Maine Healthy Beaches Program
Oceanographic and Meteorological Study

Microbial Pollution Levels and Transport Pathways at the Kennebunk River and Goochs Beach

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in cooperation with

TABLE OF CONTENTS

INTRODUCTION

The purpose of this report is to research potential relationships between high levels of *Enterococci* bacteria from data provided by the Maine Healthy Beaches Program for Goochs Beach and hydrodynamic and meteorological conditions that may influence recorded bacteria levels. This report supplements a previous study completed by the Maine Geological Survey (MGS, Slovinsky and Dickson, 2008a) of the ebbing tidal currents in the vicinity of the Kennebunk River.

Maine Healthy Beaches Program Data

The Maine Healthy Beaches Program has been monitoring *Enterococci* levels at five locations in Kennebunk: KBK-1 through KBK-5. Another location, COLONY-1, located at Colony Beach, was added in 2005. Locations KBK-1, KBK-2, and COLONY-1 (hereafter, COL-1) are in the Goochs Beach area. The sample locations are shown in Figure 1. Samples were typically collected once a week during the summer months (i.e., Memorial Day through Labor Day), and recorded *Enterococci* levels (col/100mL), the time of sampling, salinity (ppm), air and water temperature (ºC), tidal stage, and site observations. Information relating to the available sampling dataset is shown in Table 1.

Site	2003	2004	2005	2006	2007	Total
KBK-1	15	15	19	32	12	93
KBK-2	15	15	20	32	20	102
COL-1			13	15	14	42

Table 1. Number of collected water quality samples for each site (Maine Healthy Beaches Program).

Supplemental Hydrodynamic and Meteorological Data

MGS was able to acquire additional oceanographic and meteorological data that corresponded with the periods of data collection. We focused on 2004-2007 since no samples exceeded required *Enterococci* levels in 2003 (see Table 2). Hydrodynamic data was available from the Gulf of Maine Ocean Observing System (GoMOOS, http://www.gomoos.org) Buoy B (Western Maine Shelf). This included hourly significant wave height, wind speed and direction, daily precipitation, and hourly tidal data. For ease in comparison with the daily sampling protocol, significant wave height, wind speed and direction, and hourly tidal data (i.e., averaged high and averaged low) were calculated for each 24 hour period. Daily meteorological conditions, including precipitation data for the Portland International Jetport, were available from the National Oceanic and Atmospheric Administration's National Climatic Data Center (http://cdo.ncdc.noaa.gov/CDO/cdo).

RESULTS

Initial Data Analysis

Analysis of collected data from the MHBP shows that 195 total samples were collected at KBK-1 and KBK-2 from 2003 to 2007, with an additional 42 samples taken at COL-1, for a total of 237 samples. Of these, a total of 32 samples showed *Enterococci* levels that exceeded 104 col/100mL (approximately 13%, Table 2). Of the samples, KBK-1 was generally the lowest scoring sample, while KBK-2, located at the western end of Goochs Beach, accounted for the largest number of high samples. About 60% of the exceedences were at KBK-2.

	2003			2004			2005			2006			2007			Total 2003 - 2007		
Site	**N**	**N>104**	**%**	**N**	**N>104**	**%**	**N**	**N>104**	**%**	**N**	**N>104**	**%**	**N**	**N>104**	**%**	**N**	**N>104**	**%**
KBK-1	15	0	0.0	15	1	6.7	19	1	5.3	32	6	18.8	12	1	8.3	93	9	9.7
KBK-2	15	1	6.7	15	2	13.3	20	5	25.0	32	6	18.8	20	5	25.0	102	19	18.6
COL-1							13	0	0.0	15	2	13.3	14	2	14.3	42	4	9.5

Table 2. Collected sample data, including exceedences, for KBK-1, KBK-2, and COL-1 from 2003 through 2007 (Maine Healthy Beaches Program).

Results from the current study by MGS (Slovinsky and Dickson, 2008a) showed that ebbing currents from the Kennebunk River traveled southward in a distinct body, while entraining water from either side. The Goochs Beach study area was divided into 5 different current zones, based on the patterns observed during an ebbing tide. We compared the higher scoring samples to try to discern any patterns that might relate to pollution distribution.

There were 19 occurrences when samples were collected *on the same date* and at least one sample recorded exceeded 104 col/100mL. Of these, 14 days (74%) exhibited higher bacteria values at KBK-2 than KBK-1. If the source of pollution is the river, then currents, at some point, are bringing bacteria to the western end of the beach more than to the eastern end.

Initial Data Relationships

This section describes the potential relationships between the recorded bacteria levels and other data collected by volunteers as part of the Maine Healthy Beaches Program. Notably, salinity and water temperature are investigated.

Salinity. Since we assume that the Kennebunk River accounts for some of the sourcing of bacteria, we would assume, in general, that lower salinity levels would relate to higher bacteria counts. Figure 2 shows the relationship between *Enterococci* and recorded salinity for the three sample locations. Salinity recordings taken at Goochs Beach indicate that the water mass is influenced by freshwater – the average salinity for all samples recorded was approximately 31 parts per thousand (ppt), which is below the average salinity for ocean water (approximately 35 ppt). It is especially noted at the Colony site (COL-1), the higher bacteria levels were commonly recorded at lower salinity levels (in the 23-26 ppt range). This may be attributed to freshwater from the Kennebunk River that is returning to the beach at this sample location. Otherwise, there was no discernable pattern for the influence of salinity, other than the fact that most recorded salinities were below the average for ocean water.

Water Temperature. Next, we analyzed the relationship of water temperatures recorded by the MHB volunteers during sample collection with high *Enterococci* scores. There appeared to be little clear relationship between water temperature and high bacteria counts. There were several instances where higher scores seemed to relate to a certain temperature range. For example, at KBK-1, the highest bacteria counts occurred when temperatures were 15-18ºC, though there were many samples at these temperatures that were below 104 col/100mL. Similarly, the three highest readings for KBK-2 occurred from 14-16ºC. For both, there were also exceedences at lower temperatures. At COL-1, no pattern at all was discerned. Thus, it appears that water temperature generally does not relate to or predict higher *Enterococci* scores.

Additional Data Relationships

MGS next investigated the relationships between *Enterococci* levels and potential forcings, such as tidal elevation and precipitation. Each of these factors is discussed below.

Tidal Elevation. We averaged the two low and two high tide elevations for each day that data was collected to determine an average daily low and high tide elevation (referenced to Mean Lower Low Water, MLLW). We then combined these values to determine an average daily total tidal swing or tidal range.

The *highest* bacteria counts appear to have occurred at around the 9.5 ft MLLW mark. However, about 60% of all tidal range values were in the 9.40-9.65 ft range. For KBK-1, 5 of the 9 high bacteria counts occurred within this range. Above 9.65 ft MLLW, there were no exceedences. For KBK-2, 13 of the 19 high counts, including the highest recorded, occurred within this range. Three additional exceedences occurred above this tidal range, and 3 below that range. For COL-1, all 4 high counts occurred in this tidal range. Although it is difficult to say that this tide range will produce high bacteria counts, it seems that tidal ranges lower than 9.4 ft MLLW relate with reduced bacteria counts. Tidal ranges above that elevation but below 9.5 ft MLLW appear to have higher incidents of elevated bacteria levels.

Tidal Stage. We next analyzed the bacteria levels for each location in the context of tidal stage at the time of sampling. Of the 237 total readings taken from 2003-2007, roughly 53% occurred on a flooding tide, and 47% occurred during an ebbing tide (Table 3). Of these, about 29% were taken during a midflooding tide, and 21% taken on a mid-ebbing tide. The data shows that the majority of high scoring samples were collected during a flooding (low to high) tide. Of the 129 total incoming tide samples taken, 19 samples exceeded the recommended bacteria levels, roughly 15%. For ebbing tides, there were 13 samples of 112 total samples recorded that exceeded bacteria levels, or 13%. So it appears that roughly the same percentage of incoming and outgoing tides can have high-scoring samples.

There was a relatively even distribution of sample exceedences for each sample location. At KBK-1, 6 of 48 samples (12.5%) taken during flooding tides had high bacteria counts, as opposed to 3 of 45 samples (6.7%) during ebbing tides. At KBK-2, both flooding and ebbing tides had roughly the same percentage (20%) of high bacteria counts. For COL-1, just over 7% of recorded samples had high bacteria counts during flooding tides, while 11% of ebbing tide samples had high bacteria counts.

Tidal	KBK-1		KBK-2		COL-1		N	Percent	>104	Percent
Stage	N	N>104	N	N>104	N	N>104	(Total)	All Tides	Total	Exceed
L	9	0	5	0	6	0	20	8.2	0	0.0
LF	6	2	8	2	4	2	18	7.4	6	33.3
MF	27	3	30	7	13	0	70	28.8	10	14.3
HF	6	1	10	2	2	0	18	7.4	3	16.7
H	7	0	7	3	3	0	17	7.0	3	17.6
HE	9	1	10	2	2	0	21	8.6	3	14.3
ME	21	1	20	3	11	1	52	21.4	5	9.6
LE	8	1	12	0	1	1	21	8.6	2	9.5
Total	93	9	102	19	42	4	237	97.5	32	13.5

Table 3. Tidal stages associated with samples collected at Goochs Beach from 2004-2007.

Wave Height. We next investigated the potential influence of nearshore wave height, measured at GoMOOS Buoy B (Western Maine Shelf), on bacteria counts. Similar to other beaches we have studied, we would expect that days with higher wave heights would result in lower scores due to additional mixing that may occur, especially along more open locations like KBK-1 and KBK-2 as opposed to COL-1, which is more sheltered. Of the all the days that had wave height data recorded (i.e., for each day of each month for which wave data was collected from 2004-2007), wave heights were equal to or under 3 feet for 79% of the time. Thus, the majority of samples were collected during such conditions. In fact, there were 75 sample days of the total 95 sample days (i.e., days that at least 1 sample was recorded at one of the three locations) where wave heights were 3 feet or less when samples were recorded. This accounted for 172 total samples recorded. Of these, there were a total of 27 samples that recorded high bacteria counts (16%). Of the 42 samples which were recorded when wave heights were greater than 3 feet, 5 samples had high bacteria counts (19%).

If we increase the cutoff wave height to 4 feet, then only 3 samples of 21 (or 14%) exceed recommended bacteria limits. However, at 4.5 feet or greater, only 1 of 13 samples (8%) had high bacteria counts.

Based on this data, it *does not appear* that an increase in wave height *significantly impacts* bacteria levels at the sample locations at Goochs Beach. *However, if waves exceed 4.5 feet, this does appear to decrease high counts by roughly half.*

Wind Direction. Next, we investigated the role of wind direction on bacteria levels. Wind directions were taken from the GoMOOS Buoy B (Western Maine shelf). Wind directions, recorded for each hour, were averaged over a 24 hour period so that a wind direction could be used to correlate with a sample date. The limitation in this method is that wind directions vary throughout the day, and could be averaged to be a different direction than the wind at the time a sample was taken. At the same time, wind directions prior to a sampling time could have an influence on that sample, yet not be represented if only the wind direction at the time a sample was taken was used.

We examined all samples in relation to wind direction (Figure 6). There did appear to be a relationship between higher bacteria levels and winds directed from the southeast-southwest (170-220º from north) for KBK-1, but especially for KBK-2. At KBK-2, 10 of 19 samples that had bacteria levels that exceeded 104 col/100mL were collected when the wind was directed from the southeast to southwest. Of the days that samples were collected at least at one of the locations, the wind was from these directions for 50% of the time. This is likely due to the fact that sampling occurs in the summer months, when these wind directions are dominant. There were several very high readings, including the highest, at KBK-2 when winds were more from the southeast and easterly directions. This could cause pollutants that exit the Kennebunk River to migrate to the west, towards the sampling location at KBK-2.

At COL-1, it seems like the higher bacteria counts occurred with a southwest to more westerly directed wind. This makes some sense, as river water could be directed to this portion of the beach under any westerly wind conditions.

Winds from the north, northeast, and east (0-90º from N) generally correlated with clean water conditions for all sample locations, aside from two readings at KBK-2. These winds blow offshore to alongshore, and probably help push any polluted water away from the beach.

Thus, *it appears that wind direction does play a role in directing bacteria that exits the river to different portions of Goochs Beach.*

Precipitation. Daily precipitation data was available from the NOAA National Climate Data Center for the Portland International Jetport. If we inspect direct correlation between rainfall recorded *on the day of sampling*, we found little clear pattern (Figure 7). We also inspected total precipitation that occurred within 5 days preceding the day samples were taken (Figure 8).

On first inspection of Figure 8, it appears that high bacteria count data has a bimodal distribution – high bacteria counts within the range of roughly one cumulative inch or less of rainfall, and high counts with cumulative rainfall of two inches or greater. This is especially notable for sample location KBK-2.

There were 19 sampling days with zero to trace (i.e., 0.01 inches or less) cumulative rainfall amounts. Of these, there were a total of 5 days where at least one sample location had a high bacteria count (26%). All of these were recorded at KBK-2. Therefore, since a total of 19 samples at KBK-2 were high, this accounts for 26% of all high samples at KBK-2. Neither KBK-1 nor COL-1 had any high counts with zero to trace rainfall amounts.

This data indicates that KBK-2 could be receiving bacteria sourced from the Kennebunk River *without the influence of rainfall*.

There were 73 days when samples were taken that rainfall within the preceding 5 days was one inch or less (79% of all rainfall days). Of these days, 16 days had at least one sample of the three locations where Enterococci levels were above 104 col/100mL, accounting for 20%). In fact, a total of 22 samples (of 32 total exceedences, which accounts for 69% of all high bacteria counts) exceeded bacteria levels with rainfall equal to or less than one inch. Thirteen of these samples were collected at KBK-2. This accounts for 68% of the exceedences seen at KBK-2. This almost triples the number of high counts at KBK-2.

At KBK-1, which appears to be “clean” with zero to trace cumulative rainfall amounts, a total of 7 samples (78% of all high samples) had high bacteria counts with cumulative rainfall of one inch or less.

Of the days that rainfall within the week preceding a sample *exceeded 1 inch* (18 days total), there were 5 days (28%) where bacteria levels were high. Rainfall amounts of greater than one inch did not seem to significantly impact either KBK-1 or COL-1 readings. However, KBK-2 did have several high readings that seemed to increase after 2 inches of rain had fallen.

Based on these results, it appears that water quality at KBK-2 can be compromised *without the influence of rainfall.* At the same time, it seems that KBK-1 and COL-1 are clean without the influence of rainfall. However, if cumulative rainfall of one inch or less does occur within 5 days of sample collection, it seems that water quality *at all locations is diminished.* This is likely due to an increase in the amount of bacteria being discharged by the Kennebunk River, but also a potential significant increase in non-point runoff from Beach

Avenue. *There are numerous direct outfalls along the seawall at Goochs Beach that drain Beach Avenue which could be sourcing bacteria.*

DISCUSSION

Based on the results of the current study and this analysis, it appears that high bacteria counts at Goochs Beach likely originate from two sources: the Kennebunk River, and run-off after rain events from Beach Avenue and potentially sections of Beach Avenue. A third source could be naturally occurring seaweed that piles up at the western end of Goochs Beach (near KBK-2).

In addition to these sources, it is likely that different meteorological and oceanographic conditions play a role in influencing bacteria levels and distribution in the Goochs Beach area as they do at Ogunquit Beach (Slovinsky and Dickson, 2008b) and elsewhere (Boehm, *et al*., 2004; Santoro and Boehm, 2007; Boehm and Weisberg, 2005; Ki, *et al*., 2007; Kim *et al*., 2004; Reeves *et al*., 2004; Sanders *et al*., 2005).

The previously completed current study at Goochs Beach (Slovinsky and Dickson, 2008a) identified distinct current zones during an ebbing tide: an Entrainment Current Zone (ECZ), an offshore Slack Current Zone (SCZ), a Nearshore Current Zone (NCZ), and a Western Fringe Current Zone (WFCZ) and Eastern Fringe Current Zone (EFCZ, see Figure 9). The dominant ECZ, caused by the ebbing Kennebunk River, strongly entrains water from the east and west and directs it southwards (offshore). Here, the SCZ is encountered. It is possible that some of the **water moved offshore by the ebbing currents** – if it is high in bacteria – can enter the SCZ, and be **returned to the beach on the next flooding tide**. We also noted **ebbing currents are directed towards the western end of the beach**. It is possible that this mechanism could be the cause of diverting pollutants **from the river to the KBK-2** sample site. It is also possible that these current patterns are directing **seaweed** to the western end of the beach, which can be a source for high bacteria counts as well (see Figure 9).

A California study (Kim *et al*., 2004) found that calm periods during the nighttime (generally when winds were calmest and wind-driven waves were lowest) likely allowed bacteria sourced from a river to be entrained within and just outside of the surf-zone (the Slack Current Zone or SCZ at Goochs Beach) on falling tides, allowing for the **bacteria to be moved toward swimming beaches during the day** by flooding tides, onshore winds, and waves. This phenomenon was identified at Ogunquit Beach (Slovinsky and Dickson, 2008b). Similar to Ogunquit, this **nighttime transport** may be occurring at Goochs Beach as well.

Wind direction appears to play a potential role in distributing bacteria at the sample locations along Goochs Beach. Wind from the **south, southeast, and southwest**, would help direct polluted water towards the beach, with winds of a more **westerly** component directing pollutants towards COL-1, and winds from with a southeasterly component directing pollutants more towards KBK-2. N**orth, northeast, and east winds appear to result in better water quality**. This may relate to either (a) storm events that usually produce wave mixing and strong north-northeast winds, or (b) offshore-directed winds that entrain surface water seaward and hence move pollutants away from the beach.

Based on precipitation data, it appears that **KBK-2 receives pollutants regardless of the amount of precipitation that occurred**. It is the only sample location that continued to record high bacteria levels with zero to trace cumulative precipitation. Precipitation does appear to impact all locations, likely through an increase in the volume of pollutants introduced by the river, and also run-off from outfalls along Beach Avenue which discharge directly to Goochs Beach. Interestingly, **precipitation amounts greater than one inch do not significantly increase bacteria counts at KBK-1 or COL-1. Precipitation greater than 2 inches can cause even higher counts at KBK-2**.

It does not appear that offshore wave heights significantly decrease bacteria levels at the sample locations. However, **when waves are 4.5 feet or greater** (as measured at the GoMOOS Buoy B), **bacteria levels do appear to be reduced**. This would likely occur with wave approach from the southeast and east. However, these wave approach directions may actually help transport bacteria along the beach towards KBK-2. With southwest wind-wave approach, bacteria could be transported to the east, towards COL-1. It appears that larger offshore waves (greater than 4.5 feet) **may help to reduce bacterial levels** at Goochs Beach. Similar wave transport phenomenon of bacteria was observed at several California beaches (Kim *et. al*., 2004; Santoro and Boehm, 2007).

Nineteen of 32 (59%) high bacteria samples occurred during flooding tidal stages. There is a slight bias in the data, with flooding tides accounting for 52%, and ebbing tides the remaining 48%. However, this result likely indicates that pollutants that are most likely being **released from the river on an ebbing tide *are being directed towards the beach on the flooding tide*.** As mentioned earlier, it is possible that pollutants that are sourced from the river could be entering the SCZ, and be returned to the beach during the next flooding tide.

Finally, pollutants could be introduced to the Goochs Beach area from the **stormwater outfalls** along Goochs Beach. These outfalls drain storm water from Beach Avenue, and discharge directly onto the beach. On a previous site visit on July 6, 2006, we photographed one of these suspect outfalls near the western end of the seawall (Figure 10). It is clear that some type of discharge is occurring from the outfall. These outfalls sit very low on the seawall, and have the potential to harbor bacteria that may be released by some high tides.

CONCLUSIONS

Based on the coastal circulation at Goochs Beach and the mouth of the Kennebunk River and oceanographic and meteorological conditions during and preceding samples collected to measure bacteria concentrations along Goochs and Colony Beaches, the following conclusions are drawn from the data:

- It seems that there are three likely sources of pollution at Goochs Beach: (1) the Kennebunk River, (2) run-off from Beach Avenue, and (3) naturally occurring seaweed that collects at the western end of Goochs Beach.

- The sample location with the most and consistently highest scores was KBK-2. Sourcing of pollutants to the KBK-2 site could be the river itself (ebb currents direct water towards the western end of the beach, as likely do flooding currents), or naturally occurring seaweed that is deposited by tides on the beach.

- It is likely that pollutants are reaching the western end of Goochs Beach from the outfalls along Beach Avenue, which direct run-off directly onto Goochs Beach.

- Lower salinity levels generally do not appear to correlate with higher bacteria counts.

- Water temperature generally does not appear to be a good indicator of higher bacteria counts.

- Tidal elevations between 9.4-9.65 ft MLLW generally do appear to relate to higher bacteria counts.

- Wave height does not generally appear to significantly decrease bacteria counts unless it is greater than 4.5 feet (at Western Maine Shelf Buoy).

- North to east winds generally correlate with lower bacteria counts, while southeast to southwest winds correlate with higher counts.

- It is not clear that rainfall necessarily correlates to higher bacteria counts, though precipitation amounts between 0.5-1” within 5 days of a sampling date generally had the highest counts.

RECOMMENDATIONS

We recommend that the Maine Healthy Beaches Program and Town of Kennebunk further investigate the role that the existing outfalls along the seawalls of Goochs Beach may play in elevating beach bacteria levels, from times of (a) increased freshwater discharge and (b) when high tides or surf can introduce saltwater into the outfalls.

We recommend that the Maine Healthy Beaches Program and Town of Kennebunk investigate the naturally deposited seaweed at the western end of Goochs Beach as a source for producing elevated bacteria levels. Depending on the outcome, a seaweed management plan may help improve water quality.

We also recommend that the Maine Healthy Beaches Program begin to work with the Towns of Kennebunk and Kennebunkport to investigate what the upstream sources of bacteria discharged into the Kennebunk River might be. This might include additional study of septic systems, urban runoff, leaking wastewater pipes, or natural inputs from wildlife in the watershed.

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