E.coli and coliform concentrations in developed and undeveloped nearshore surface water within an inland lake

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Abstract— *There are a number of sources that impact the microbial water quality of nearshore surface water. These include development, avian species, and rainfall, to name just a few. It is often difficult to elucidate the exact cause of these changes due to numerous variables that cannot be controlled. However, the development of shorelines has often been implicated in eroded nearshore water quality. This study utilized a single lake that has minimal inputs of microorganisms from external sources such as rivers, outfalls, avian species, etc.. The lack can easily be divided into developed and undeveloped regions as the US Forest Service owns a good portion of the lake shoreline. This greatly decreases the variables between sampling locations. The overall objective of this study was to evaluate if residential development along an inland lakeshore would impact E.coli and/or coliforms found in the adjacent nearshore surface water. The developed regions of the lake showed significantly higher (alpha<0.05) concentrations of coliforms and E.coli when compared to undeveloped regions for all three seasons of the study. While the study lasted three sample seasons, each year resulted in very similar overall results to each other. Yearly means of coliforms and E.coli at each sample location group were compared to each other and found that the means between these groups were similar each year and not statistically different. While this project does not suggest what the cause of the increased coliform and E.coli concentrations in the nearshore, it does provide an important contribution to other work that suggests development may adversely impact nearshore water quality. This unique study site could be used for future studies due to unusual ability to control extraneous inputs of coliforms and E.coli.*

***Keywords—* bacteria in water, E. coli, inland lake, shoreline development, water quality.**

I. INTRODUCTION

The use of recreational water sites along lakes, rivers, or oceans, are one of the most popular activities in many parts of the world. However, these waters contain varying levels of health risk as it relates to microbial water quality. Fecal material from swimmers, domestic animals (dogs, cattle, and horses), as well as waterfowl (geese, gulls, and ducks), all lead to increases in microbial loading at beaches [1,3]. Additionally, rainfall and runoff due to rainfall events has been associated with increasing microbial levels in recreational waters along numerous beaches including several coastal areas in Wisconsin [1,2] [Kinzelman, Racine County, WI Health Department, personal communication, 2003]. This runoff can lead to beach closures and potentially unsanitary conditions at recreational water sites [4,5] When one considers the Great Lakes region is home to over 40,000 lakes and over 20% of the worlds freshwater resources, the impact of development on shorelines and water quality is an environmental, economic, and social issue.

The sources of these microbial pollutants are often diverse and are difficult to identify. Heavy rainfall was implicated in increasing bacterial contamination at beaches in several areas of the country [1,6]. On the Santa Monica Bay beaches in southern California, health departments typically issue warnings for the public to avoid recreational water contact for 3 days following a rainfall event [3]. The negative impact of stormwater on beach water quality has led to a myriad of option for controlling stormwater. Some of these include grass buffer partitions [7], stormwater detention basins [8], media filters [9], catch basin inserts, and infiltration units [10] to name just a few.

The very large population of waterfowl along coastal waters is not a new occurrence in many areas. The large quantity of various birds are not only a nuisance during a day at the beach but have the potential to carry diseases harmful to humans. Pathogens like *Salmonella* are generally not found in high numbers in one individual gull or goose, but when 100’s or 1000’s of gulls or geese are roosting in one area a health hazard arises [11]. There are a number of investigators that have attempted to evaluate the effects that avian species have on indicator organisms in recreational water quality. The avian species that can impact recreational waters include gulls, geese, ducks, and/or pigeons [5,12,13].

In the last ten years there has been increased concern involving fecal contamination at recreational beaches. In 2000, the United States Congress passed the Beaches Assessment and Coastal Health (BEACH) Act that provided specific criteria for beach monitoring, better public notification, and increased funding for state and local health departments to develop and continue beach monitoring programs [14]. Since the onset of this program there has been both an abundance of data collected on fecal indicator concentrations in the Great Lakes and on research related to the potential sources of contamination. Outside of most major metropolitan areas there are no combined sewer systems and none that discharge to an inland lake in Wisconsin.

Naturally occurring microbes are ubiquitous in water and include such organisms as *Escherichia coli,* or *E.coli*. It is the difference between the natural cycling of these organisms and the artificial inputs of these organisms that has confounded water quality researchers. When these microbes do not occur in normal concentrations, concerns are raised regarding the public health risks. Generally, the bacteria that are associated with fecal contamination are thought to be those that reside in mammalian intestines [15]. Once mammalian feces are defecated into the environment the microbes existing in these feces have the potential to cause disease. Bacteria capable of causing disease, or pathogens, are the primary concern when it comes to evaluating water quality and the risk of microbial content to public health [15]. In general, pathogens can be difficult to monitor and expensive and time consuming to examine. Recreational water quality is generally measured using indicator organisms or bacteria that have traditionally been thought to behave similarly to pathogens [16]. These organisms are much easier to test for and are extremely cost effective.

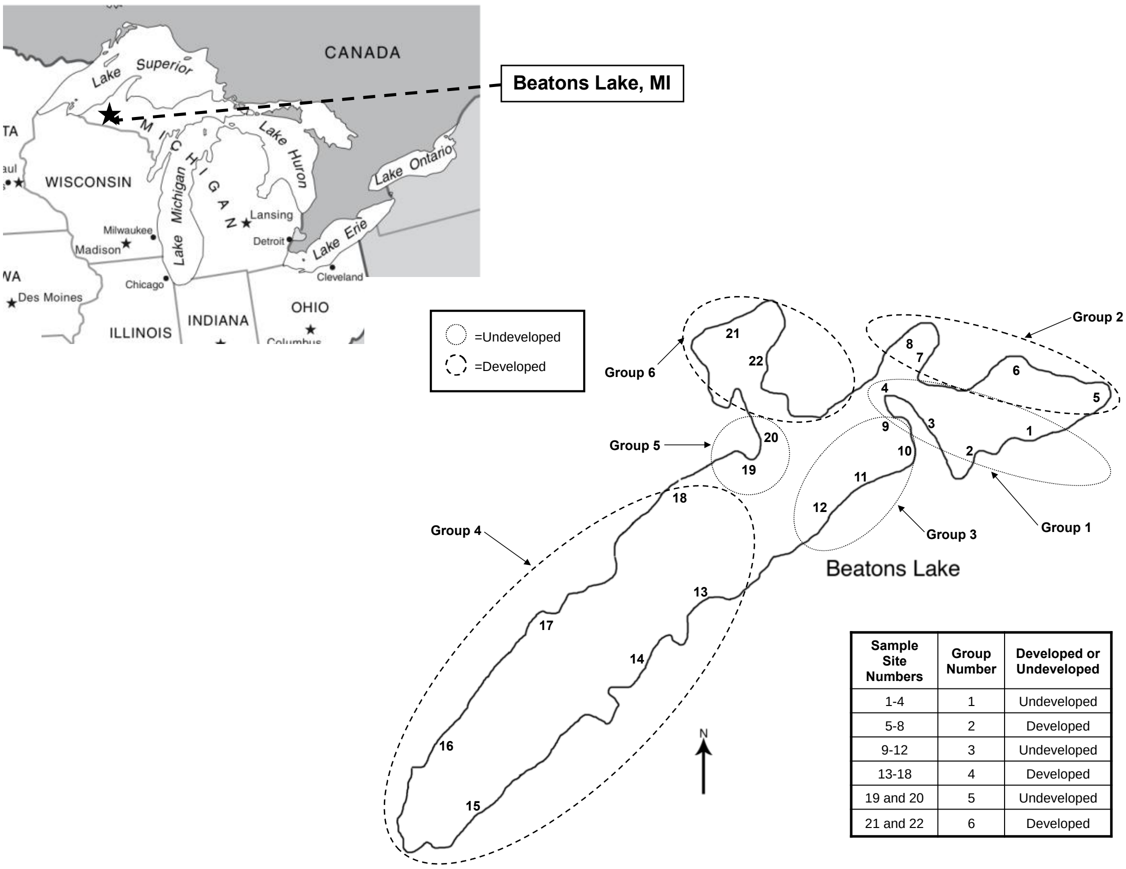
The impact of development of the water quality in adjacent surface waters has been studied by a number of researchers [17-20]. Many of these impacts include increased nutrient loadings, sediment runoff, and introduction of invasive species to the shoreline or riparian zone of the lake [21]. Furthermore, the leakage of sewerage from failing or improperly installed septic systems can be an issue for rural areas [22,23]. The removal of vegetative buffers, increased pet wastes, septic contributions, and planting of lawns instead of thicker diverse vegetation can increase the probability of runoff from developed sites. Clearly, the development of lakeshore property has the potential to not only impact the land upon which construction takes place, but also the adjacent water resources [24-26]. However, we are aware of no studies that have looked at the indicator organism (i.e., coliforms or *E.coli*) contributions based exclusively on the development status of the shoreline in a single lake setting. In most cases, this is almost impossible due to confounding factors at the water sampling sites such as transient waterfowl, currents, water inputs from outside areas, storm sewers, to name just a few [27,28].

The overall objective of this study was to evaluate if residential development along an inland lakeshore would impact *E.coli* and/or coliforms found in the adjacent nearshore surface water.

II. MATERIALS AND METHODS

2.1 Sample site selection

Beatons Lake, MI is approximately 1.7 km^2 lake located in Michigan's Upper Peninsula (Figure 1). Beatons Lake is spring fed, reaches depths of greater than 28m, and has no steam inflows and contains only one outflow. Development on the lake dates to the 1920s and quite a bit of the shoreline is undeveloped land owned by the US Forest Service (USFS). Additionally, this lake is typically home to 4 Common Loons (*Gavia immer*), but is almost constantly and continually devoid of other waterfowl such as geese and gulls. In fact, two game cameras placed on the lake throughout the period of study found that no avian species were observed on the water on any day other than the aforementioned Loons. The lake is unique in that there has not been development of new areas of the lake in at least 10 years before this study and the lake is almost self-contained and has minimal waterfowl contributions to fecal loads. There is no influent flow and only a small outflow for the spring-fed lake. Two Loon nesting platforms are present out in the lake and were not near any sampling site and are not near shorelines. Ten samples collected each year 10 m from each platform found no sample with detectable *E.coli* and coliforms with a mean of 51.0 MPN/100mL (+/- S.D. 23.9).



Sample Site Numbers	Group Number	Developed or Undeveloped
1-4	1	Undeveloped
5-8	2	Developed
9-12	3	Undeveloped
13-18	4	Developed
19 and 20	5	Undeveloped
21 and 22	6	Developed

FIGURE 1. MAP OF BEATONS LAKE SAMPLE SITES.

2.2 Water Sample Collection

Recreational water samples were collected from the twenty two sample site along the shoreline of Beatons Lake, MI. Twelve of these sample sites were located in the riparian zone of developed shoreline (Figure 2). Ten of these sample sites were from the riparian zone of undeveloped and generally inaccessible shoreline owned by the USFS. Samples were collected in 30 cm of water with collection occurring approximately 15 cm below the water surface. All water samples were collected into 100mL sterile, polystyrene collection bottles (IDEXX Corp., Portland, ME) and placed at 4ºC until *E. coli* concentration analysis was conducted. Care was taken to collect samples in a uniform and non-intrusive way as not to contaminate samples with excess disruption of sediments or floating debris. Samples were analyzed within 4 hours of collection.

2.3 Sample Analysis

The defined substrate test, Colilert™ (IDEXX Corp., Portland, ME), was used to analyze all samples for *E. coli* and coliform concentrations [29]. Incubation and microbial enumeration from samples were conducted following the manufacturer's recommendations. All water samples were maintained at 4°C until analysis and *E. coli* concentrations were expressed as most probable number/100 mL water (MPN/100 mL). The laboratory at the Vilas County Health Department is a Wisconsin State Certified Laboratory (certification #105-445) in Eagle River, WI with a Quality Assurance plan on file with the WI Department of Agriculture, Trade and Consumer Protection (DATCP) maintained by the University of Wisconsin Oshkosh was utilized for all analysis. Positive, negative, and proficiency testing controls were prepared in accordance with the laboratory's quality assurance plan.

2.4 Statistical and Graphical Analysis

Statistical analysis (ANOVA and t-tests) was performed with Systat 11.0. Figures were generated with Microsoft Excel 2011.

III. RESULTS

Overall, results from the three-year study showed that the developed shoreline regions contained higher concentrations of both coliforms (Fig. 2) and *E.coli* (Fig. 3) in nearshore waters when all data was combined (n=726 for each parameter). During each year there were a total of 242 samples collected for both coliforms and *E.coli*, with 22 samples collected for each per sampling event. Table 1 and Figs 2 & 3 also show that each year of the study concentrations showed greater means for developed nearshore water sampling sites. This was true of both the coliform and *E.coli* analysis.

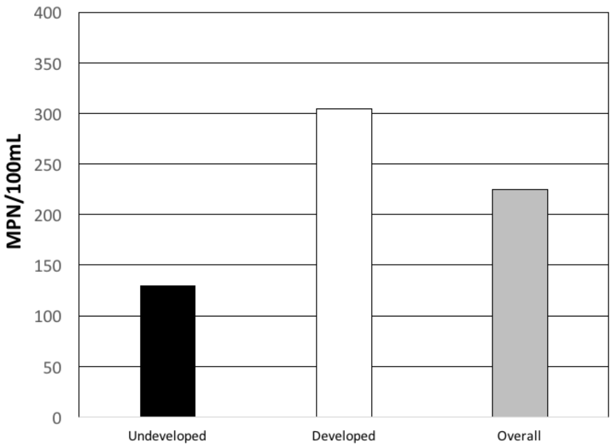


FIGURE 2 MEAN VALUE FOR COLIFORMS BY SITE FOR ALL YEARS STUDIED.

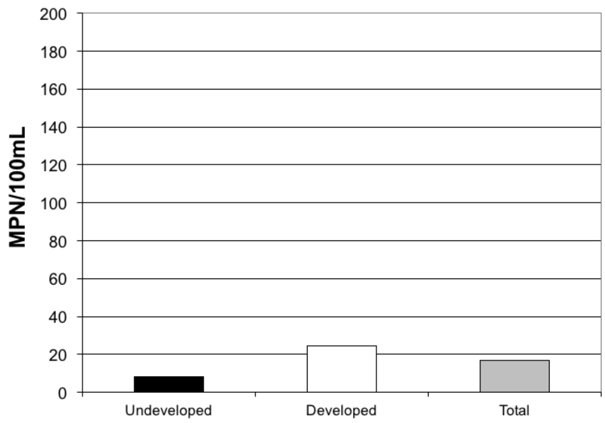
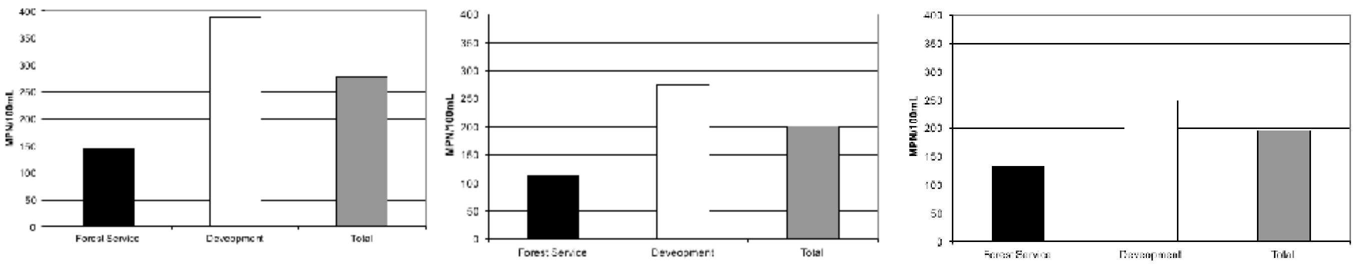


FIGURE 3. MEAN VALUE FOR *E.COLI* BY SITE FOR ALL YEARS STUDIED

Furthermore, Figs. 4 and 5 illustrate the differences between developed shoreline and undeveloped regions of Beatons Lake (N=242 per year per analysis) with years separated. Taken with the lack of coliforms and *E.coli* found in central lake samples, it appears that shoreline development has something to do with the elevated concentrations in the developed nearshore areas of the lake. The source of coliforms and *E.coli* at these sites is unknown but could be runoff from pet waste, increased wild animal activity in cleared areas, cleaned shorelines for swimming, decreased vegetative/filtering on the shoreline, increased overland runoff to the surface water, etc.. It should be noted that the overall concentrations of *E.coli* are very low in these samples when compared to the US EPA recreational water beach advisory and/or closure criteria of 235 *E.coli*/100mL of water [30]. While the absolute concentration of coliforms and *E.coli* are slightly different for each of the three years of the study, the pattern is clear and the same for each of the three years.

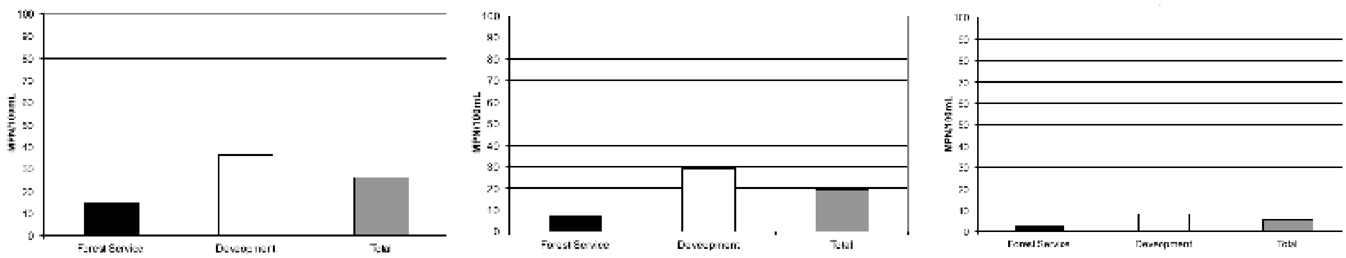
TABLE 1
MEAN VALUES FOR COLIFORMS AND *E.COLI* FOR EACH OF THE YEARS STUDIED. N= 242 PER YEAR PER ANALYSIS

		Coliforms (MPN/100mL)		*E.coli* (MPN/100mL)	
		Mean	**SD**	**Mean**	**SD**
2005	Undeveloped	146.0	81.2	14.7	10.3
	Developed	388.7	350.6	36.0	27.0
	Overall	278.4	290.6	26.3	23.6
2006	Undeveloped	112.1	81.1	7.2	7.0
	Developed	274.9	297.3	29.3	45.7
	Overall	200.9	240.0	19.2	35.8
2007	Undeveloped	131.5	125.0	2.6	2.2
	Developed	249.3	316.4	8.3	4.7
	Overall	195.7	254.8	5.7	4.7



(A) (B) (C)

FIGURE 4. TOTAL COLIFORM CONCENTRATIONS FOR 2005 (A), 2006 (B), AND 2007 (C) SAMPLING SEASONS.



(A) (B) (C)

FIGURE 5 *E.COLI* CONCENTRATIONS FOR 2005 (A), 2006 (B), AND 2007 (C) SAMPLING SEASONS.

The differences in coliform and *E.coli* concentrations between developed and undeveloped sampling sites was significant (alpha >0.05) when the three seasons are combined (p<0.001) and for each year of the study (Table 2). In fact, when the years are separated, most years also showed significant differences between developed and undeveloped regions each year for coliform and *E.coli* concentrations. There were only a few yearly comparisons that showed differences at a level alpha>0.05. While not statistically different, the mean values were still very different from each other. While means were different between years, each year has different weather, etc. that can account to differences between years and it is difficult to compare between years. Additionally, yearly the means of coliforms and *E.coli* at each sample location group were compared to each other (i.e., undeveloped groups to each other and developed groups to each other) and found that the means between these groups were similar each year (data not presented) and not statistically different. This suggests that each group of developed and undeveloped behaved similarly to each other and there were not a small amount of groups (or one) that unduly influenced overall means in the developed and undeveloped groups. That is, each grouping within the two major groups (developed and undeveloped) were similar in their results when compared to each other for each year of the three year study.

TABLE 2
COMPARISON OF SAMPLING BETWEEN YEARS AND LOCATIONS USING T-TESTS. THOSE MEANS THAT ARE DIFFERENT (P>0.05) ARE IN BOLD. OVERALL MEANS WERE SIGNIFICANTLY DIFFERENT EACH YEAR BETWEEN DEVELOPED AND UNDEVELOPED SAMPLING AREAS.

	Coliform	*E.coli*
Developed versus Undeveloped		
2005	0.00	0.00
2006	0.00	0.00
2007	0.00	0.00
Undeveloped		
2005 vs 2006	0.00	0.00
2005 vs 2007	**0.16**	0.00
2006 vs 2007	**0.09**	0.00
Developed		
2005 vs 2006	0.00	**0.15**
2005 vs 2007	0.00	0.00
2006 vs 2007	**0.50**	0.00

IV. CONCLUSION

This is the first study that the author is aware of on the coliforms and *E.coli* concentrations within a single lake that has minimal inputs of microorganisms from external sources such as rivers, outfalls, avian species, etc.. Additionally, the fact that a good portion of the lake shoreline has never been developed it also presented a unique opportunity to evaluate the differences in coliforms and *E.coli* in the nearshore environment with minimal differences in location and water conditions. While the concentrations of each parameter found during this study were relatively low, the same trends could be found in locations with markedly higher concentrations of these microorganisms.

The developed regions of the lake showed significantly higher concentrations of coliforms and *E.coli* when compared to undeveloped regions for all three seasons of the study. While the study lasted three sample seasons, each year resulted in very similar overall results to each other. That is, the trends were the same each year and show a clear relationship between development and an impact on coliform and *E.coli* concentrations in nearshore water. Additionally, yearly the means of coliforms and *E.coli* at each sample location group were compared to each other (i.e., undeveloped groups to each other and developed groups to each other) and found that the means between these groups were similar each year and not statistically different. This suggests that even the sample groups within the bigger developed and undeveloped groups behaved similarly.

While this project does not suggest what the cause of the increased coliform and *E.coli* concentrations in the nearshore water of the developed regions of the lake, there are a number of plausible possibilities that would be supported by other specific studies. Some of these influences could be failing septic systems, infiltration from septic leach fields, runoff from pet waste, increased wild animal activity in cleared areas, cleaned shorelines for swimming, decreased vegetative/filtering on the shoreline, increased overland runoff to the surface water, etc.. Each of these possible sources could be evaluated in future studies to elucidate the relative percent contribution to the nearshore water.

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