0.82***	***0.67***	***0.41***	***0.55***
Dry Standard		**+/- 10%**		**+/- 1C°**		**7.6–8.6**		**≥75%**		**≤0.20 NTU**		**≤0.15 µg/L**	

† distance from shore ‡ geometric mean *italics exceed standard*

Nitrate+nitrite geometric mean concentrations in 2024 (Table 3) were elevated along all four transects compared with historic means and tended to decrease with distance from shore, as is the case with the historic means. Nitrate+nitrite means for both historic and 2024 data also decreased from Transect M-1 through

Table 3. Station by station comparison of historic (2018 - 2023) geometric means (*n* = 27) with 2024 geometric means (*n* = 4) for phosphorus, nitrogen and silicate compounds.

Transect	DFS† (m)	NO_3+NO_2 (µgN/L)		NH_4 (µgN/L)		TN (µgN/L)		PO_4 (µgP/L)		TP (µgP/L)		Silicates (µg/L)	
		Historic	2024	Historic	2024	Historic	2024	Historic	2024	Historic	2024	Historic	2024
M-1	2	*39*	*72*	*18*	*38*	*164*	*258*	3.1	5.0	11	9	219	392
	10	*34*	*42*	*18*	*32*	*143*	*188*	2.8	4.4	8	9	193	219
	50	*30*	*40*	*17*	*32*	*138*	*196*	2.9	4.5	10	9	202	218
	Means	***30***	***47***	***19***	***36***	***142***	***205***	**2.8**	**4.4**	**9**	**9**	**189**	**255**
M-2	2	*23*	*36*	*14*	*37*	*115*	*171*	4.4	7.2	*22*	12	277	328
	10	*21*	*28*	*16*	*43*	*113*	*160*	3.9	6.5	*12*	11	239	246
	50	*19*	*28*	*14*	*40*	*111*	*168*	3.4	7.1	*9*	12	206	321
	100	*16*	*19*	*18*	*31*	*106*	*143*	2.6	4.6	*10*	10	172	152
	Means	***20***	***28***	***16***	***38***	***111***	***160***	**3.6**	**6.4**	**13**	**11**	**223**	**262**
M-3	2	*30*	*34*	*21*	*41*	*146*	*174*	3.4	9.8	8	10	219	263
	10	*27*	*30*	*13*	*32*	*123*	*158*	3.2	10.0	7	10	151	226
	50	*17*	*22*	*20*	*32*	*113*	*141*	2.8	9.2	9	9	114	150
	100	*11*	*15*	*14*	*24*	*105*	*149*	2.5	8.9	8	9	86	112
	Means	***21***	***25***	***17***	***32***	***122***	***155***	**3.0**	**9.5**	**8**	**9**	**142**	**188**
M-4	2	*12*	*22*	*16*	*25*	99	111	3.3	6.7	8	12	338	390
	10	*12*	*22*	*24*	*39*	99	*126*	3.1	6.3	9	11	282	370
	50	*8*	*14*	*22*	*25*	92	105	2.4	6.6	8	10	197	238
	100	*6*	*13*	*19*	*30*	88	108	2.4	5.4	6	12	90	165
	Means	***10***	***18***	***20***	***30***	**94**	**113**	**2.8**	**6.3**	**8**	**11**	**227**	**290**
Dry Standard		**≥3.5 µgN/L**		**≥2µgN/L**		**≥110 µgN/L**		**ns**		**≥16µgP/L**		**ns**	
† distance from shore		*italics exceed criteria*						ns - no standard					

M-4. Geometric mean ammonia concentrations in 2024 were elevated along all four transects and demonstrated no apparent trend with distance from shore, but were lowest at the control Transect M-4. Total nitrogen geometric means in 2024 were elevated along all four transects, compared with historic means and tended to decrease with distance from shore, as did the historic data. Ortho-phosphate geometric means for 2024 were notably elevated along all four transects compared with historic means, but total phosphate means were more or less right around the historic TP means. Ortho-phosphate geometric means for 2024 tended to decrease with distance from shore, a pattern not really seen in the 2024 TP means nor the historic TP means . Silicate means were elevated during 2024 along all four transects.

Discussion

Based on our experience, the nitrogen and phosphorus moieties exceeding state nutrient criteria, and criteria established for turbidity and chlorophyll α in Hawaiian nearshore waters is more the common occurrence than the exception. Nutrient enrichment of a specific coastal water body can occur from a variety of causes: (1) groundwater intrusion[3]; (2) resuspension of bottom sediments; (3) biological excretion products plus other biological recycling; (4) longshore current transport from other areas; and (5) land surface runoff during storm events (includes enhanced input from stream freshets). Turbidity is typically elevated by land runoff and by resuspension of bottom sediments due to wind and wave action in shallow water near shore. State water quality criteria account for these typical influences by differentiating between "open coastal waters" (nearshore; between the shore and the 183-m [600-ft] depth contour) and "oceanic waters" (offshore, beyond the 183-m depth contour) and distinguishing between "wet" and "dry" coasts (HDOH, 2021). An exception is made for waters off the Kona coast where special criteria have been developed to account for the considerable groundwater input there (HDOH, 2021). The majority of Hawaiian coastal waters, including those off Maui, are subject to criteria that were developed over 50 years ago and in need of re-evaluation.

Nearshore Waters

As noted above, groundwater is a demonstrable source of soluble nutrients in nearshore coastal waters (Laws et al., 2004; MRC, 2011; *AECOS*, 2016, 2018, 2019). The historic (2018 through 2023) and 2024 geometric means for nitrate+nitrite and ortho-phosphate concentrations are shown in Figure 3 along each of the four transects. The most notable features of these data are: (1) 2024 station results (green circles) had generally higher salinities; (2) historic data (red circles) demonstrated a strong correlation between salinity and nitrate+nitrite (as indicated by R^2 values[4]), especially along all transects except

[3] Groundwater, in comparison to marine receiving water, is characterized by very low salinity and typically high soluble nutrient content.

[4] The coefficient of determination or goodness of fit (R^2 value) in these graphs is an estimate of how much of the variability in mean nutrient results can be attributed to sample salinity. The R^2 values and best-fit lines are shown for the historic data sets.

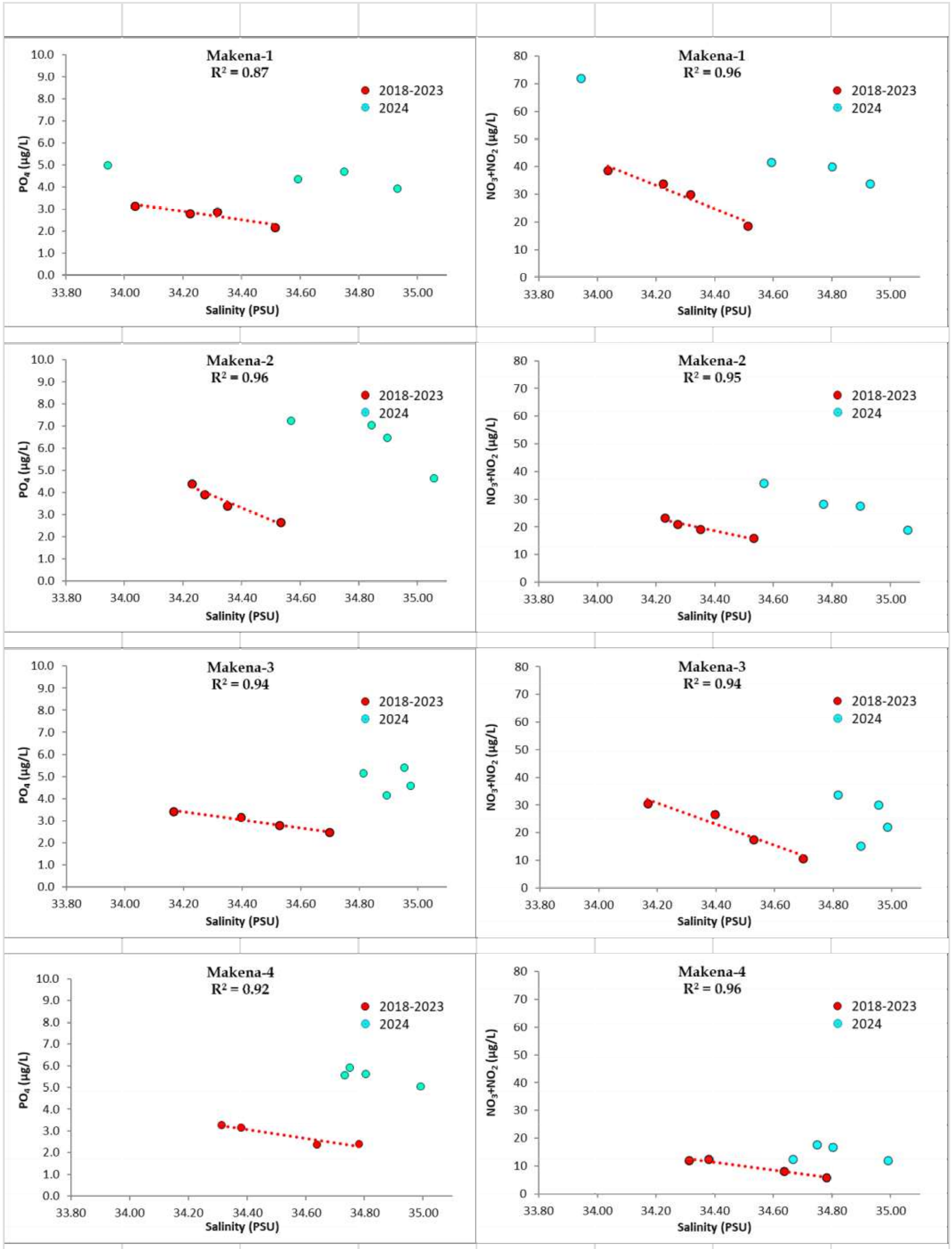

Figure 3. Distribution of historic (2018-2023) and 2024 ortho-phosphate transect means (left) and nitrate+nitrite transect means (right) as a function of salinity.

M-1. These results indicate low salinity groundwater as the primary source of nitrate+nitrite in the nearshore waters. Ortho-phosphate, on the other hand, is available from groundwater and, presumably, other sources such as sediment in shallow nearshore waters. Ammonium (not graphed) demonstrates little to no significant relationship to salinity and is likely unrelated to groundwater influx.

We know that low salinity groundwater enters nearshore waters off MG&BC and entrained nutrients can also enter the monitoring area with longshore water currents that are influenced by tide and wind. Figure 4 shows the Pacific Islands Ocean Observing System modeling results (PacIOOS, 2024) estimate of the direction and speed of these currents and indicate the morning currents (0200 through 1100 hours) during each sampling event in 2024. Note that the flow patterns for each date are similar: some portion of each flow regime is generally from northerly to southerly. In the past, southerly to northerly flow has occurred, but not on any of the 2024 events.

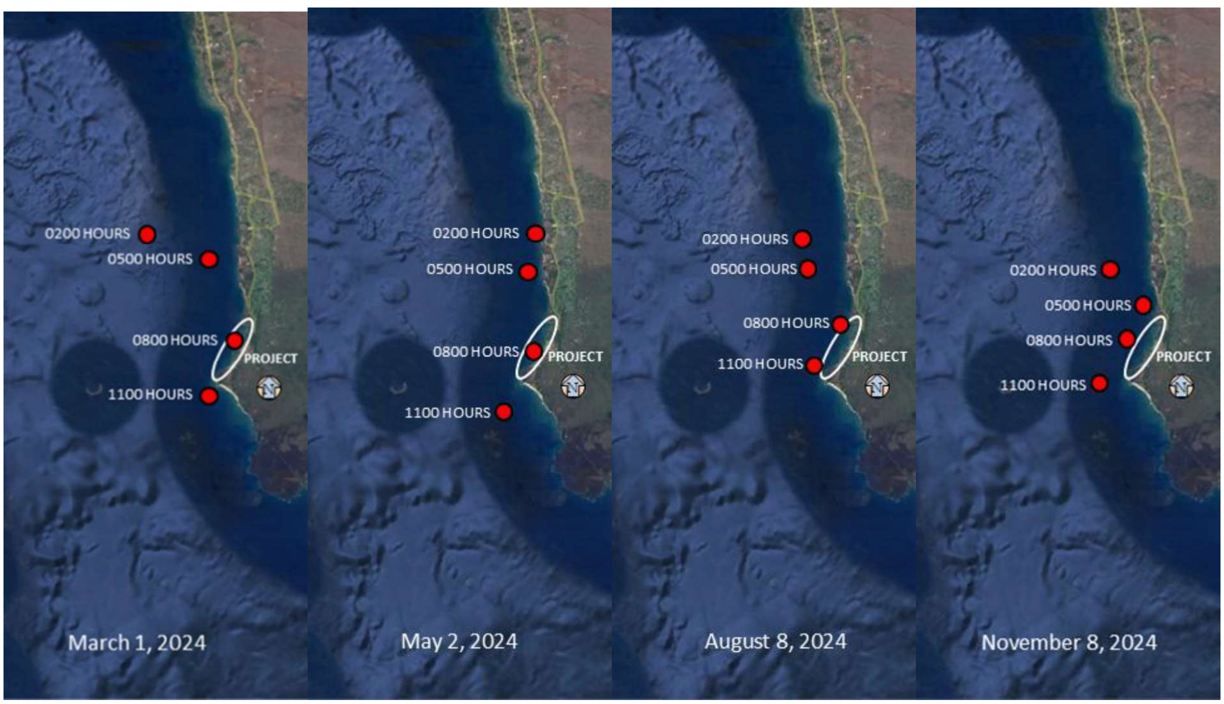

Figure 4. Estimated nearshore currents prior to sampling (0200 & 0500 hours) and during and after sampling (0800 & 1100 hours) based on PacIOOS calculations (PacIOOs, 2024).

Water Supply Wells

We are tracking monthly MG&BC turf fertilization amounts and irrigation rates (data provided by MG&BC) along with nutrient concentrations in the irrigation supply wells (shown in Table 4). Nitrate+nitrite means are high compared with both ortho-phosphate and ammonium in these well waters. Only nitrate+nitrite in the groundwater is likely to be detected as it seeps into nearshore marine waters where it mixes into the seawater. Ortho-phosphate, and even more so, ammonium, would be diluted to non-detectable levels very near to the shore.

Table 4. Annual geometric mean soluble nutrient concentrations and mean salinity values in well water for golf course and landscaping irrigation during *AECOS* sampling events.

Year	PO_4 (µgP/L)	NO_3+NO_2 (µgN/L)	NH_4 (µgN/L)	Salinity (PSU)
2018	39	1806	17	1.25
2019	40	1569	18	1.38
2020	64	1755	15	1.25
2021	64	1786	28	1.33
2022	64	1786	28	1.33
2023	59	1743	47	1.37
2024	58	1989	37	1.39
Grand Mean	**55**	**1776**	**27**	**1.33**

Sources of Groundwater Nutrients in Mākena Coastal Waters

The mean distribution of nutrients, especially nitrate+nitrite, along all transects demonstrate decreasing concentrations with distance from shore, and as might be expected, are mirrored by increasing salinity offshore. This information tells us that groundwater seepage/intrusion is a source of nitrate+nitrite in the nearshore waters. The nutrients in groundwater at MG&BC have two possible origins: (1) a remote source: present in groundwater that originates upslope of the resort and that can be measured in well water; and (2) a local source: seepage of MG&BC excess irrigation water into the groundwater. Brackish water pumped from the several wells is used to irrigate MG&BC grounds and the North Golf Course. The golf course, an 18-hole facility encompassing 91.8 ac (37.2 ha) of MG&BC property, is irrigated, and fertilized on a regular basis using water from three wells, Seibu Well 3, Seibu Well 4, Seibu Well 6, and sometimes Seibu Well 5 (Fig. 2). Water supplied from Seibu Well 1 is used to irrigate landscape vegetation along Mākena Alanui Road.

Irrigation and Fertilizer Tracking

During normal MG&BC operations, R-1 effluent from the Mākena Waste Water Reclamation Facility (WWRF) used to be pumped into No. 10 Lake, where it mixed with well water, and then used to supply water for irrigation purposes. At the present time, the WWRF is not operational because MG&BC has been closed for redevelopment since 2017. Only a controlled-release nitrate+nitrite fertilizer is used to fertilize the golf course turf; phosphorus-containing fertilizers are used several times a year in small quantities.

Water and nutrients not directly assimilated by golf course turf and other vegetation during irrigation (or water loss to evapotranspiration), filter down through the soil to eventually reach local groundwater. We can assume that this excess irrigation water does not remix with water drawn from the wells for at least two reasons: 1) irrigation occurs mostly downslope of all wells with excess irrigation water moving seaward upon reaching groundwater; and 2) well water is drawn from a depth of 200 ft or more below ground, far below the groundwater surface.

Most ortho-phosphate in irrigation water not taken up by the turf grasses is adsorbed to subsurface soil particles (Busman et al., 2002; Laws et al., 2004) and effectively lost to the groundwater nutrient pool. Nitrogen on the other hand, may change form in subsurface soils and groundwater, but is typically present as soluble nitrate+nitrite in groundwater. Groundwater movement is towards the ocean shore, so eventually this water with its soluble nutrients enters nearshore waters, resulting in nutrient enrichment or "subsidy".

We track turf and landscape fertilization/irrigation data provided by MG&BC monthly. Nutrients are measured in irrigation supply wells on each quarterly sampling event, and averaged over the year, are assumed to be representative of the nutrient concentration of the irrigation water being applied. However, most is taken up by turf grass and other plants (or otherwise lost). A U.S. Geologic Survey report estimates that only about 20% (as an average for nitrogen fertilizer applied on Maui golf courses) actually reaches the groundwater (USGS, 2018) and we refer to this as the "residual" concentration.

Table 5 presents a comparison of estimated groundwater "residual" concentrations with nearshore (2-m stations) nitrate+nitrite concentrations. In this table, the residual is given for each monitoring year as an annual mean. The concentrations at each 2-m station are calculated as expected concentrations utilizing the inverse relationship (described below) that exists between salinity and nitrate+nitrite in these waters.

Table 5. Estimated arithmetic means for annual nitrate+nitrite fertilizer residual amounts and calculated total daily nitrate+nitrite subsidy at 2 m stations on monitoring transects.

	Nitrate+Nitrite Residual	Station nitrate+nitrite subsidy			
Date	**Amounts**	**M-1**	**M-2**	**M-3**	**M-4**
Year	**Annual (µg/L)**	**Nitrate+Nitrite (µg/L)**			
2018	397	0	0	47	0
2019	237	27	11	40	0
2020	316	9	0	51	0
2021	687	0	0	4	0
2022	678	0	0	0	0
2023	465	11	0	0	0
2024	324	12	0	0	0
Grand Mean	**474**	**8**	**2**	**20**	**0**

We obtain a rough estimate of the nitrate+nitrite subsidy to the nearshore waters by first calculating the salinity reciprocal (*Sw*) for the Seibu well data and this becomes our salinity factor for the contribution of groundwater seeping out at the shore. The amount of nitrate+nitrite expected in the nearshore from groundwater should be a function of the proportion of groundwater present, calculated using the equation:

$$\textit{Expected groundwater contribution} = \frac{Ss \ x \ C}{Sw}$$

Where:

Ss = Salinity reciprocal at 2 m stations;

C = Mean monthly nitrate+nitrite concentration for all Seibu wells;

Sw = Mean salinity reciprocal for Seibu wells.

Utilizing the inverse relationship between salinity and nitrate+nitrite in these waters, a nitrate+nitrite subsidy at the shore is obtained by subtracting this calculated expected contribution from the actual (measured) nitrate+nitrite concentration on 2 m stations. Although transect M-4 is not in the same nearshore area as MG&BC, we make the assumption that the groundwater in that area can be represented by the Seibu well data. Negative values are sometimes generated, but as these are meaningless, they are presented as zero (no subsidy) in Table 5

Of course, we have no direct knowledge of when a fertilizer application on the land might be expressed in groundwater seeping out at the shore, if at all. The subsidies shown in Table 5 are certainly very rough and at best may be an indication of the magnitude of the groundwater influence. The lowest annual mean fertilizer residual estimate occurred in 2019 when nitrate+nitrite concentrations were highest at all 2 m stations except Transect M-4 (*AECOS*, 2019). The highest mean fertilizer residual fertilizer amount occurred in 2021 and 2022 when nitrate+nitrite concentrations were lowest at all 2 m stations. Many more samples will be required before this approach can generate statistically meaningful results, but trends are becoming apparent.

Fates of Groundwater Nutrients in Mākena Coastal Waters

Nutrients infiltrating to coastal waters have important implications regarding biological assemblages in these waters. For example, growth of marine benthic algae in Hawaiian coastal waters is typically regulated by nutrient supply, usually dissolved forms of inorganic nitrogen (nitrate, nitrite, and/or ammonium) or phosphorus (ortho-phosphate) and referred to as dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP). Typically, in pristine coastal waters, either DIN or DIP occurs in insufficient concentration to sustain runaway algal growth (Atkinson and Smith, 1983; Smith, 1984; Larned, 1998). Outbreaks of excessive amounts of algae off West Maui have been attributed to elevated concentrations of both DIN and DIP in sewage effluent injected into groundwater and migrating to nearshore waters (Laws et al., 2004; Dollar and Andrews, 1997; Dailer, 2010; MRC, 2011). No such algal outbreaks have been recorded for nearshore waters off MG&BC (MRC, 2006; *AECOS*, 2016, 2020). That excessive algal growth has not been seen in waters off Mākena may be due to several factors, including a limit on the supply of DIP or DIN in these coastal waters.

Nutrient Limitation

Determination of which nutrient is present in a limiting concentration, and thus potentially regulating algal growth, can be calculated by comparing molar ratios of DIN to DIP concentrations. So-called "N:P ratios" measured in 20 Hawaiian algae species range from 15:1 to 44:1, with a mean of about 29:1 (Atkinson and Smith, 1983). Thus, in Hawaiian nearshore waters, it is assumed that DIP is potentially limiting when environmental N:P exceeds 29:1 and DIN is potentially limiting when N:P ratio is less than 29:1. When a particular substance becomes limiting, any excess of other substances necessary for growth remain unused in the environment (Liebig's Law of the Minimum). As an example, once all the available DIP is taken up by algae, uptake of nitrogen (up to that point being used for growth in an amount roughly equal to 29 times the phosphorus uptake) ceases and further algal growth becomes limited.

Table 6. Geometric mean DIP and DIN molar distributions and DIN:DIP ratios for *AECOS* historic (2018 - 2023) and 2024 sampling events.

Transect	DFS† (m)	DIP (μM/L)		DIN (μM/L)		DIN:DIP ratio		N/P Limited potential	
		Historic	2025	Historic	2025	Historic	August	Historic	August
M-1	2	0.10	0.16	4	8	40	49	P	P
	10	0.09	0.14	4	5	41	38	P	P
	50	0.09	0.15	3	5	36	36	P	P
	100	0.07	0.13	3	5	42	42	P	P
M-2	2	0.14	0.23	3	5	20	22	N	N
	10	0.12	0.21	3	5	21	24	N	N
	50	0.11	0.23	2	5	23	21	N	N
	100	0.08	0.15	2	4	30	24	P	N
M-3	2	0.11	0.17	4	5	33	32	P	P
	10	0.10	0.17	3	4	27	25	N	N
	50	0.09	0.13	3	4	30	29	P	N
	100	0.08	0.13	2	3	22	21	N	N
M-4	2	0.11	0.19	2	4	19	19	N	N
	10	0.10	0.18	3	4	26	22	N	N
	50	0.08	0.17	2	2	28	14	N	N
	100	0.08	0.16	2	2	23	15	N	N

Geometric mean molar DIP and DIN concentrations and N:P ratios for all four transects are shown in Table 6 (above) for the historic (2018 - 2023) and 2024 data sets. Historic ratios demonstrated typically DIP limitation at along both Transect M-1 and M-3, but an increase in DIP concentrations (see Fig. 3 above) possibly due to heavy runoff levels in 2021 and 2022 has resulted in DIN now being the primary limiting nutrient in the Mākena nearshore coastal waters.

While a scarcity of benthic algae in coastal waters off MG&BC is likely due to low DIN or DIP concentrations, the general absence of silty sediments in nearshore waters may also have an influence. Sedimentation from terrestrial runoff cannot only adversely affect coral assemblages, but also provides a source of nutrients for algae (Raffaelli et al., 1998; Laws et al., 2004; Fabricius, 2005). Based on benthic surveys (MRC, 2006; *AECOS*, 2016 & 2020), a limited amount of land-derived sediment accumulates in this area off Maui.

References Cited

AECOS, Inc. (*AECOS*). 2016. Marine biological surveys for the proposed Mākena Resort M-5/M-6/S-7/B-2 project, Mākena, Maui. Prep. for: ATC Mākena Holdings, LLC. *AECOS* Report No. 1470A: 56 pp.

________. 2018. Mākena Golf and Beach Club quarterly water quality sampling event. June 2018. *AECOS* Report No. 1535A. 15 pp.

________. 2019. Mākena Golf and Beach Club quarterly water quality sampling event. March 2019. *AECOS* Report No. 1535D. 8 pp.

________. 2020. Marine biological surveys for the proposed Mākena Future Lands Project, Mākena Maui. Report No. 1602. 36 pp. + appendices,

Atkinson, M. J. and S. V. Smith. 1983. C:N:P ratios of benthic marine plants. *Limnol. Oceanogr.* 28(3): 568-574.

Busman, L., J. Lamb, G. Randall, G. Rehm and M. Schmitt. 2002. The nature of phosphorus in soils. URL: https://extension.umn.edu/phosphorus-and-potassium/understanding-phosphorus-minnesota-soils; last retrieved April 13, 2019.

Dailer, M. L. 2010. Using δ15N values in algal tissue to map locations and potential sources of anthropogenic nutrient inputs on the island of Maui, Hawai'i. *Mar. Pollut. Bull.* 60(5): 655-671.

Dollar, S. and C. Andrews. 1997. Algal Blooms off West Maui; Assessing Causal Linkages between Land and the Coastal Ocean. National Oceanic and Atmospheric Coastal Ocean Program Office.

Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of coral and coral reefs: review and synthesis. *Mar. Poll. Bull.*, 50: 125 -146.

Giambelluca, T. W., Q. Chen, A. G. Frazier, J. P. Price, Y. L. Chen, P. S. Chu, J. K. Eischeid, and D. M. Delparte, 2013: online Rainfall Atlas of Hawai'i. *Bull. Amer. Meteor. Soc.* 94, 313:326, doi: 10.1175.BAMS-D-11-00228.1

Hawaiʻi Department of Health (HDOH). 2021. Hawaiʻi Administrative Rules, Title 11, Department of Health, Chapter 54, Water Quality Standards. October 22, 2021. 106 pp.

______. 2024. 2024 State of Hawaiʻi water quality monitoring and assessment report: integrated report to the U.S. Environmental Protection Agency and the U.S. Congress pursuant to §303(3) and §305(b), Clean Water Act (P.L. 97-117). 163 pp.

Hawaiʻi Department of Land and Natural Resources (HDLNR). 2020. Status of Maui's Coral Reefs. URL: http://dlnr.hawaii.gov/dar/files/2014/04/-MauiReef Declines.pdf. Last retrieved February 21, 2020.

Larned, S. T. 1998. Nitrogen- versus phosphorus-limited growth and sources of nutrients for coral reef macroalgae. *Mar. Biol.,* 132(3): 409-421.

Laws, A. E., D. Brown, and C. Peace. 2004. Coastal water quality in the Kihei and Lahaina districts of the Island of Maui, Hawaiian Islands: impacts from physical habitat and groundwater seepage: implications for water quality standards. *Inter. J. Environ. Poll*., 22(5): 531-546.

Marine Research Consultants (MRC). 2006. Marine Biota Monitoring Mākena Resort, Mākena, Maui. Annual Report for 2005. Prep for Mākena Resort Corp. 18 pp.

______. 2011. An evaluation of causal factors affecting coral reef community structure in Maʻalaea Bay, Maui, Hawaii. Job No. WW09-22. Prep. for County of Maui. 84 pp.

Pacific Islands Ocean Observing System (PacIOOS). 2024. Available on at URL: https://www.pacioos.hawaii.edu/currents-category/model/; last retrieved November 8, 2024.

Raffaelli, D. G., J. A. Raven , and L. J. Poole. 1998. Ecological impact of green algal blooms. *Oceanography and Marine Biology: an Annual Review*, 36: 97-125.

Smith, S. V. 1984. Phosphorus versus nitrogen limitation in the marine environment. *Limnol. Oceanogr.,* 29(6): 1149-1160.

Standard Methods (SM). 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation.

Standard Methods (SM). 2017. Standard Methods for the Examination of Water and Wastewater, 23rd Edition. American Public Health Association, American Water Works Association, Water Environment Federation.

U.S. Environmental Protection Agency (USEPA). 1993a. Method 353.2 Revision 2.0: Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 15 pp.

________. 1993b. Method 180.1: Determination of Turbidity by Nephelometry. Version 2. Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 11 pp.

________. 1997a. Method 349.0: Determination of Ammonia in Estuarine and Coastal Waters by Gas Segmented Continuous Flow Colorimetric Analysis. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 16 pp.

________. 1997b. Method 365.5: Determination of Ortho-Phosphate in Estuarine and Coastal Waters by Automated Colorimetry Analysis. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 9 pp.

________. 1997c. Method 366.0: Determination of Dissolved Silicate in Estuarine and Coastal Waters by Gas Segmented Continuous Flow Colorimetric Analysis. National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 13 pp.

U.S. Geological Survey. (USGS). 2018. Spatially Distributed Groundwater Recharge Estimated Using a Water-Budget Model for the Island of Maui, Hawaiʻi, 1978-2007. *Scientific Investigations Report 2014-5168*. U.S. Department of the Interior. U.S. Geological Survey. 64 pp.