Environmental Science & Technology

Article

pubs.acs.org/est

Watershed Assessment with Beach Microbial Source Tracking and Outcomes of Resulting Gull Management

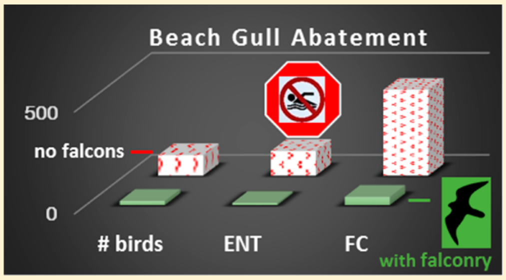
Kelly D. Goodwin,[*,†] Steve Gruber,[‡,§] Mary Vondrak,[∥,⊥] and Andrea Crumpacker[‡]

[†]Atlantic Oceanographic & Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, NOAA, 4301 Rickenbacker Causeway, Miami, Florida 33149, United States

[‡]Weston Solutions, Inc., 5817 Dryden Place, Suite 101, Carlsbad, California 92008, United States

[∥]City of San Clemente, 910 Calle Negocio, Suite 100, San Clemente, California 92673, United States

Supporting Information



ABSTRACT: Total maximum daily load (TMDL) implementation at a southern California beach involved ultraviolet treatment of watershed drainage that provided >97% reduction in fecal indicator bacteria (FIB) concentrations. However, this pollutant control measure did not provide sufficient improvement of beach water quality, prompting further assessment. Investigation included microbial source tracking (MST) for human, gull, and canine fecal sources, monitoring of enterococci and fecal coliform, and measurement of chemical and physical water quality parameters for samples collected from watershed, groundwater, and beach sites, including a beach scour pond and tidal creek. FIB variability remained poorly modeled in regression analysis. However, MST revealed correlations between FIB and gull source tracking markers, leading to recommendations to manage gulls as a pollutant source. Beach conditions were followed for three years after implementation of a best management practice (BMP) to abate gulls using a falconry program for the beach and an upland landfill. The gull abatement BMP was associated with improved beach water quality, and this appears to be the first report of falconry in the context of TMDL implementation. Overall, MST data enabled management action despite an inability to fully model FIB dynamics in the coupled watershed−beach system.

INTRODUCTION

Recreational and inland waters in the United States are monitored for water quality to protect designated uses such as aquatic or terrestrial habitats, agriculture, or recreational contact. Benchmarks set at national, state, or watershed levels exist for a suite of chemical, physical, and biological water quality parameters, and water bodies failing to meet set criteria are listed by states as impaired under section 303(d) of the Clean Water Act,[1] leading to a total maximum daily load (TMDL) regulatory action. The resulting pressure to formulate and adopt a TMDL typically leads to scientific scrutiny and management response to understand and remediate the source of impairment. Costs are substantial, with estimates to implement pollution control measures reaching over $3 billion per year nationally, not including expenses for water quality monitoring and TMDL development. That estimate was based on 22000 listed water bodies and 36000 TMDLs,[2] whereas there are currently greater than 42000 impaired waters and 69000 TMDLs in the United States.[3] Given the fiscal burden of the TMDL process, tools to better guide TMDL approaches are needed, and evaluation of the efficacy of TMDL management actions is warranted.

The majority of listed impairments are caused by failure to meet criteria for microbial water quality followed by nutrients and metals.[3] Criteria for primary contact recreation (REC-1) with marine waters in California for enterococci (ENT) and fecal coliforms (FC) are stipulated for a 30 day rolling geometric mean (ENT = 35, FC = 200 MPN/100 mL) and for single grab samples (ENT = 104, FC = 400 MPN/100 mL).[4,5] Poche Beach, located in Dana Point, California, exemplifies a site with a TMDL due to bacterial exceedances. Common for southern California, the beach receives drainage primarily through concrete-lined flood control channels. The main channel, the M01, was listed as impaired for cadmium, nickel, phosphorus, and turbidity.[6,7] Combined watershed flows from the M01 channel and the Cascadita channel tributary terminated at the beach, forming a scour pond which could connect to the ocean via a short (∼10 m) tidal creek. Assuming a watershed approach to address bacteria exceedances at the beach, management action included construction of a sand filtration/UV treatment facility located immediately upstream of the scour pond to treat watershed flows[8] with effluent discharged into the scour pond (Figure 1).

Despite investment of more than $3 million to construct the UV treatment facility, bacteria criteria exceedances in the surf zone persisted,[8] prompting further investigation into water quality at the beach and the associated watershed. Microbial

Received: May 23, 2016
Revised: August 15, 2016
Accepted: August 18, 2016
Published: August 18, 2016

DOI: 10.1021/acs.est.6b02564
Environ. Sci. Technol. 2016, 50, 9900−9906

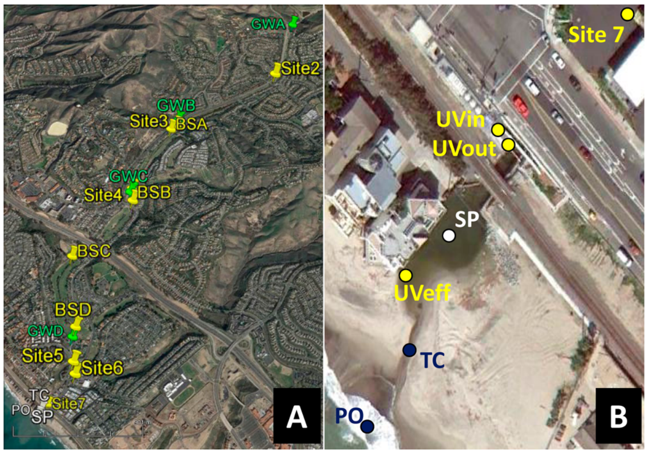


Figure 1. (A) Station locations in the watershed (yellow), groundwater (green), and beach (white, see panel B for zoomed view). (B) Station locations on the beach, including prior to (UV_{in}) and immediately after (UV_{out}) treatment; the area of effluent discharge (UV_{eff}) located in a scour pond (SP); and the tidal creek (TC) connecting the scour pond to the surf zone (PO) (Google Earth Image, 2016 TerraMetrics; map data: SIO, NOAA, United States Navy, NGA, GEBCO).

Table 1. Parameter Abbreviations and Units

abbreviation	parameter (unit)
Amm	ammonia-N (mg/L)
ADF	average dry flow per month (cfs)
CdD	cadmium, dissolved (mg/L)
CdT	cadmium, total (mg/L)
condct	conductivity (μS/cm)
DO	dissolved oxygen (mg/L)
distshore	distance from shore (m)
DogMST	canine marker (log copies per 100 mL)
ENT	enterococci (log MPN per 100 mL)
FC	fecal coliform (log MPN per 100 mL)
flow	flow (cfs)
GenBact	general *Bacteroides* (±)
GullMST	gull marker (log copies per 100 mL)
HumMST	human marker (±)
NiD	nickel, dissolved (mg/L)
NiT	nickel, total (mg/L)
nitrate	nitrate-N (mg/L)
nitrite	nitrite-N (mg/L)
nbird	number of birds
ndog	number of dogs
pH	pH
sal	salinity (ppt)
TDS	total dissolved solids (mg/L)
TKN	total Kjeldahl-N (mg/L)
TOP	total orthophosphate as P (log mg/L)
TP	total phosphorus (mg/L)
TSS	total suspended solids (mg/L)
turb	turbidity (NTU)
WT	water temperature (°C)

source tracking (MST) protocols to determine fecal hosts were included in water quality assessments with the goal of informing additional best management practices (BMP), and as a result, a gull abatement program was adopted. Findings that supported this management decision and outcomes of that action are provided here with FIB data reviewed for three years after implementation of gull abatement programs that employed falcons.

MATERIALS AND METHODS

Sample Collection. Stations were sampled prior to gull abatement efforts during 13 separate events during the period of January 2011−July 2012. Sampling after implementation of gull abatement occurred during the period of August 15, 2013−November 12, 2015, as described in more detail below. Samples were collected from various stations (Figure 1) located in the watershed (channel, swale, and groundwater), scour pond (including the area of discharge from the UV treatment facility), tidal creek connecting the scour pond to the ocean, and surf zone (adjacent, north, and south of the tidal creek). An additional description is provided in Table S1. Surface water was collected from the M01 channel in five separate surveys (BF1−BF4, S24) and from a riparian swale located in a golf course during one survey (BS2). Groundwater was sampled in four separate surveys (G1−G4). Lower station numbers were associated with more upland sites located further inland from the shore (Table S1). For stations on the beach and base of the watershed (Figure 1B), sampling was conducted during three dry weather surveys (BSP1−3), as detailed in the Supporting Information.

Sample Analysis. Samples were collected for analysis of a variety of parameters (Table 1) with additional details provided in Table S2. Briefly, water samples (100 mL) for culture analysis were analyzed for enterococci (Enterolert) and fecal coliform (SM 9221E) in accordance with the Environmental Laboratory Accreditation Program (ELAP). For MST analysis, extracted DNA was analyzed by real-time PCR (Table S3) for human (HumMST), gull (GullMST), and canine sources (DogMST) as described in publications from the Source Identification Pilot Program (SIPP),[9−13] and a subset of samples were analyzed for a general *Bacteroides* marker (GenBact).[14,15] To calculate averages, a cycle threshold (Ct) value of 40 was substituted for not detected (ND) reactions (no amplification), and calculations proceeded using the standard curve for that run.[9] Each DNA extract was tested for PCR inhibition with *Bacteroides dorei* DNA (DSMZ 17855) added to HumMST reactions that contained extracted sample DNA at (a) full strength and (b) extract diluted 1:10 by molecular-grade water. DNA was considered inhibited if the difference in Ct between the undiluted and diluted extracts exceeded 1.5 cycles. In addition, the GenBact assay functioned as an inhibition control given the presence of that target in all samples tested except groundwater. Water chemistry analysis utilized standard methods,[16,17] and flow was monitored at sites 3 through 7 with stream stage data converted into continuous flow measurements using Manning's equation.[18] See the Supporting Information for further details.

Bird Abatement BMP Programs. Professional bird abatement services (Adam's Falconry Service) were used to control gulls at Poche Beach starting in August 2013 and at the Prima Deshecha Landfill starting in January 2014. The falconry schedule for the beach in 2013 (August 9−September 26) was 7 days per week for 10 h per day for the first 2 weeks followed by 6 days per week (Monday−Saturday) for 8 h per day. In 2014 and 2015, the schedule for the beach was 4 days per week (Monday−Thursday) for 8 h per day (8am−4 pm) for the periods June 2−September 8, 2014 and May 5−October 28, 2015. This program included periodic flight over the beach and ocean based on a pilot study that suggested that falcons merely resting on the beach did not deter gulls from occupying adjacent ocean water. The schedule for the landfill was 5 days per week (Monday−Friday) for 8 h per day starting in January and ending June 25, 2014. The bird abatement program at the landfill has been ongoing since September 22, 2014 with falconry service typically 5−6 days per week for 6−10 h per day. FIB concentrations were monitored with and without active falcon deterrent for stations SP, TC, and UV_{eff} (Table S1) and from the following additional stations: entering the UV treatment facility from the M01 channel (UV_{in}), immediately after treatment (UV_{out}), and from seawater collected 23 m north (PO23N) and 23 m south (PO23S) of the tidal creek. Bird counts were monitored at the beach during 2013.

Statistical Analysis. All hypothesis testing (parametric and nonparametric) was performed with α = 0.05. Parameter distributions were tested using Minitab16 distribution identification, and parameters were transformed as appropriate to allow for parametric statistical analysis when possible. All FIB and MST concentrations were log transformed (Table S2). Many parameters demonstrated normal distributions without transformation, whereas watershed samples achieved normal distributions for log transformed TOP and Johnson transformed CdD, CdT, nitrate, NiD, NiT, TDS, TKN, TP, and turb (see Table 1 for abbreviations). Those transformations were used for Pearson correlation coefficients, one-way ANOVA (α = 0.05), principal component analysis (PCA), and general linear regression (GLR) analysis of watershed samples. Nitrite and Amm data sets contained a large number of nondetects (43% and 32%, respectively); therefore, distribution identification used the Minitab16 arbitrary censoring option. For analysis involving these parameters, nonparametric statistical analysis was performed using NADA macros for Minitab[19] to deal with nondetects (Kruskal−Wallis = censKW.mac v.3.4, α = 0.05).

■ RESULTS

Comparison to Benchmarks. REC-1 criteria for bacteria[5] applied only to ocean receiving waters but nonetheless provided a good basis to compare across sample types. Except for groundwater, concentrations of FIB were generally higher than the REC-1 single sample criteria with 89% and 64% of analyzed seawater samples exceeding recreational water quality guidelines for enterococci (>104 MPN per 100 mL) and fecal coliform (>400 MPN per 100 mL), respectively (Table 2). In addition, more than 10% of watershed, tidal creek, and seawater samples exceeded the concentration stipulated for REC-2 criteria (>4000 FC MPN per 100 mL) in the applicable Basin Plan.[20] All or almost all tidal creek, scour pond, and watershed samples exceeded the basin plan benchmark criteria for TP,[20] and concentrations of cadmium and nickel in the watershed (M01 channel) tended to be higher than the California Toxics Rule maximum chronic concentrations[21] (Table S4). The number of samples analyzed for each parameter are provided for the study overall (Table S12) and for each sample type (Tables 3−6 and S5).

Patterns of FIB, MST, and Water Quality Parameters. In groundwater samples, FIB were rarely detected. ENT was detected in two samples, and FC was detected in a separate two samples (2/16). Not surprisingly, there were no significant correlations observed between FIB and other parameters. Several water chemistry parameters showed a tendency for higher concentrations closer to the beach, including TKN, Amm, and NiD. In addition, these parameters were strongly correlated to each other (Table S5).

Table 2. Concentrations of ENT and FC (MPN/100 mL) by Sample Type and Comparison to Benchmarks

sample type (abbreviation)	ENT geomean	ENT % > 104[a]	FC geomean	FC % > 400[a]	FC % > 4000[b]	*n*
groundwater (GW)	11	0	20	0	0	16
watershed (WS)	1406	90	1231	68	31	72
UV discharge (UV_{eff})	499	100	1141	88	0	8
scour pond (SP)	280	100	1301	92	8	12
tidal creek (TC)	1308	100	2348	100	25	8
seawater (PO)	860	89	768	64	18	28

[a] Single sample REC-1;[5] only primary contact marine waters are required to meet REC-1 criteria. [b] REC-2 criteria[20] for purposes of comparison.

Table 3. Pearson Correlations for Watershed Stations[a]

parameter	ENT	FC	distshore	other correlations
FC			0.50	TOP (0.66), TP (0.62)
ENT		0.78	0.57	TOP (0.63), TP (0.59)
TOP	0.63	0.66	0.74	TP (0.88)
TP	0.59	0.62	0.82	TOP (0.88), turb (0.64), flow (−0.59), nitrate (0.56), ADF (−0.50)

[a] Results provided for significant correlations (α = 0.05) with values >0.5. A negative correlation with distshore (Table S1) indicates higher values measured closer to the beach. Each station was sampled as follows: site 7 (*n* = 15, 5 events); sites 3, 4, and 6 (*n* = 8, 5 events); sites 2 and 5 (*n* = 4, 1 event); and BSA-D (*n* = 6, 1 event). Each had *n* per parameter as follows: FIB = 72, pH, WT, condct = 48; sal, DO, turb, GenBact, HumMST = 32; nitrate, nitrite, Amm, TKN, TP = 28; TOP, TDS, TSS, metals = 24; ADF = 41; flow = 33; GullMST and DogMST = not applicable. See Table S2 for log normal and Johnson transformed variables.

In samples collected from the watershed, concentrations of FIB were correlated with distance from the shore (Tables 3 and S1) with geomean concentrations as high as 10488 MPN ENT/100 mL measured in site 2 from the upper reaches of the watershed. FIB concentrations were significantly lower in samples collected from the M01 channel stations located furthest downslope (sites 6 and 7) compared to those more upland, and concentrations did not differ significantly across the upper watershed stations (α = 0.05, Figure 2 and Table S6).

Despite relatively higher FIB concentrations measured in the upper watershed, human marker was not detected there (Table 4). Instead, human marker was detected in only two samples (2/32) which were collected from the stations with the lowest FIB concentrations (sites 6 and 7, Table S6). All groundwater samples were negative for both human and general *Bacteroides* markers. Otherwise, all DNA extracts tested for human marker were positive for the general *Bacteroides* marker (Table 4), indicating that *Bacteroides* DNA was amplifiable and not subject to gross inhibition.

Similar to the pattern observed for FIB, higher concentrations of TP and TOP were measured in upland stations. In turn, these nutrients were correlated with both ENT and FC (Table 3). Median concentrations of TP and TOP (Table S6) were significantly higher near the top of the watershed (sites 2

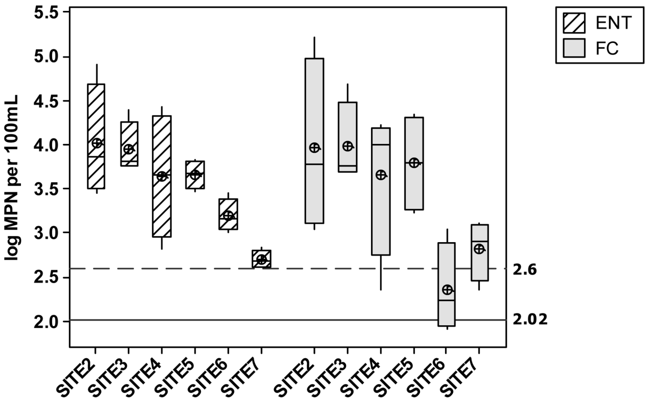


Figure 2. Box and whisker plot showing quartiles (25th and 75th percentile), median (horizontal line), mean (circle with cross hair), and outliers for ENT and FC in water collected from watershed stations during survey S24 (n = 4 for each station). For reference, the marine REC-1 single sample exceedance criteria are represented by a solid line for ENT and dotted line for FC.

Table 4. Detection of HumMST and GenBact

sample type	human (% and fraction)	general (% and fraction)
groundwater	0, (0/16)	0, (0/16)
watershed	6, (2/32)	100, (32/32)
UV discharge area	0, (0/2)	100, (2/2)
scour pond	0, (0/8)	100, (8/8)
tidal creek	0, (0/8)	100, (8/8)
seawater	0, (0/23)	100, (23/23)
overall	2, (2/89)	82, (73/89)

and 3) compared to samples collected from the golf course (site 4), the channel downstream from the golf course (site 5), the Cascadita channel (site 6), and the base of the watershed (site 7) (α = 0.05, Kruskal–Wallis). Despite correlations of FIB with TOP and TP, only FC and distshore emerged from stepwise regression against ENT. A GLR model of ENT with FC and distshore provided an adjusted r^2 of 64%, and the variance inflation factor (VIF) was low (1.3), indicating acceptable multicollinearity. Overall, despite noteworthy correlations, FIB variability in the watershed remained poorly characterized.

Beach and Watershed Base Stations. Concentrations of ENT, FC, and GullMST measured at stations located on the beach (PO, SP, TC) and at the base of the watershed (site 7) were variable (Figures 3 and S1). Surf zone concentrations of these three analytes did not differ significantly within approximately 100 m of the tidal creek (α = 0.05, Figure 3). Mean FIB concentrations in samples did not differ significantly between stations located on the beach or site 7 except that seawater ENT was significantly higher compared to scour pond samples (α = 0.05, Table 5 and Figure S1).

Highest GullMST concentrations were measured in seawater with mean concentrations significantly higher compared to those of the tidal creek, scour pond, or site 7 samples (α = 0.05, Table 5). In contrast, the lowest mean concentrations of DogMST were measured in seawater, but concentrations were not significantly different from samples collected from site 7 at the base of the watershed (Table 5). DogMST concentrations were not significantly correlated to concentrations of ENT, FC, or GullMST.

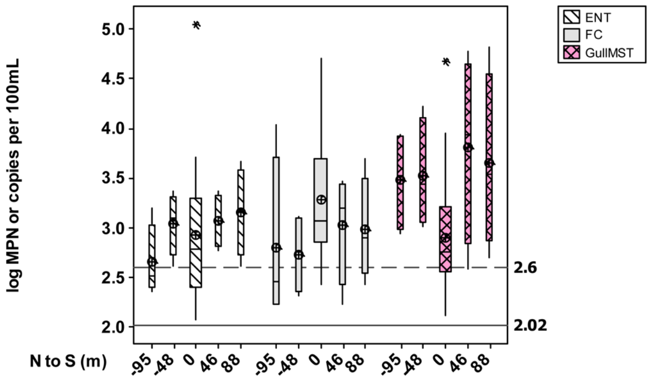


Figure 3. Box and whisker plot for ENT, FC, and GullMST for surf zone seawater collected from stations PO300N, PO150N, PO, PO150S, and PO300S (Table S1) spaced approximately 46 m apart (n = 4 for each station, survey BSP3). Distance on the x-axis is plotted relative to the 0 m station (PO) adjacent to the tidal creek exiting the scour pond. Plot is as described in Figure 2.

Table 5. Geomean Concentrations for Stations Located at the Beach and Watershed Base[a]

description (station)	ENT	FC	GullMST	DogMST
watershed base (site 7)	825	347	762	76
scour pond (SP)	1563	731	395	54
tidal creek (TC)	2348	1060	1308	155
seawater (PO)	3379	4016	3173	20

[a] FIB = log MPN/100 mL; MST = log copies/100 mL; surveys BSP 2 and 3; n = 8 for each except n = 4 for DogMST.

Table 6. Pearson Correlations for Beach and Watershed Base Stations[a]

				r^2 (p-value)	
description	station	n	parameter	ENT	FC
watershed	site 7	8	GullMST	NS	NS
			FC	NS	
scour pond	SP	8	GullMST	0.78 (0.022)	NS
			FC	NS	
tidal creek	TC	8	GullMST	0.83 (0.011)	NS
			FC	NS	
surf zone	all PO	24	GullMST	0.57 (0.003)	0.60 (0.002)
			FC	0.85 (0.000)	

[a] All PO = PO, PO150N, PO150S, PO300N, and PO300S (Table S1). NS = not significant.

ENT and GullMST concentrations were correlated for all stations located on the beach (Table 6). The observed relationship between ENT and GullMST was strongest for sites adjacent to the scour pond with the adjusted r^2 dropping from 71 to 30% when ocean sites north and south were added to the regression, with highly variable GullMST concentrations measured south of the scour pond (Figure 3). Regression results were similar when samples were analyzed separately by site; the relationship between ENT and GullMST was consistently indicated (adjusted r^2: 54, 63, and 71% for SP, TC, and PO, respectively). ENT and FC concentrations were correlated for seawater samples only but not for tidal creek, scour pond, or site 7 (Table 6). For FC, regression analysis suggested only ENT as a term, and the model could explain up to only 38% of the FC variability. A GLR model of ENT against

DOI: 10.1021/acs.est.6b02564
Environ. Sci. Technol. 2016, 50, 9900−9906

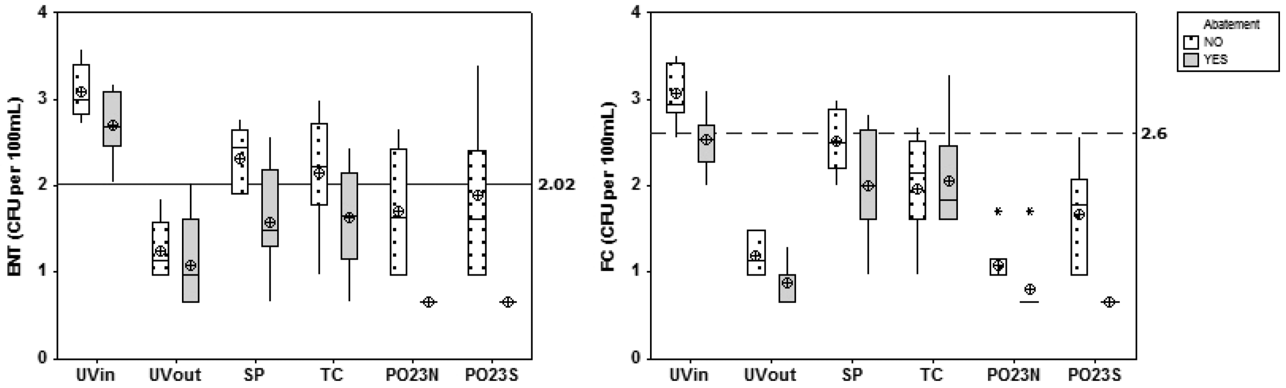


Figure 4. Box and whisker plots for ENT and FC, as described in Figure 2, for samples collected during periods with similar rainfall either without gull abatement at the beach or landfill ("No" = June–July 2013; $n = 7$) or with falconry active at both locations ("Yes" = June–July 2014; $n = 7$). Water samples were collected from the following stations: UV treatment facility prior to (UV_{in}) and immediately after treatment (UV_{out}), scour pond (SP), tidal creek (TC), surf zone 23 m north (PO23N), and surf zone 23 m south (PO23S) of the tidal creek.

GullMST and FC provided an adjusted $r^2 = 56\%$ ($n = 40$, VIF = 1.2).

Overall, these data indicated a relationship with FIB and gull marker with significant uncharacterized sources of FIB variability. However, GLR performance was improved when GullMST was treated as the dependent variable, and ENT and condct were incorporated into a GLR model with an adjusted r^2 of 72% ($n = 24$, VIF = 1.3, stations PO, TC, and SP). Chemical parameters were available for a small subset of the beach data ($n = 12$), and although the data set was small, it is noteworthy that ENT and nitrate were incorporated into a model of GullMST variability with an adjusted r^2 of 90% (VIF = 1.4).

Bird Abatement Results. MST results from the 2011–2012 assessments showed elevated concentrations of gull marker on the beach (Table 5 and Figure S1) and correlations between FIB and GullMST concentrations (Table 6). These results were used to support a recommendation for a bird abatement BMP, and falcons were used to control gulls at the beach starting in 2013. Gull counts were recorded to assess the effectiveness of the abatement program in 2013. Prior to initiation of the falcon program, an average of 304 gulls were counted at Poche Beach compared to 57 during gull abatement ($n = 7$ days of observations each, pre-abatement: June 13–July 31, 2013, post-abatement: August 9–September 26, 2013); therefore, gull counts at the beach were reduced by a factor of 5 during this observation period.

The BMP program was evaluated with regard to FIB concentrations for the period of May 2013–November 2015. Surf zone concentrations of FIB were significantly lower when falconry was active compared to those when it was not. Significant reductions ($\alpha = 0.05$) were also seen for ENT in the scour pond and tidal creek (Table S7). Geomean concentrations of both ENT and FC were 7 MPN/100 mL during this time frame ($n = 108$ total for stations PO23N and PO23S) compared to almost 800 MPN/100 mL for ENT and FC during the 2011–2012 assessment (Table 2). In addition to evaluation of the gull abatement BMP, this data set allowed evaluation of the UV treatment structural BMP, and the measured reduction in FIB concentrations between UV_{in} and UV_{out} (Figure 1B) averaged 97% for ENT and 96% for FC ($n = 54$, each).

BMP evaluation for gull abatement was complicated by the occurrence of two overlapping programs (beach and landfill) with start dates that varied by year. To allow a more direct comparison, samples from June and July of 2013 ($n = 7$) with no bird abatement at either the beach or the landfill were compared to samples from June and July of 2014 ($n = 7$) with bird abatement at both the beach and the landfill except for one day in which the program was active only at the beach. Rainfall was similar for the two time periods with 0.05 in. for June–July of 2013 and 0.06 in. for June–July of 2014.[22] Results showed marked reductions associated with bird abatement in both ENT and FC for beach sites (Figure 4) with significant reductions ($\alpha = 0.05$) for ENT in the scour pond and surf zone north and south of the scour pond. For FC, reductions were significant at UV_{in}, UV_{out}, and the southern surf zone station; FC was low in the northern station with and without falconry (Figure 4).

■ DISCUSSION

The observed failure to meet benchmarks (Tables 2 and S4) was consistent with an overall assessment status of impaired water quality for the study area. In 2012, the EPA listed impairments for bacteria at Poche Beach, and cadmium, nickel, phosphorus, and turbidity in the watershed (Prima Deshecha Creek, water ID: CAR9013000020010924090843).[7] Using a watershed approach for the TMDL, a UV treatment facility to treat runoff was constructed to address bacterial water quality impairments at the beach. FIB removal of ~97% was reported for the facility,[8] and the data reported here showed reductions of similar magnitude. However, this investment in pollutant control did not produce the remediation desired for beach receiving waters. The treated effluent was discharged into the scour pond, and given that FIB concentrations there exceeded water quality criteria (Figures 4 and S1), any benefit derived from UV treatment may have been lost before reaching the ocean.

Although correlations were observed between FIB, TOP, and TP in watershed samples (Table 3), regression analysis indicated that the measured parameters failed to fully account for the observed variability in FIB. It is possible that not all relevant parameters were measured. For example, Surbeck et al.[29] found DOC to be strongly correlated with FIB concentrations in an urban stream, and microcosm studies showed FIB growth with DOC concentrations in runoff above 7 mg/L and phosphorus concentrations above 0.07 mg/L. DOC was not measured in this study, but TP concentrations were above this threshold at every station sampled in the M01 channel (Table S6), suggesting that nutrient concentrations may have been sufficient to support environmental persistence and/or growth of FIB. In any case, naturalized bacteria[30−34] are likely to have contributed to FIB concentrations in the scour pond and tidal creek, suggesting that reduction or removal of the scour pond could benefit local water quality.

Regardless of the configuration of the scour pond or UV effluent discharge, MST results suggested that treating watershed runoff did not address a primary pollutant source. Concentrations and patterns of GullMST (Figures 3 and S1 and Table 6) suggested bird fecal contamination at the beach as a potentially important source of FIB. In contrast, relationships between FIB and MST markers for dog and human markers were not apparent (Tables 4 and 5), with the two human detections found in samples from sites 6 and 7, which showed the lowest concentrations of FIB (Table S6).

It was speculated that the freshwater scour pond and tidal creek encouraged gulls to congregate at the beach. Observations supported a connection between the scour pond and gull populations. Gulls were observed drinking from the creek over the course of this study, suggesting that the flowing fresh water could serve as an attractant. In 2011, camera images recorded an average of 169 gulls per survey (with counts varying between 0−720 birds), and they tended to congregate near the tidal creek outlet of the scour pond.[8] These values were comparable to the number of birds counted during this study during water sample collection (0−200 birds) and during a fecal collection exercise in which food was left on a tarp (635−1115). It was also speculated that the upland landfill provided a gull foraging ground. In addition to concern over significant FIB loads[23,24] and the presence of pathogens in gull feces,[25] the landfill as a feeding ground raised the possibility of increased pathogen load in the gull gut microbiome.[26]

A gull abatement BMP recommendation was given based on the 2011−2012 FIB and MST data presented here, and falconry was initiated as a gull deterrent BMP in 2013. Decreased bird counts measured in 2013 and decreased FIB concentrations associated with gull abatement in 2013−2015 (Figure 4 and Table S7) suggest that the initial MST findings enabled effective management action despite an incomplete understanding of FIB dynamics in the study of area. Beach water quality improvements were observed at another site after employing dogs for bird abatement.[27] Although falconry has been utilized to control birds at landfills,[28] this appears to be the first report of falconry used to address a bacteria TMDL. Overall, the results of this study suggest that MST assessment can inform BMP implementation to improve water quality despite a complex and dynamic system in which FIB variability is not fully characterized.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.6b02564.

> Figure S1, box and whisker plot of ENT, FC, and GullMST for stations located at the beach and base of the watershed (site 7); Table S1, station locations and descriptions; Table S2, sample size and range of values for analyzed parameters; Table S3, summary of real-time PCR methods; Table S4, percent failure to meet benchmark criteria for water chemistry; Table S5, Pearson correlations for groundwater samples; Table S6, water quality parameter concentrations for watershed M01 channel stations; and Table S7, sites showing significant reduction in FIB with falconry programs (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*Phone: 858-546-7142, fax: 858-546-7003, e-mail: kelly.goodwin@noaa.gov, stationed at 8901 La Jolla Shores Drive, La Jolla, California 92037.

Present Addresses

[§]S.G.: Burns and McDonnell Engineering, Inc., 4225 Executive Square, Suite 500, La Jolla, CA 92037

[⊥]M.V.: City of Laguna Beach, 505 Forest Avenue, Laguna Beach, CA 92651

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors acknowledge the Prima Deshecha Watershed Bacteria Source Identification Study Technical Advisory Committee, Anthony Trinh for laboratory analysis, and the Weston Solutions field team for collection and transport of field samples. Work was supported by the City of San Clemente's Clean Ocean Fund, and work for K.G. was carried out under CRADA Identification No. 50-23 3RR3HWSP13.

■ REFERENCES

(1) Federal Water Pollution Control Act (the "Clean Water Act"). 2011; http://www.waterboards.ca.gov/laws_regulations/docs/fedwaterpollutioncontrolact.pdf.

(2) The National Costs of the Total Maximum Daily Load Program (Draft Report). EPA 841-D-01−003; United States Environmental Protection Agency Office of Water, 2001; http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901K0800.TXT.

(3) National Summary of Impaired Waters and TMDL Information. United States Environmental Protection Agency, https://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T#causes_303d (Accessed May 18, 2016).

(4) An Act to Amend Sections 115880, 115885, and 115915 of the Health and Safety Code Relating to Public Beaches. *California Assembly Bill 411*, Chapter 765, 1997; ftp://www.leginfo.ca.gov/pub/97-98/bill/asm/ab_0401-0450/ab_411_bill_19971008_chaptered.pdf.

(5) Regulations for Ocean Beaches and Ocean Water-Contact Sports Areas Pursuant to AB 411. California Department of Health Services, 2016; https://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Beaches.aspx.

(6) 2013 San Clemente Coastal Streams Watershed Workplan. *Orange County Stormwater Program*; City of San Clemente, County of Orange, and the Orange County Flood Control District, January 1, 2013; http://prg.ocpublicworks.com/DocmgmtInternet/Download.aspx?id=925.

(7) Final California 2012 Integrated Report. *Clean Water Act Section 303(d) List 305(d)*; California Environmental Protection Agency, California State Water Resources Control Board, 2015; http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2012.shtml.

(8) Poche Beach Ultraviolet Light Bacteria Disinfection Project Final Report. County of Orange, 2012; http://www.swrcb.ca.gov/water_issues/programs/beaches/cbi_projects/docs/summaries/304_pochebeach.pdf.

(9) Boehm, A. B.; Van de Werfhorst, L. C.; Griffith, J. F.; Holden, P. A.; Jay, J. A.; Shanks, O. C.; Wang, D.; Weisberg, S. B. Performance of forty-one microbial source tracking methods: A twenty-seven laboratory evaluation study. *Water Res.* **2013**, 47 (18), 6812−6828.

(10) Layton, B. A.; Cao, Y.; Ebentier, D. L.; Hanley, K.; Ballestè, E.; Brandão, J.; Byappanahalli, M.; Converse, R.; Farnleitner, A. H.; Gentry-Shields, J.; Gidley, M. L.; Gourmelon, M.; Lee, C. S.; Lee, J.; Lozach, S.; Madi, T.; Meijer, W. G.; Noble, R.; Peed, L.; Reischer, G. H.; Rodrigues, R.; Rose, J. B.; Schriewer, A.; Sinigalliano, C.; Srinivasan, S.; Stewart, J.; Van De Werfhorst, L. C.; Wang, D.; Whitman, R.; Wuertz, S.; Jay, J.; Holden, P. A.; Boehm, A. B.; Shanks, O.; Griffith, J. F. Performance of human fecal anaerobe-associated PCR-based assays in a multi-laboratory method evaluation study. *Water Res.* **2013**, *47* (18), 6897−6908.

(11) Sinigalliano, C. D.; Ervin, J. S.; Van De Werfhorst, L. C.; Badgley, B. D.; Balleste, E.; Bartkowiak, J.; Boehm, A. B.; Byappanahalli, M.; Goodwin, K. D.; Gourmelon, M.; Griffith, J.; Holden, P. A.; Jay, J.; Layton, B.; Lee, C.; Lee, J.; Meijer, W. G.; Noble, R.; Raith, M.; Ryu, H.; Sadowsky, M. J.; Schriewer, A.; Wang, D.; Wanless, D.; Whitman, R.; Wuertz, S.; Santo Domingo, J. W. Multi-laboratory evaluations of the performance of *Catellicoccus marimammalium* PCR assays developed to target gull fecal sources. *Water Res.* **2013**, *47* (18), 6883−6896.

(12) Schriewer, A.; Goodwin, K. D.; Sinigalliano, C. D.; Cox, A. M.; Wanless, D.; Bartkowiak, J.; Ebentier, D. L.; Hanley, K. T.; Ervin, J.; Deering, L. A.; Shanks, O. C.; Peed, L. A.; Meijer, W. G.; Griffith, J. F.; SantoDomingo, J.; Jay, J. A.; Holden, P. A.; Wuertz, S. Performance evaluation of canine-associated *Bacteroidales* assays in a multi-laboratory comparison study. *Water Res.* **2013**, *47* (18), 6909−6920.

(13) Griffith, J. F.; Layton, B. A.; Boehm, A. B.; Holden, P. A.; Jay, J. A.; Hagedorn, C.; McGee, C. D.; Weisberg, S. B. The California Microbial Source Identification Manual: A tiered approach to identifying fecal pollution sources to beaches. *Technical Report 804*; Southern California Coastal Water Research Project (SCCWRP), 2013; http://www.swrcb.ca.gov/water_issues/programs/beaches/cbi_projects/docs/sipp_manual.pdf.

(14) Bernhard, A. E.; Field, K. G. A PCR assay to discriminate human and ruminant feces on the basis of host differences in *Bacteroides-Prevotella* genes encoding 16S rRNA. *Appl. Environ. Microbiol.* **2000**, *66* (10), 4571−4574.

(15) Dick, L. K.; Field, K. G. Rapid estimation of numbers of fecal *Bacteroidetes* by use of a quantitative PCR assay for 16S rRNA genes. *Appl. Environ. Microbiol.* **2004**, *70* (9), 5695−5697.

(16) Standard Methods for the Examination of Water and Wastewater - Standard Methods Online. *American Public Health Association (APHA)*; Water Environment Federation Publication: Washington, D.C., 2012.

(17) Method 200.8: Determination of Trace Elements in Waters and Wastes by ICP-MS, Revision 5.4, EPA/600/R-94/111; United States Environmental Protection Agency, 1994.

(18) Meaurement and Computation of Streamflow Vol. 1: Measurment of Stage and Discharge. *Water Supply Paper 2175*; United States Geological Survey, 1982; http://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_vol1.html.

(19) Helsel, D. R. *Statistics for Censored Environmental Data Using Minitab and R*, 2nd ed.; John Wily & Sons, Inc.: Hoboken, NJ, 2012.

(20) Water Quality Control Plan for the San Diego Basin (9) September 8, 1994, with amendments effective on or before April 4, 2011. *San Diego Basin Plan*; State of California Regional Water Quality Control Board San Diego Region: San Diego, CA, August 28, 2012; http://www.swrcb.ca.gov/sandiego/water_issues/programs/basin_plan.

(21) Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California. Federal Register, Vol. 65, No. 97, 40 CFR Part 131. *California Toxics Rule*; United States Environmental Protection Agency, May 18, 2000; http://www.waterboards.ca.gov/water_issues/programs/tmdl/records/state_board/2003/ref476.pdf.

(22) Historic Rainfall Data for Orange County Watershed. Orange County Public Works: Orange County, CA, 2016; http://ocwatersheds.com/rainrecords/rainfalldata/historic_data (Accessed May 10, 2016).

(23) Fogarty, L. R.; Haack, S. K.; Wolcott, M. J.; Whitman, R. L. Abundance and characteristics of the recreational water quality indicator bacteria *Escherichia coli* and enterococci in gull faeces. *J. Appl. Microbiol.* **2003**, *94* (5), 865−878.

(24) Wright, M. E.; Solo-Gabriele, H. M.; Elmir, S.; Fleming, L. E. Microbial load from animal feces at a recreational beach. *Mar. Pollut. Bull.* **2009**, *58* (11), 1649−1656.

(25) Kinzelman, J.; McLellan, S. L.; Amick, A.; Preedit, J.; Scopel, C. O.; Olapade, O.; Gradus, S.; Singh, A.; Sedmak, G. Identification of human enteric pathogens in gull feces at Southwestern Lake Michigan bathing beaches. *Can. J. Microbiol.* **2008**, *54* (12), 1006−1015.

(26) Ramos, R.; Cerda-Cuellar, M.; Ramirez, F.; Jover, L.; Ruiz, X. Influence of refuse sites on the prevalence of *Campylobacter* spp. and *Salmonella* serovars in seagulls. *Appl. Environ. Microbiol.* **2010**, *76* (9), 3052−3056.

(27) Converse, R. R.; Kinzelman, J. L.; Sams, E. A.; Hudgens, E.; Dufour, A. P.; Ryu, H.; Santo-Domingo, J. W.; Kelty, C. A.; Shanks, O. C.; Siefring, S. D.; Haugland, R. A.; Wade, T. J. Dramatic improvements in beach water quality following gull removal. *Environ. Sci. Technol.* **2012**, *46*, 10206−10213.

(28) Cook, A.; Rushton, S.; Allan, J.; Baxter, A. An evaluation of techniques to control problem bird species on landfill sites. *Environ. Manage.* **2008**, *41* (6), 834−843.

(29) Surbeck, C. Q.; Jiang, S. C.; Grant, S. B. Ecological control of fecal indicator bacteria in an urban stream. *Environ. Sci. Technol.* **2010**, *44* (2), 631−637.

(30) Byappanahalli, M. N.; Nevers, M. B.; Korajkic, A.; Staley, Z. R.; Harwood, V. J. Enterococci in the environment. *Microbiol. Mol. Biol. R.* **2012**, *76* (4), 685−706.

(31) Ishii, S.; Sadowsky, M. J. *Escherichia coli* in the environment: implications for water quality and human health. *Microbes. Environ.* **2008**, *23* (2), 101−108.

(32) Byappanahalli, M.; Fowler, M.; Shively, D.; Whitman, R. Ubiquity and persistence of *Escherichia coli* in a Midwestern coastal stream. *Appl. Environ. Microbiol.* **2003**, *69* (8), 4549−4555.

(33) Craig, D. L.; Fallowfield, H. J.; Cromar, N. J. Use of microcosms to determine persistence of *Escherichia coli* in recreational coastal water and sediment and validation with in situ measurements. *J. Appl. Microbiol.* **2004**, *96* (5), 922−930.

(34) He, L. M.; Lu, J.; Shi, W. Variability of fecal indicator bacteria in flowing and ponded waters in southern California: Implications for bacterial TMDL development and implementation. *Water Res.* **2007**, *41* (14), 3132−3140.