Bobcaygeon Beach Water Quality Report

May 2018

KAWARTHA CONSERVATION

Discover • Protect • Restore

About Kawartha Conservation

Who we are

We are a watershed-based organization that uses planning, stewardship, science, and conservation lands management to protect and sustain outstanding water quality and quantity supported by healthy landscapes.

Why is watershed management important?

Abundant, clean water is the lifeblood of the Kawarthas. It is essential for our quality of life, health, and continued prosperity. It supplies our drinking water, maintains property values, sustains an agricultural industry, and contributes to a tourism-based economy that relies on recreational boating, fishing, and swimming. Our programs and services promote an integrated watershed approach that balance human, environmental, and economic needs.

The community we support

We focus our programs and services within the natural boundaries of the Kawartha watershed, which extend from Lake Scugog in the southwest and Pigeon Lake in the east, to Balsam Lake in the northwest and Crystal Lake in the northeast – a total of 2,563 square kilometers.

Our history and governance

In 1979, we were established by our municipal partners under the *Ontario Conservation Authorities Act*.
The natural boundaries of our watershed overlap the six municipalities that govern Kawartha Conservation through representation on our Board of Directors. Our municipal partners include the City of Kawartha Lakes, Region of Durham, Township of Scugog, Township of Brock, Municipality of Clarington, Municipality of Trent Lakes, and Township of Cavan Monaghan.

Kawartha Conservation

T: 705.328.2271

F: 705.328.2286

277 Kenrei Road, Lindsay ON K9V 4R1

GenInfo@KawarthaConservation.com

KawarthaConservation.com

Acknowledgements

This report was written by Debbie Balika, Water Quality Specialist, Kawartha Conservation. Peer editors include Brett Tregunno, Aquatic Biologist, Dave Pridham, Manager Environmental Technical Services and Richard Ovcharovich, Haliburton Kawartha Pine Ridge District Health Department (HKPR). Others whom contributed to the development of this project include:

Councilor Kathleen Seymour Fagan	City of Kawartha Lakes
Pamela O'Brien	Public Health Ontario
Richard Ovcharovich	HKPR
Martha Hodge	HKPR
Nancy Aspden	Kawartha Conservation
Rob Stavinga	Kawartha Conservation

Funding for this project was provided by the City of Kawartha Lakes and the Public Health Ontario.

Table of Contents

Abbreviations

CKL:	City of Kawartha Lakes
CWQG:	Canadian Water Quality Guideline
EC:	Environment Canada
E.coli:	*Escherichia coli*
masl:	Meters above sea level
OMNRF:	Ontario Ministry of Natural Resources and Forestry
MOECC:	Ontario Ministry of the Environment and Climate Change
PWQMN:	Provincial Water Quality Monitoring Network
PWQO:	Provincial Water Quality Objectives
SLMP:	Sturgeon Lake Management Plan
TKN:	Total Kjeldahl Nitrogen
TN:	Total Nitrogen
TP:	Total Phosphorus
TSS:	Total suspended solids
TSW:	Trent Severn Waterway

Introduction

Kawartha Conservation plays a pivotal role in natural resource management within its 2600km^2 jurisdiction. Through the lake management planning process a number of water quality issues have been identified throughout the region which can have lasting impacts on tourism, recreational opportunities and ecological health. As highlighted in the Sturgeon Lake Management Plan, Bobcaygeon Beach Park is a priority concern as it is highly used, in a most desirable location, and posted approximately 30% of the time from June to the end of August (2010 to 2015). High *E. coli* concentrations are likely the result of a combination of factors including: excessive feces from birds, particularly Canada Geese, combined with urban runoff and pet feces following storm events, and/or shallow, warm waters with limited water circulation" (SLMP; 2014). Concentrations of fecal indicator bacteria (FIB) such as *E.coli* have been used as a method to assess recreational water quality and the risk to human health. Human health risks are determined based the threshold of 100cfu/100ml using the geomean calculation (Ontario Public Health Standards, Beach Management Guidance Document 2014).

Although, recreational water quality thresholds have been widely studied, there has been evidence that FIB in sand may act as a reservoir or source (sink) and play a role in water quality. Previous studies have concluded that sand located near the shoreline at freshwater beaches demonstrated higher concentrations of E.coli than the adjacent shallow surface water and can be considered known reservoirs for *E. coli* (Kinzelman et al., 2004: Staley et al.,2015; Vogel et al 2016., Vogel et al 2017). The fecal concentration of foreshore sand is a result of contamination via wildlife (mostly shore birds), surface water (wave action), ground water and storm water runoff.

The aim of this study is to determine where the greatest densities of *E.coli* occur at the beach and 3 upstream sites and attempt to establish any relationships between *E.coli* densities, water chemistry parameters and shoreline conditions. Finally, foreshore *E.coli* densities will be quantified. Thus, in collaboration with the Haliburton, Kawartha Pine Ridge District Health Unit, a small scale study was carried out from June to the end of August.

2.0 Methodology

Site Description

Bobcaygeon Beach Park, also known as Verulam Beach, is located on the Trent Severn Waterway on Sturgeon Lake, Ontario (Figure 1). The park is adjacent to a main road and high density residences with little to no buffer zone to the beach. One beach and three upstream monitoring sites were spatially distributed, based on sampling accessibility and distance from the beach site (Figure 2).

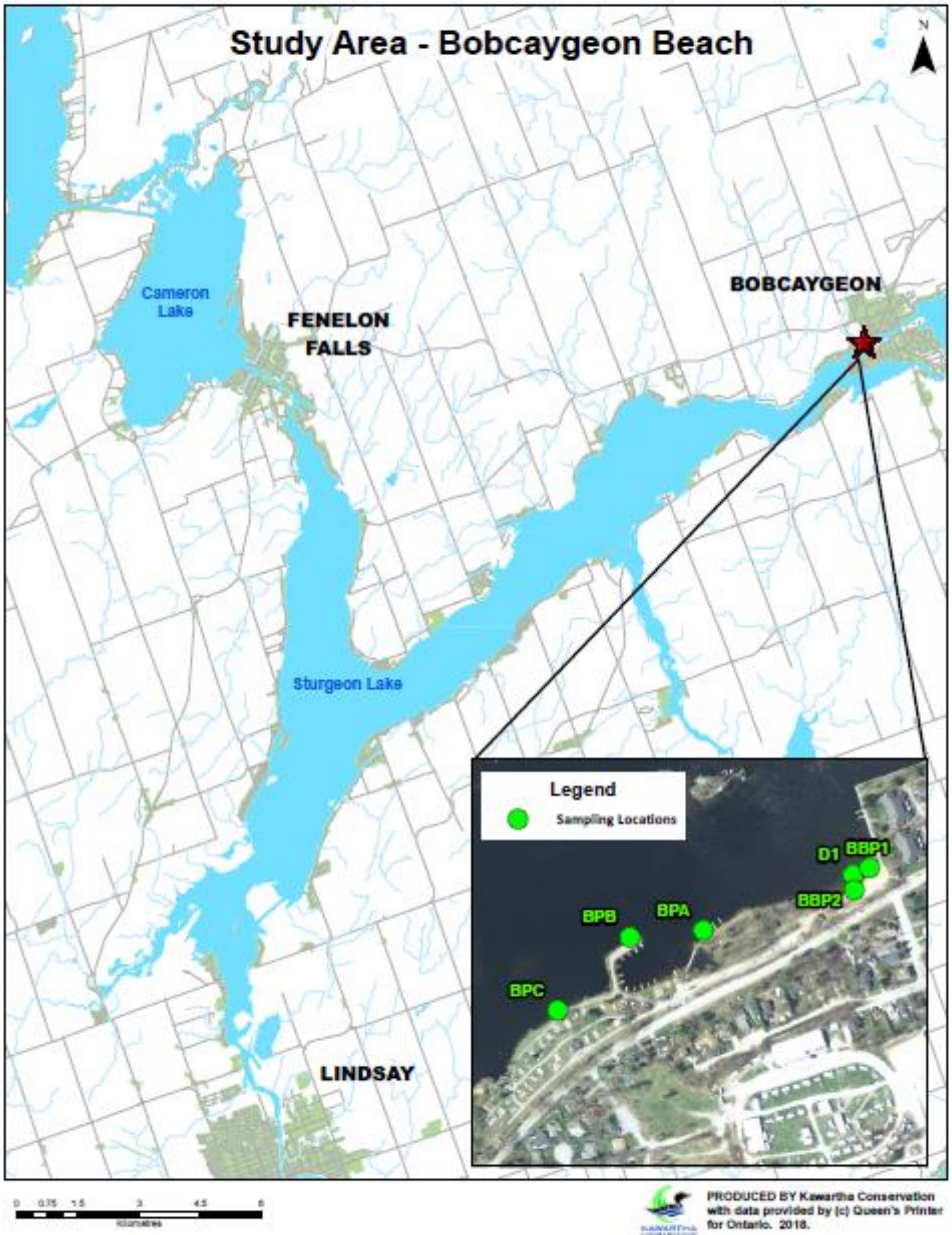


Figure 1. Location of study area, Bobcaygeon Beach Park, Bobcaygeon, Ontario.

Figure 2. Bobcaygeon Beach Park sampling sites (Table 1).

Table 1. Sampling sites

Site code	**Water/ sand *E.coli* sample sites**	**Water chemistry**	**Vegetated buffer condition**
D1	water	weekly	beach
BPA	water	NA	Well vegetated
BPB	water	weekly	degraded
BPC	water	NA	degraded
BBP1	sand	NA	beach
BBP2	sand	NA	beach

Sampling methods

The Ontario Public Health Standards, Beach Management Guidance Document (2014) provides a monitoring protocol which includes water sample collection 15 to 30cms below the water surface in water depth of 1 to 1.5m and in water less than 1m in depth an appropriate distance from the shore. Water samples for *E.coli* were collected at the beach site (D1) on a daily basis (Monday to Friday) from mid-June to the end of August, generally around 9:00am, by HKPR staff. Additional data such as water and air temperature, turbidity, previous rainfall, bather density, wave direction, wave height and any observation of potential pollution sources (i.e. dogs on beach) was collected each time sampling took place.

Water samples for *E.coli*, at upstream monitoring sites, were sampled weekly (Wednesdays) generally around 9:00am. At the beach (site- D1) and at one upstream site (site-BPB) weekly water samples were also collected for total phosphorus, nitrogen, total suspended solids and chloride analyses. General water quality data such as dissolved oxygen, conductivity, turbidity and pH were collected with an YSI DDS handheld multi probe. At upstream sites BPA and BPC were sampled weekly for *E.coli* as per Public Health Ontario beach guidelines protocols (Figure 2).

Beach sand samples were collected on a weekly basis (Wednesdays) including sand temperatures. Samples were taken at 2 separate locations along a transect 3m inward from the swash (where the waves meet the foreshore) area (Figure 3). A composite sample from 5 subsamples spaced 30cm apart and 10cm deep were taken with a sterilized scoop and placed in a sterile amber glass bottle (Staley et al 2016). Samples were sent to an outside accredited lab, SGS, Environmental Laboratories.

Figure 3. Beach sampling site (D1) and sand sampling sites (BBP1 & BBP2) located 3m up shore of swash area.

Escherichia coli densities are determined by membrane filtration technique. The sample is filtered by a vacuum through a 47mm diameter, 0.45µm pore size cellulose-ester gridded membrane filter. The bacterial cells trapped on the surface of the filter form colonies when placed on mFC Basal medium and are incubated inverted at 44.5ºC +/- 0.5ºC for 24 + 2 hours. The media uses the chromogenic substrate BCIG (5-bromo-6-cloro-3-indolyl-B-D-glucuronide) for quantitative recovery of *Escherichia coli* from aqueous, soil, and sludge samples. The BCIG gives visible blue colonies (SGS Laboratories 2018). Details on CFU calculation methods can be found in Appendix A.

Data analysis

E.coli values determined from water samples were calculated and recorded in GEOMEAN. *E.coli* values determined from sand samples were recorded in raw form. All data was LOG transformed (a value of 1 was added to prior transformation to omit any zeros or negatives). *E. coli* concentrations were determined to be normally distributed prior to analysis (Kolmogorov-Smirnov, SigmaPlot V.13). All surface water quality data were determined to achieve normality except for total suspended solids (Shapiro-Wilk, SigmaPlot V.13). ANOVA was used to determine significant variation between sites using both water and sand *E.coli* and surface water quality data. Linear regression analysis was performed to compare *E.coli* concentrations in sand and water with surface water quality parameters and precipitation amount.

3.0 Results

Surface water temperatures at all sites ranged from 19.5ºC to 24ºC during the study period. The highest temperature was recorded at site BPB on July 19th, 2017 while the lowest was recorded at site D1 on June 28, 2017 (Table 2). The mean temperature was 21ºC and the median was identical. Water temperatures did not vary significantly between sites ($P<0.05$, T Test, SigmaPlot, V.13.)

Dissolved oxygen concentrations ranged from 6.35mg/L to 9.15mg/L (Table 1). Overall mean dissolved oxygen concentrations were generally lower at the D1 site in comparison to the BPB site calculated at 7.04mg/L and 8.5mg/L respectively and the median values were very similar (Table 1). Dissolved oxygen concentrations varied significantly between sites ($P<0.05$, T Test, SigmaPlot V.13.).

Conductivity measurements ranged from 172.4 µS to 236.2µS and did not vary significantly between the two sites ($P>0.05$, T Test, SigmaPlot V.13.). The mean conductivity values were 203.42µS at D1 and 194.99 µS at site BPB and median values were similar (Table 2).

pH values ranged from 7.50 to 9.01. Mean values at were calculated at 8.22 and 8.37 at sites D1 and BPB respectively and median values demonstrated similar findings (Table 2). pH values did not vary significantly site-wise ($P>0.05$, T Test, SigmaPlot V.13.).

Nutrients

Phosphorus

Phosphorus is one of the two primary nutrients required for the growth of aquatic plants and algae in streams and lakes. Even in elevated levels phosphorus is not considered toxic to plants and animals, but its high concentrations in water can cause the process of eutrophication, which results in excessive algal growth, and a corresponding depletion of dissolved oxygen in the water column. The Provincial Water Quality Objective (PWQO) for total phosphorus (TP) concentrations in watercourses is set at 0.030 mg/L, in order to prevent nuisance algae and aquatic plant growth (MOECC, 1994). The PWQO for TP concentrations in lakes is 0.020 mg/L and/or 0.010 mg/L for those lakes with a natural TP level below this value (MOECC, 1994). The PWQO value being considered for Sturgeon Lake is 0.020mg/L.

Table 2. General water chemistry characteristics.

Water Temperature					
Site	**min**	**max**	**median**	**mean**	**Samples (n)**
BPB	20.2	24.0	21.35	21.83	24
D1	19.5	23.8	21.40	21.57	24
Dissolved oxygen					
BPB	6.48	9.15	8.58	8.32	24
D1	6.35	8.16	7.51	7.04	24
Conductivity					
BPB	172.40	208.90	197.10	194.99	24
D1	176.40	236.20	202.1	203.42	24
pH					
BPB	8.00	8.61	8.18	8.23	24
D1	7.50	9.01	8.35	8.37	24

Overall Sturgeon Lake is considered to have relatively good water quality and is designated as a mesotrophic water body (SLMP 2014). According to Lake Partner Program data for Sturgeon Lake, total phosphorus concentrations are within the 0.02mg/L PWQO. More recent data from Kawartha Conservation's on going citizen science near shore water quality monitoring program demonstrates a similar trend in total phosphorus concentrations and are also within the same PWQO (Kawartha Conservation; N.P. 2018) .

Average phosphorus concentrations over the entire study period at both the beach (D1) and upstream site (BPB) reached the PWQO and measured 0.02mg/L, however weekly single sampling results demonstrated some exceedances well above the PWQO (Figure 4). Median concentrations were the same as the mean concentrations (0.02mg/L).

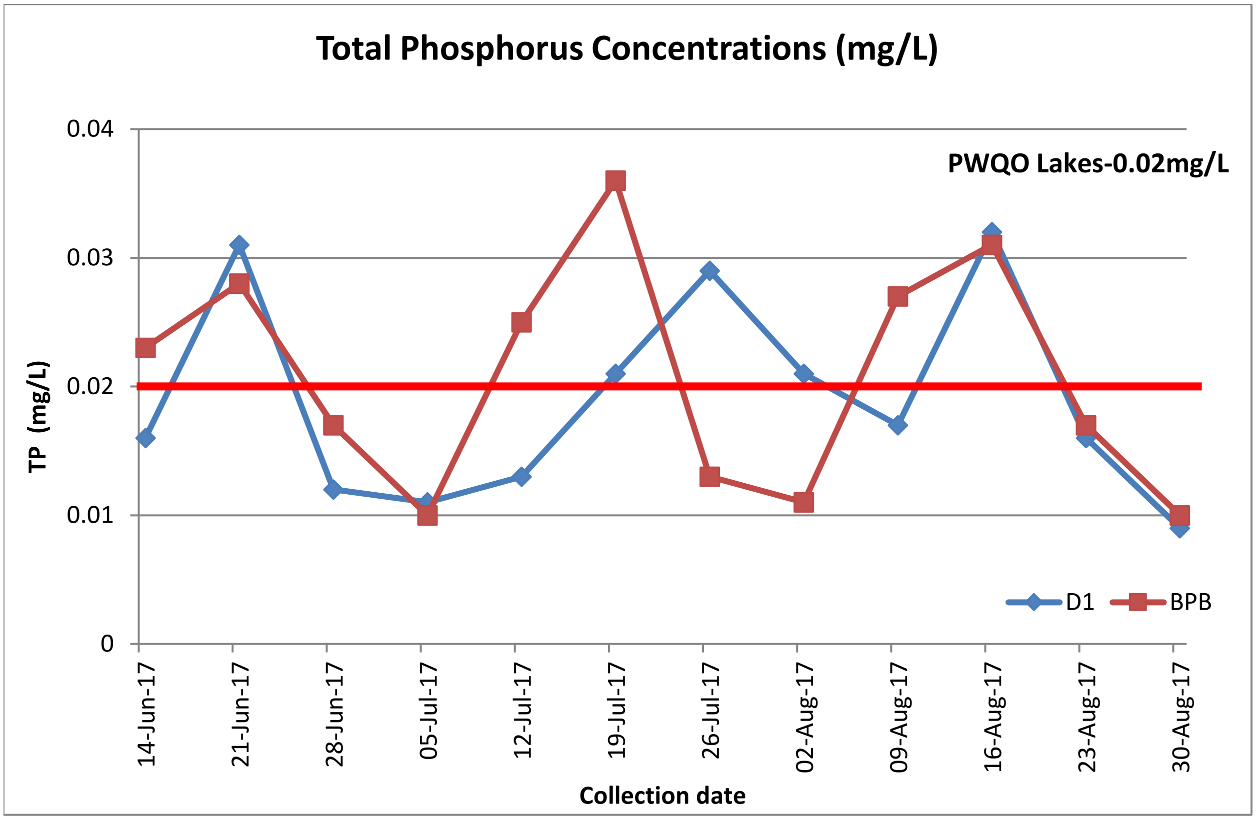


Figure 4: Total phosphorus concentrations at sites D1 and BPB.

There was no significant variation between sites D1 and BPB and both sites followed the same general trend (P>0.05, T-Test, SigmaPlot V.13.) Regression analysis showed a weak positive correlation between total phosphorus and *E.coli* water samples (r^2=0.16, P<0.05, Microsoft Excel 2010) and total phosphorus and total nitrogen (r^2= 0.11, P<0.05, Microsoft Excel 2010).

From a biological perspective an abundance of filamentous green algae, which is limited by phosphorus concentrations was noted consistently at sites BPB and BPC (Figure 5).

Figure 5. Abundance of filamentous green algae at site BPB.

Nitrogen is another key nutrient vital for the development of algae and aquatic plants. Nitrogen is present in surface water in several chemical forms such as free ammonia and ammonium, nitrite, nitrate and organic nitrogen. Nitrates are essential for plant growth in both terrestrial and aquatic ecosystems because they are highly soluble and mobile in water solutions and are the most available for plant consumption. Anthropogenic sources of nitrates include inorganic fertilizers, septic systems and wastewater treatment plants. Concentrations of total nitrates in surface water reflect general land use and anthropogenic pressure within the various parts of the watershed.

Total Kjeldahl nitrogen (TKN) is a measure of total organic nitrogen plus total ammonia and in some cases can show the presence of fresh organic pollution in a water body or the level of phytoplankton development in lake water.

Total nitrogen (TN) includes both inorganic and organic forms of nitrogen. There is no provincial or federal guideline for total nitrogen concentrations in surface water. Alberta Environment has established a surface water quality guideline for total nitrogen at 1.0 mg/L (Alberta Environment, 1999). This guideline was used by Environment Canada for reporting on water quality in Lake Winnipeg (Environment Canada, 2013a, 2013b). It provides us with an opportunity to use the above-mentioned guideline as a nitrogen interim guideline for streams and lakes in the Kawartha Conservation watershed. Indirect toxic effects resulting from eutrophication may still occur at nitrate concentrations below the guideline value, depending on the total amount of nitrogen in water (CCME, 2007).

Total nitrogen concentrations were well within the interim PWQO of 1.0mg/L (Figure 5). Many samples at both sites, D1 and BPB fell below the lab detection limit. The mean concentrations were 0.07mg/L and 0.04 mg/L at sites D1 and BPB respectively. Median values were identical at both sites measuring 0.02mg/L.

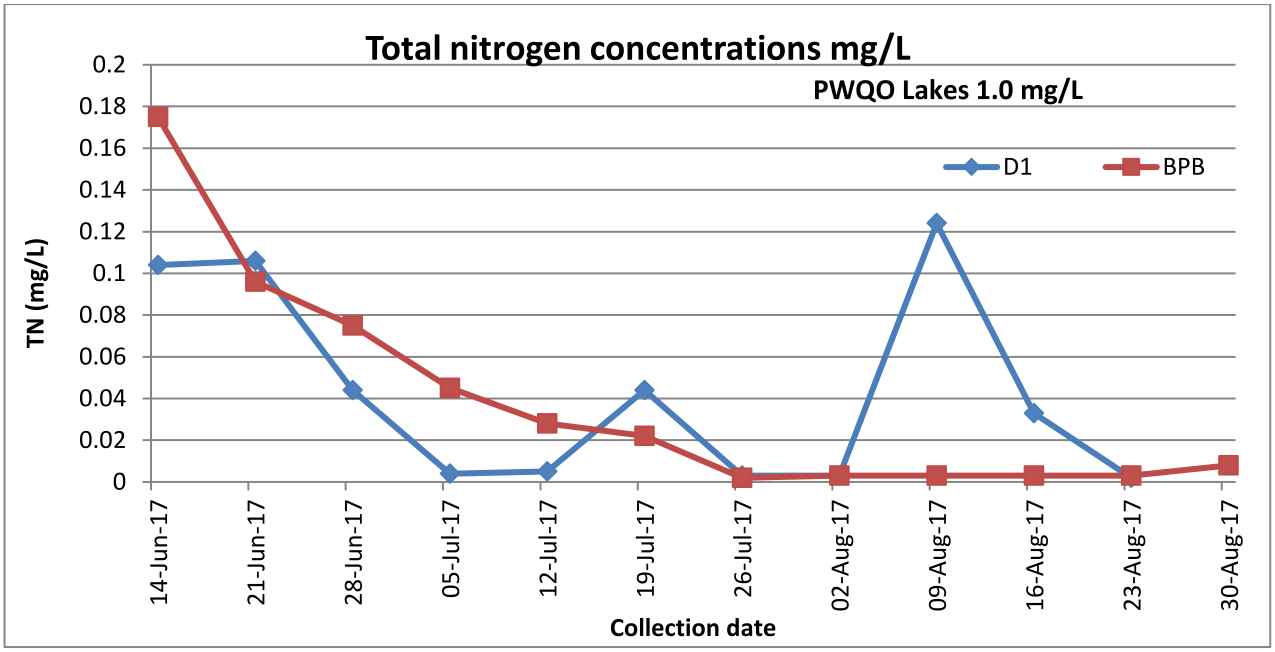


Figure 5. Total nitrogen concentrations at sites D1 and BPB during the study period.

There was no significant difference in total nitrogen concentrations between sites D1 and BPB (T- test, SigmaPlot V.13). Linear regression analysis suggests a weak positive correlation between *E.coli* and nitrogen concentrations (r^2= 0.19, P<0.05, Microsoft Excel 2010).

***Escherichia coli*-Water samples**

Escherichia coli water samples were collected at 4 sites during the study period. *E.coli* concentrations (water samples) ranged from 9cfu/100ml to 1000cfu/100ml over the duration of the study (Figure 6). The highest concentrations (>1000-geomean transformed to 1000 for better linearity) were found at multiple locations at various times throughout the study. For example on August 23rd site BPB recorded geomean *E.coli* concentrations at >1000 and on August 30th site BPC recorded the same value. The mean concentrations recorded at each site, over the duration of the study were: D1=115 cfu/100ml, BPA=30.80 cfu/100ml, BPB=123.88 cfu/100ml, BPC=169.40 cfu/100ml while median values were recorded as 61.50 cfu/100ml, 21.78 cfu/100ml, 11.00cfu/100ml, and 35.59 cfu/100ml respectively (Table 3).

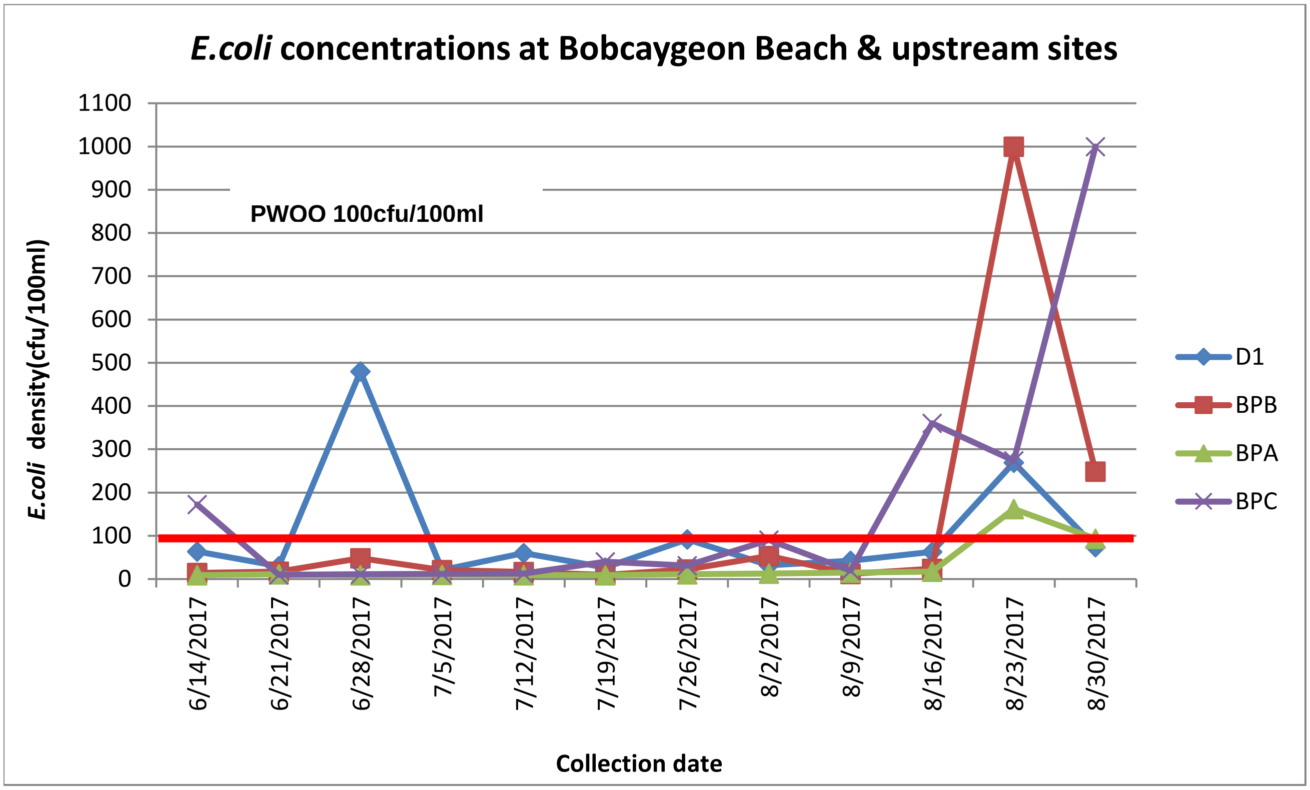


Figure 6. *E. coli* concentrations at all four sites (D1, BPA, BPB, BPC) over the study period (June to August).

There were several exceedances of the threshold of 100cfu/100ml using the geomean calculation during the study period (Public Health Ontario, 2018). Site D1 had 21% exceedances which resulted in 10 postings over the duration of the study period (pooled data from HKPR, n=48). Site BPB had 16% exceedance rate. The highest rate of exceedances occurred at site BPC (33%). Additionally, the highest recorded concentration was over 1000 cfu/100ml at site BPC.

Site BPA recorded the most consistent lowest concentrations with only 1 recorded exceedance on August 23, 2017. All other recorded *E.coli* values at site BPA were well within the threshold 100cfu/100ml and ranged from 9 to 17.45 cfu/100ml (Table 3).

Table 3. Descriptive statistics of *E.coli* results according to sampling sites.

Site	**min**	**max**	**median**	**mean**	**samples (n)**
D1	14.15	480	60	97.5499	13
BPA	9	162.0821	11.00073	30.79607	12
BPB	9.59	1000	21.77742	123.8873	12
BPC	9.79	1000	35.59312	169.4076	12
BBP1 (sand)	2000	20000	4000	5600	10
BBP2 (sand)	1000	22000	5000	7900	10

E.coli concentrations varied significantly between sites ($F_{3,44}$=2.82, P<0.05, One Way ANOVA on Ranks, SigmaPlot, V.13.) Post- hoc multiple comparisons were carried out using Tukey's HSD and showed that there is a significant variance between the following sites: D1 vs BPA, and BPA vs BPC. There was no significant difference between sites BPC with sites D1 and BPB (P<0.05, Tukeys HSD, SigmaPlot V.13.)

Escherichia coli **(Sand samples)**
E.coli concentrations in sand ranged from 1000cfu/100ml to 22000 cfu/100ml (raw values) over the study period. The mean & median concentrations were 7900 cfu/100ml and 5000 cfu/100 respectively.

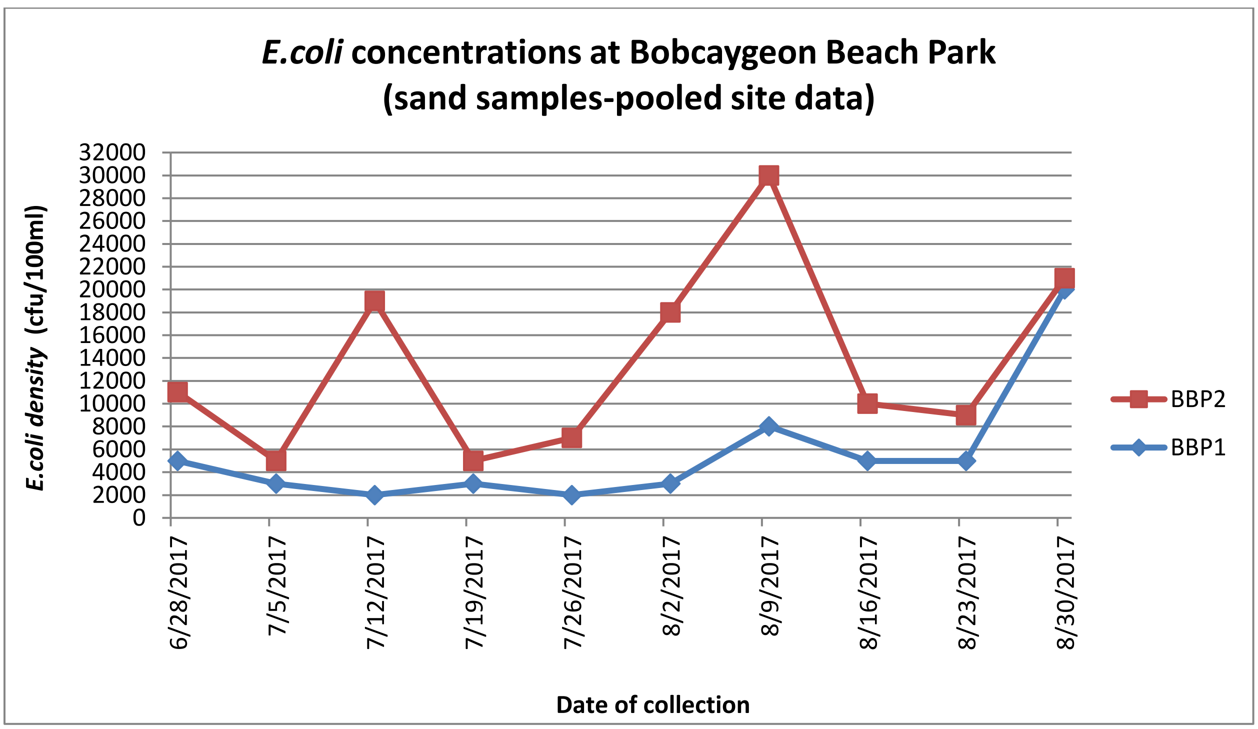


Figure 7. *E.coli* densities in sand samples at sites BBP1 and BBP2.

The maximum concentration was recorded on August 9th at site BBP2 measuring 22000 cfu/100ml

In order to understand the effect that the amount of precipitation may have on *E.coli* densities in the sand, data was pooled from both sites and linear regression was performed on precipitation amount and *E.coli* densities. Precipitation amount was calculated using rainfall (mm) 48 hours before sand sampling events and then transformed to LOG values. A weak positive correlation between precipitation (48 hours prior) and pooled *E.coli* sand sample sites was evident; however the *P* value (0.74) was more than the 0.05 threshold of significance (Microsoft Excel 2010) (Figure 8).

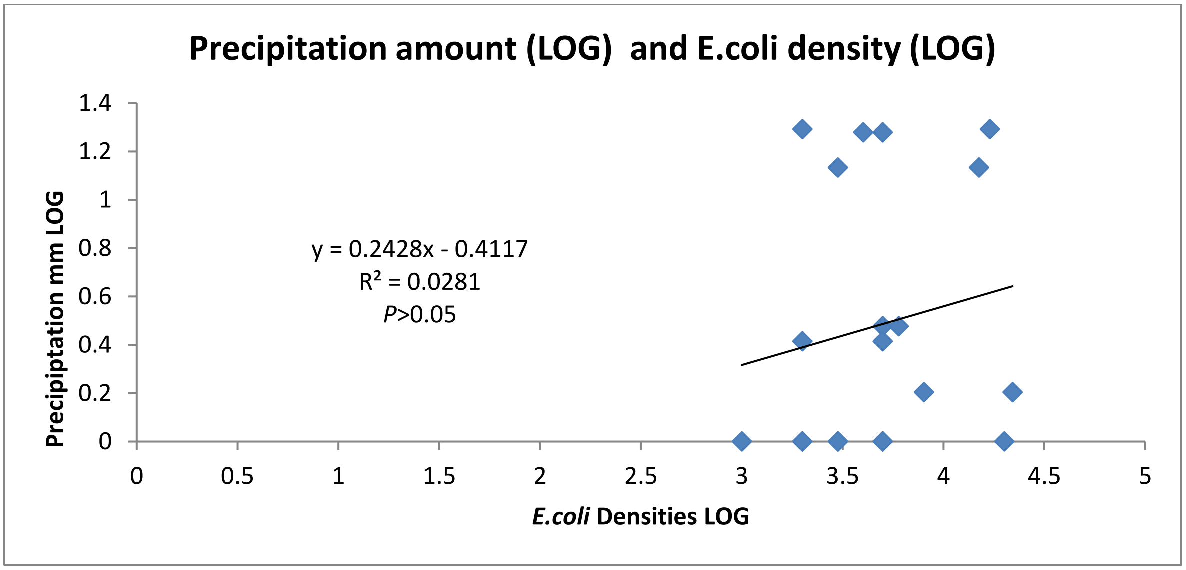


Figure 8. Pooled site data (BBP1 & BBP2) regression analysis with precipitation versus *E. coli* densities.

When the *E.coli* dataset (sand samples) was separated and analyzed site wise, a significant stronger correlation between precipitation and *E.coli* densities at site BBP2 was determined (r^2= 0.31, P<0.05, Linear Regression, Microsoft Excel 2010). This significant correlation means that *E.coli* concentrations increased as precipitation amounts increased (Figure 9).

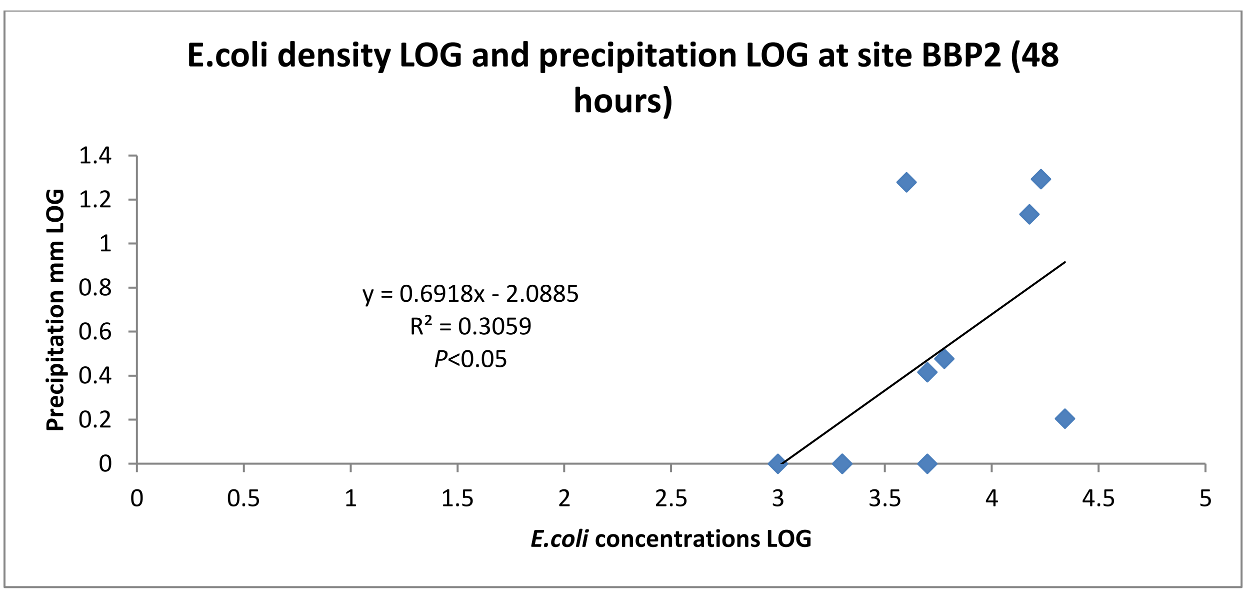


Figure 9. Linear regression results of *E.coli* concentrations and rainfall in mm.

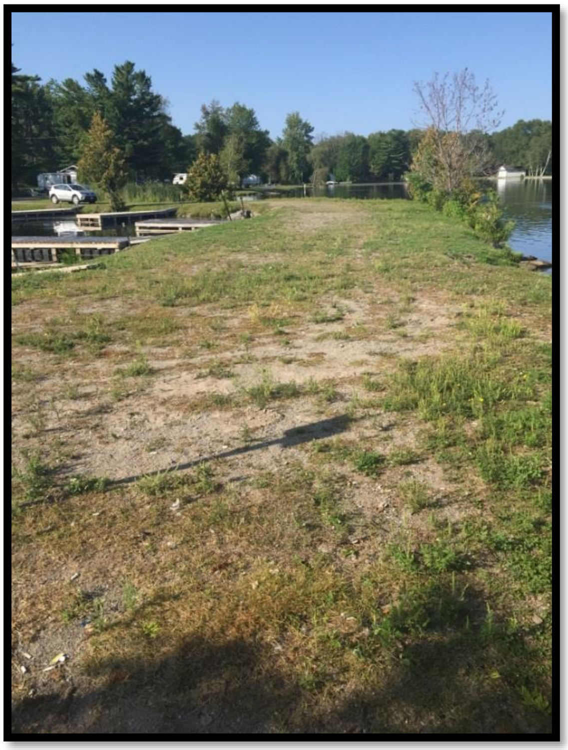
4.0 Discussion

Concentrations of fecal indicator bacteria (FIB) such as *E.coli* have been used as a method to assess recreational water quality and the risk to human health. The province of Ontario uses the Ontario Public Health Standards, Beach Management Guidance Document (2014) to determine health risks applying the threshold of 100cfu/100ml using the geomean calculation (Public Health Ontario, 2018). Bobcaygeon beach has experienced beach postings due to unsafe *E.coli* concentrations historically and on an ongoing basis.

In 2017 there were 10 postings over the HKPR beach monitoring surveillance period (June-August). *E.coli* density results from upstream sites indicated that there were some similarities between sites, but also some marked differences. Site BPA varied significantly from the other four sites and experienced only one recorded observation of elevated *E.coli* densities. This particular site (BPA) is the only site that has a naturalized shoreline. The shoreline was remediated through intensive Dogwood plantings in this area in previous years (Figure 10).

Figure 10. Naturalized strip of Bobcaygeon Beach Park at sampling site BPA.

The low *E.coli* concentrations observed at site BPA may be attributed to an enhanced shoreline which acts as a buffer to any run off entering the lake. The Ministry of Natural Resources (MNRF) recommends a minimum of a 30m wide vegetated area to provide and protect aquatic habitats" (2012). The area adjacent to site BPA meets the minimum recommendations. Unfortunately, the two other upstream sites are considered heavily degraded and do not have a substantive amount of vegetation in order to promote good water quality. Both sites BPB and BPC are turf based with little to no effect on mitigating run off (Figures 11, 12 & 13). Additionally, the lack of vegetation and type of current vegetation (turf) is encouraging large congregations of waterfowl to converge for feeding and thus defecation.



Figures 11 & 12. Degraded/absent vegetated buffer zones at site BPB.

Figure 13. Degraded/absent vegetated buffer zones at site BPC.

It is highly possible that the Bobcaygeon Beach is being influenced by stormwater runoff and may be contributing to the *E.coli* densities in the beach sand. As mentioned previously, foreshore areas have a reservoir effect of FIB including *E.coli* (Vogel et al; 2017). It is postulated that contamination of the foreshore area can be due to water fowl, ground water, bacterial transfer from wrack (washed up debris), bather input and nonpoint stormwater inputs (Nevers et al; 2016)(Figure 14).

Figure14. Example of washed up organic debris on the north side of the beach.

Whitman et al: 2006, explains that *E. coli* populations found in the sand adsorb tightly onto particles (sand/sediment) in moist nearshore areas as they can be protected from environmental elements such as solar radiance and ultimately cell death. Whitman further indicates that large rainfall events could instigate a resuspension of sand *E.coli* lakeward to the nearshore areas. The results at Bobcaygeon Beach agreed with this principal as findings demonstrated that as rainfall amounts increased *E.coli* concentrations in the sand did also. Although the mechanism for horizontal distribution is clear, the origin of *E.coli* populations within the sand are still unknown (Whitman et al: 2006). There is a possibility that populations are naturally occurring in nature and widespread and can persist (Whitman et al; 2006). As mentioned earlier, Health Canada and the USA Environmental Protection Agency do not currently have guidelines for *E.coli* monitoring in sand, nor any thresholds to adhere to. The high densities of E.coli found in the sand and the E.coli densities found in the water reach near significance (P=0.06, site BBP2).

Evidence of stormwater inputs was observed at the Bobcaygeon Beach by way of channelization from the pathway into the unsaturated backshore of the beach area (Figure 15). Parks staff piles sand at the stormwater entry areas in an attempt to inhibit runoff over the beach (CKL Park staff, 2017).

Figure 15. Evidence of stormwater pooling in the upshore area.

The beach itself has very limited vegetated areas to allow for filtration of stormwater to occur before reaching the beach and lake (Figure 16).

Figure 16. Impervious surfaces adjacent to the beach area.

Stormwater catchment areas are located adjacent to Bobcaygeon Beach (Figures 17 & 18). The catchment in Figure 17 was inactive, however a pool of water was observed on several occasions during the study period. The holding capacity of this closed off outfall was not determined, but any potential role of a soaker pit should be identified due to the possibility of flashy rain events and sheet flow from the roadway and adjacent parking lot. Sites with increased shoreline vegetated buffers has less E.coli densities and provides some indication that elevated levels are influenced by surface water runoff.

Figures 17 & 18. Stormwater catchments adjunct to the beach.

In this study *E.coli* densities in sand increased with rain events, however there may be other influences that were not examined and beyond the scope of this project (for example pore water and upshore testing, rainfall intensity, sheet flow, *E.coli* DNA tracing etc.).

Additionally, the effects of the fountain on water quality and/or as a goose deterrent were not examined during this study however. Data from this study could be considered as baseline information that future studies could be carried out.

Finally, best management practices for the beach itself were not fully examined (i.e. raking vs. not raking). It would be interesting to determine if the daily raking which is carried out at the beach has an effect on *E.coli* densities. In terms of influential effects on *E.coli* densities, in both water and sand, beach best management practices it is responsible an *E.coli* resuspension effect from the collected aquatic vegetation which is stored on the edge of the beach for disposal at a later date.

5.0 Summary/ Recommendations

Bobcaygeon Beach Park is a highly visited recreational area on Sturgeon Lake which is posted approximately 30% of the time (June –August). The intent of this project was to determine where the greatest densities of *E.coli* occur at the beach and 3 upstream sites, in addition to an attempt to establish any relationships between *E.coli* densities, water chemistry parameters and shoreline conditions and quantify foreshore *E.coli* densities.

Recommendations include further examination of stormwater inputs (via flows), better beach management practices and improved shoreline conditions in order to reduce beach postings and protect the economic, social and ecological value of this area.

Finally, as the City of Kawartha Lakes moves forwards with new plans for the beach and park area, Kawartha Conservation can provide some ecological and stewardship insights for consideration during the planning phase of the Bobcaygeon Beach Park.

6.0 References

Byappanahalli, M., Nevers, M., Whitman, R., Zhongfu, G., Shively, D., Spoljaric, A., Przybyla- Kelly, K. 2015. Wildlife, urban inputs, and landscape configuration are responsible for degraded swimming water quality at an embayed beach. Journal of Great Lakes Research (41):165-163.

Ishii, S., Hansen, D., Hicks, R., Sadowsky, M. 2007. Beach sand and sediments are temporal sinks and sources of Escherichia coli in Lake Superior. Environmental Science Technology (41) : 2203-2209.

Kawartha Conservation. 2014. Sturgeon Lake Management Plan.

Ministry of Health and Long Term Care, Public Health Division. 2014. Beach Management Guidance Document.

Nevers, M., Przybyla-Kelly, K., Spoljaric, A., Shively, D., Whitman, R., Byappanahalli, M. 2016. Freshwater wrack along Great Lakes coasts harbors Escherichia coli: Potential for bacterial transfer between watershed environments. Journal of Great Lakes Research (42):760-767.

Oun, A., Yin, Z., Munir, M., Xagoraraki, I. Microbial pollution characterization of water and sediment at two beaches in Sagninaw, Michigan. 2017. Journal of Great Lakes Research (43): 64-72.

Severn Sound Environmental Association. 2013. Status of Recreational Water Quality at Little Lake Park.

Staley, Z., Robinson, C., Edge, T. 2016. Comparison of the occurrence and survival of fecal indicator bacteria in recreational sand between urban beach, playground and sandbox settings in Toronto, Ontario. Science of the Total Environmental (541): 520-527.

Vogel, L., Edge, T., O'Carroll, D., Solo- Gabriele, H., Kushnir, C., Robinson, C. 2017. Evaluation of methods to sample fecal indicator in foreshore sand and pore water at freshwater beaches. Water Research (121):240-212.

Whitman, R., Nevers, M. 2008. Summer E.coli Patterns Responses along 23 Chicago Beaches. Environmental Science Technology (42): 9217-9224.

SI.Table 1. Water and beach sand quality results for this study.

Site_ID	Easting	Northing	Sample_Type	Collection_Date	Precip_mm	Precip_48hrs_mm	E.coli_Geomean_cfu_100mL
D1	694807.49	4934317.94	Water	2017-06-14	0.0	3.4	64.00
D1	694807.49	4934317.94	Water	2017-06-21	2.2	15.2	30.00
D1	694807.49	4934317.94	Water	2017-06-28	0.2	2.0	480.00
D1	694807.49	4934317.94	Water	2017-07-05	0.0	0.0	21.00
D1	694807.49	4934317.94	Water	2017-07-12	17.4	18.6	60.00
D1	694807.49	4934317.94	Water	2017-07-19	0.0	0.0	27.00
D1	694807.49	4934317.94	Water	2017-07-26	1.4	1.4	92.00
D1	694807.49	4934317.94	Water	2017-08-02	12.6	12.6	32.00
D1	694807.49	4934317.94	Water	2017-08-09	0.4	0.6	42.00
D1	694807.49	4934317.94	Water	2017-08-16	0.0	0.0	63.00
D1	694807.49	4934317.94	Water	2017-08-23	1.0	18.2	269.00
D1	694807.49	4934317.94	Water	2017-08-30	0.0	0.0	74.00
BPB	694558.00	4934237.00	Water	2017-06-14	0.0	3.4	14.15
BPB	694558.00	4934237.00	Water	2017-06-21	2.2	15.2	17.09
BPB	694558.00	4934237.00	Water	2017-06-28	0.2	2.0	48.34
BPB	694558.00	4934237.00	Water	2017-07-05	0.0	0.0	21.12
BPB	694558.00	4934237.00	Water	2017-07-12	17.4	18.6	16.48
BPB	694558.00	4934237.00	Water	2017-07-19	0.0	0.0	9.59
BPB	694558.00	4934237.00	Water	2017-07-26	1.4	1.4	22.44
BPB	694558.00	4934237.00	Water	2017-08-02	12.6	12.6	53.56
BPB	694558.00	4934237.00	Water	2017-08-09	0.4	0.6	11.69
BPB	694558.00	4934237.00	Water	2017-08-16	0.0	0.0	23.75
BPB	694558.00	4934237.00	Water	2017-08-23	1.0	18.2	1000.00
BPB	694558.00	4934237.00	Water	2017-08-30	0.0	0.0	248.44

SI.Table 1. Continuation.

Site_ID	Sample_Type	Collection_Date	Water_Temperature_C	Dissolved_Oxygen_mg_L	Dissolved_Oxygen_%	pH	Conductivity_µS_cm
D1	Water	2017-06-14	21.7	6.35	77.9	8.06	204.1
D1	Water	2017-06-21	20.6	7.84	87	8.45	194.9
D1	Water	2017-06-28	19.5	7.03	76.4	7.5	214.7
D1	Water	2017-07-05	21.6	1.78	20	7.74	236.2
D1	Water	2017-07-12	23.5	7.8	91.7	8.23	210.9
D1	Water	2017-07-19	23.1	7.2	83.5	8.39	224.9
D1	Water	2017-07-26	20.9	7.21	80.7	8.72	204.4
D1	Water	2017-08-02	23.8	7.8	92.4	8.31	200.1
D1	Water	2017-08-09	21.1	8.14	91.4	8.91	195.7
D1	Water	2017-08-16	21.8	8.16	93.3	9.01	193
D1	Water	2017-08-23	21.2	7.21	81.2	8.9	185.7
D1	Water	2017-08-30	20	7.98	81.7	8.26	176.4
BPB	Water	2017-06-14	21.3	6.48	73.7	8.12	197.6
BPB	Water	2017-06-21	21	7.8	87.4	8.18	192.8
BPB	Water	2017-06-28	20.2	8.59	54.8	8	192.5
BPB	Water	2017-07-05	21.5	8.56	87.1	8.07	197.3
BPB	Water	2017-07-12	23.6	8.07	95.4	8.03	208.9
BPB	Water	2017-07-19	23.5	8.78	103.3	8.33	205.5
BPB	Water	2017-07-26	21.3	9.15	103.8	8.3	203
BPB	Water	2017-08-02	24	7.8	92.8	8.12	199.5
BPB	Water	2017-08-09	21.4	9.09	102.8	8.31	196.9
BPB	Water	2017-08-16	22.7	8.69	100.8	8.47	189.8
BPB	Water	2017-08-23	21.3	8.26	93.1	8.61	172.4
BPB	Water	2017-08-30	20.2	8.63	95.6	8.17	183.7

SI.Table 1. Continuation.

Site_ID	Sample_Type	Collection_Date	Turbidity_NTU	Chloride_mg_L	Nitrite_mg_L	Nitrate_mg_L	Ammonia_mg_L
D1	Water	2017-06-14	NA	10.3	0.004	0.03	0.07
D1	Water	2017-06-21	1.4	10.2	0.006	0.04	0.06
D1	Water	2017-06-28	NA	10.1	0.004	0.04	< 0.01
D1	Water	2017-07-05	NA	10.3	0.004	< 0.02	< 0.01
D1	Water	2017-07-12	0	9.6	0.005	< 0.02	< 0.01
D1	Water	2017-07-19	2.4	9.7	0.004	< 0.02	0.04
D1	Water	2017-07-26	0.2	10	0.003	< 0.02	< 0.01
D1	Water	2017-08-02	0	9.7	0.003	< 0.02	< 0.01
D1	Water	2017-08-09	2	9.9	0.004	< 0.02	0.12
D1	Water	2017-08-16	0.4	9.6	0.003	< 0.02	0.03
D1	Water	2017-08-23	0.3	9.1	0.002	< 0.05	< 0.01
D1	Water	2017-08-30	3.2	9.5	0.003	< 0.05	< 0.01
BPB	Water	2017-06-14	NA	10.3	0.005	0.03	0.14
BPB	Water	2017-06-21	0.4	10	0.006	0.05	0.04
BPB	Water	2017-06-28	0	10	0.005	0.05	0.02
BPB	Water	2017-07-05	0	10.1	0.005	0.04	< 0.01
BPB	Water	2017-07-12	0	9.6	0.008	0.02	< 0.01
BPB	Water	2017-07-19	0.4	9.3	0.002	< 0.02	0.02
BPB	Water	2017-07-26	0.3	10	0.002	< 0.02	< 0.01
BPB	Water	2017-08-02	0	9.8	0.003	< 0.02	< 0.01
BPB	Water	2017-08-09	1.5	9.6	0.003	< 0.02	< 0.01
BPB	Water	2017-08-16	0.6	9.7	0.003	< 0.02	< 0.01
BPB	Water	2017-08-23	1.7	9.1	0.003	< 0.05	< 0.01
BPB	Water	2017-08-30	8.17	9.4	0.008	< 0.05	< 0.01

SI.Table 1. Continuation.

Site_ID	Sample_Type	Collection_Date	Total_Nitrogen_Cal	Total_Kjeldahl_Nitrogen_mg_L	Total_Phosphorus_mg_L	Total_Suspended_Solids_mg_L
D1	Water	2017-06-14	0.104	0.38	0.016	3
D1	Water	2017-06-21	0.106	0.48	0.031	3
D1	Water	2017-06-28	0.044	0.32	0.012	< 3
D1	Water	2017-07-05	0.004	0.34	0.011	< 3
D1	Water	2017-07-12	0.005	0.37	0.013	< 3
D1	Water	2017-07-19	0.044	0.52	0.021	< 3
D1	Water	2017-07-26	0.003	0.76	0.029	< 3
D1	Water	2017-08-02	0.003	0.32	0.021	< 3
D1	Water	2017-08-09	0.124	0.46	0.017	< 3
D1	Water	2017-08-16	0.033	0.43	0.032	< 3
D1	Water	2017-08-23	0.002	0.48	0.016	< 3
D1	Water	2017-08-30	0.003	0.46	0.009	< 3
BPB	Water	2017-06-14	0.175	0.4	0.023	< 3
BPB	Water	2017-06-21	0.096	0.39	0.028	4
BPB	Water	2017-06-28	0.075	0.39	0.017	24
BPB	Water	2017-07-05	0.045	0.35	0.01	< 3
BPB	Water	2017-07-12	0.028	0.23	0.025	< 3
BPB	Water	2017-07-19	0.022	0.52	0.036	< 3
BPB	Water	2017-07-26	0.002	0.47	0.013	< 3
BPB	Water	2017-08-02	0.003	0.28	0.011	< 3
BPB	Water	2017-08-09	0.003	0.54	0.027	< 3
BPB	Water	2017-08-16	0.003	0.7	0.031	< 3
BPB	Water	2017-08-23	0.003	0.4	0.017	< 3
BPB	Water	2017-08-30	0.008	0.45	0.01	< 3

SI.Table 1. Continuation.

Site_ID	Easting	Northing	Sample_Type	Collection_Date	Precip_mm	Precip_48hrs_mm	E.coli_Geomean_cfu_100mL
BPA	694640.4	4934250	Water	2017-06-14	0.0	3.4	9.39
BPA	694640.4	4934250	Water	2017-06-21	2.2	15.2	10.99
BPA	694640.4	4934250	Water	2017-06-28	0.2	2.0	9.00
BPA	694640.4	4934250	Water	2017-07-05	0.0	0.0	9.59
BPA	694640.4	4934250	Water	2017-07-12	17.4	18.6	9.19
BPA	694640.4	4934250	Water	2017-07-19	0.0	0.0	9.39
BPA	694640.4	4934250	Water	2017-07-26	1.4	1.4	11.01
BPA	694640.4	4934250	Water	2017-08-02	12.6	12.6	12.65
BPA	694640.4	4934250	Water	2017-08-09	0.4	0.6	15.33
BPA	694640.4	4934250	Water	2017-08-16	0.0	0.0	17.45
BPA	694640.4	4934250	Water	2017-08-23	1.0	18.2	162.08
BPA	694640.4	4934250	Water	2017-08-30	0.0	0.0	93.48
BPC	694477.5	4934154	Water	2017-06-14	0.0	3.4	172.58
BPC	694477.5	4934154	Water	2017-06-21	2.2	15.2	9.79
BPC	694477.5	4934154	Water	2017-06-28	0.2	2.0	11.25
BPC	694477.5	4934154	Water	2017-07-05	0.0	0.0	11.69
BPC	694477.5	4934154	Water	2017-07-12	17.4	18.6	12.92
BPC	694477.5	4934154	Water	2017-07-19	0.0	0.0	40.25
BPC	694477.5	4934154	Water	2017-07-26	1.4	1.4	30.94
BPC	694477.5	4934154	Water	2017-08-02	12.6	12.6	90.15
BPC	694477.5	4934154	Water	2017-08-09	0.4	0.6	19.33
BPC	694477.5	4934154	Water	2017-08-16	0.0	0.0	360.24
BPC	694477.5	4934154	Water	2017-08-23	1.0	18.2	273.76
BPC	694477.5	4934154	Water	2017-08-30	0.0	0.0	1000.00

SI.Table 1. Continuation.

Site_ID	Easting	Northing	Sample_Type	Collection_Date	Precip_mm	Precip_48hrs_mm	E.coli_cfu_g
BBP1	694827.1	4934326	Sand	2017-06-28	0.2	2.0	5000
BBP1	694827.1	4934326	Sand	2017-07-05	0.0	0.0	3000
BBP1	694827.1	4934326	Sand	2017-07-12	17.4	18.6	2000
BBP1	694827.1	4934326	Sand	2017-07-19	0.0	0.0	3000
BBP1	694827.1	4934326	Sand	2017-07-26	1.4	1.4	2000
BBP1	694827.1	4934326	Sand	2017-08-02	12.6	12.6	3000
BBP1	694827.1	4934326	Sand	2017-08-09	0.4	0.6	8000
BBP1	694827.1	4934326	Sand	2017-08-16	0.0	0.0	5000
BBP1	694827.1	4934326	Sand	2017-08-23	1.0	18.2	5000
BBP1	694827.1	4934326	Sand	2017-08-30	0.0	0.0	20000
BBP2	694811.1	4934300	Sand	2017-06-28	0.2	2.0	6000
BBP2	694811.1	4934300	Sand	2017-07-05	0.0	0.0	2000
BBP2	694811.1	4934300	Sand	2017-07-12	17.4	18.6	17000
BBP2	694811.1	4934300	Sand	2017-07-19	0.0	0.0	2000
BBP2	694811.1	4934300	Sand	2017-07-26	1.4	1.4	5000
BBP2	694811.1	4934300	Sand	2017-08-02	12.6	12.6	15000
BBP2	694811.1	4934300	Sand	2017-08-09	0.4	0.6	22000
BBP2	694811.1	4934300	Sand	2017-08-16	0.0	0.0	5000
BBP2	694811.1	4934300	Sand	2017-08-23	1.0	18.2	4000
BBP2	694811.1	4934300	Sand	2017-08-30	0.0	0.0	1000