2015

Near shore beach volume modeling approach for setting beach bacteria TMDLs: A case study, Hickory Grove Lake, Iowa

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Abstract

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Keywords

Beach impairment, E. coli, Fecal bacteria, TMDL.

Disciplines

Bioresource and Agricultural Engineering | Environmental Indicators and Impact Assessment | Water Resource Management

Comments

This article is published as 17. Gali, R.K.* and Soupir, M.L. 2015. Near shore beach volume modeling approach for setting beach bacteria TMDLs: A case study, Hickory Grove Lake, Iowa. Applied Engineering in Agriculture. 31(1): 73-82. doi: 10.13031/aea.31.10427 . Posted with permission.

NEAR SHORE BEACH VOLUME MODELING APPROACH FOR SETTING BEACH BACTERIA TMDLS: A CASE STUDY, HICKORY GROVE LAKE, IOWA

R. K. Gali, M. L. Soupir

ABSTRACT. *A novel approach to set bacteria Total Maximum Daily Load (TMDL) using a Near-Shore Beach Volume (NSBV) model was described along with recommendations for design of a monitoring network to support this method. Sources of fecal bacteria in the Hickory Grove Lake watershed include unpermitted septic systems, manure applications in the watershed, livestock access to streams, waterfowl, and wildlife. The Lake Inlet, Lake Outlet, and Lake Beach were monitored for* E. coli *concentrations from 2010-2012, this monitoring data was used to assess relationships between watershed bacteria loads and the beach bacteria levels. Fecal bacteria from waterfowl were identified as the major source to the Lake Beach causing the water quality impairment. The bacteria TMDL for the Hickory Grove Lake beach was set at 1.87E+11 orgs/day for the single sample maximum target and 1.01E+11 orgs/day for the geometric mean target, which correlates to the presence of fewer than five resident geese. Monitoring recommendations to support this approach include weekly beach water quality monitoring and post-event sampling; periodic spatial sampling of the lake; weekly and post-event grab sampling of the water quality at the lake inlet mixing zones; and weekly and post-event grab sampling of the water quality at the lake outlet.*

Keywords. *Beach impairment,* E. coli*, Fecal bacteria, TMDL.*

Inland lake beaches are a popular source of recreation throughout the United States and when these beaches are impaired due to poor water quality, major economic losses can occur in local communities. Pathogens are identified as the primary cause of surface water impairments in the United States; an estimated 157,151 miles of rivers and streams and 272,391 acres of lakes, reservoirs, and ponds are classified as impaired by the U.S. Environmental Protection Agency (USEPA) due to elevated pathogen levels (USEPA, 2012a). A waterbody is classified as impaired if it does not meet its designated uses and one of the primary designated uses of the inland lake beaches is contact recreation (swimming, bathing, water skiing, and water play by children). The USEPA has developed stringent water quality standards to protect humans from exposure to pathogen contaminated waters. Fecal indicator bacteria (FIB) such as the fecal coliforms, enterococci, and *Escherichia* coli are primarily used to detect fecal contamination as they are the preferred indicators of pathogens in waters (USEPA, 1986). Excessive quantities of FIB in surface waters are associated with increased risk of bacteria-induced illnesses in humans (Frenzel and Couvillion, 2002).

The goal of the Clean Water Act (CWA), passed by Congress in 1972, is to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters”. Initially, the CWA focused on point sources of pollution, but after discovering the magnitude of nonpoint source pollution, the CWA was amended in 1987 to better encompass reduction of nonpoint source pollution. The CWA requires states to identify impaired water bodies and develop pollutant-specific Total Maximum Daily Loads (TMDL). A TMDL is the sum of the pollutant loads from point sources, nonpoint sources and a margin of safety (USEPA, 2012b). The USEPA has two approaches for determining the MOS in TMDLs: Implicit and Explicit. Implicit approaches involve conservative assumptions in setting numeric targets for water quality standards and explicit approaches involve the addition of a numeric safety factor to pollutant loading estimates (USEPA, 2001). The TMDL development often involves identifying all point and nonpoint sources of the pollutant causing the water quality impairment, quantifying the pollutant contribution from each source, and determining the pollutant reductions necessary from each source to achieve water quality standards (USEPA, 2001). Point sources of FIB can include discharges from wastewater treatment plants, storm sewers, or confined feeding operations (Paul et al., 2006; Teague et al., 2009). Nonpoint sources of FIB can include runoff from agricultural croplands amended with manures, livestock pastures, urban landscapes; failing septic systems; and fecal deposition by livestock, wildlife, and waterfowl (Paul et al., 2006).

Submitted for review in September 2013 as manuscript number SW 10427; approved for publication by the Natural Resources & Environmental Systems Community of ASABE in October 2014.

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Vol. 31(1): 73-82 © 2015 American Society of Agricultural and Biological Engineers ISSN 0883-8542 DOI 10.13031/aea.31.10427

Previous studies have demonstrated various methods to set pathogen TMDLs for surface waters including load duration curves (LDC) (USEPA, 2007; KDHE, 2012), watershed scale water-quality modeling (Chin et al., 2009; Parajuli et al., 2009), risk-based load reduction (Chin, 2009), and combined Bayesian statistics and LDC (Shen and Zhao, 2010). The limitations in each approach and watershed-specific conditions such as the sources of pathogens, watershed characteristics, and hydrology have resulted in many different approaches for pathogen TMDL development. Watershed scale water quality models such as the Soil and Water Assessment Tool (SWAT) and Hydrologic Simulation Program-Fortran (HSPF) using either empirical or process-based equations, are often used to quantify and develop bacteria TMDLs (Benham et al., 2005, 2006; Baffaut and Sadeghi, 2010). These complex models require large amounts of watershed-specific input data, including measured water quality data for model calibration and validation. Benham et al. (2005) applied the HSPF model to develop bacteria TMDL in Linville Creek Watershed, Virginia, and proposed four bacteria source load reduction scenarios. The authors suggested that a detailed bacteria source characterization is necessary to enhance the accuracy and the applicability of a TMDL study (Benham et al., 2005). The complexity of predicting fate and transport of bacteria makes it challenging to apply the watershed-scale models for setting TMDLs. Wu et al. (2006) stated that a high level of uncertainty exists in TMDLs developed using watershed scale water quality models. The LDC approach recommended by the U.S. EPA for TMDL development is a simpler approach and requires flow data, numerical water quality standards, and observed water quality data. The load allocations and the load reductions necessary to achieve the water quality goal at different flow regimes can be identified using LDCs. However, this approach is limited in that it does not consider factors such as fate and transport mechanisms, decay rates, and bacteria resuspension into streams from bottom sediments. Water quality models and LDC methods are often used to establish bacteria TMDLs for flowing streams (IDNR, 2010a,b), but developing a bacteria TMDL for a standing waterbody such as a lake is a challenging task.

Typically, water samples are collected from lake beaches and a lake is classified as impaired if the FIB concentration in the sample exceeds the applicable water quality standard. Developing a TMDL for lake beaches requires clear understanding of bacteria movement in the waterbody (advection and diffusion), decay rates [due to natural decay, predation, damage by ultraviolet (UV) radiation], resuspension rates, lake water mixing coefficients in horizontal and vertical directions, and other unknown factors (Bowie et al., 1985; Jin et al., 2003). Previous studies have emphasized the importance of these processes. For example, the UV component of solar radiation greatly impacted the *E. coli* concentrations in south Lake Michigan where reductions between 34% and 99% were observed throughout a day (Whitman et al., 2004). Rehmann and Soupir (2009) found that incorporating interactions between streambed sediment and the water column improved estimates of *E. coli* concentrations in streams. Similarly, Jin et al. (2003) developed a mathematical model to estimate fecal bacteria concentrations at a beach and associated the underestimation of the fecal bacteria concentrations to resuspension and survival of microorganisms in the lake bottom sediments. Foreshore and beach sediments have been identified as important bacteria sources for lake beaches (Alm et al., 2003; Whitman and Nevers, 2003, Yamahara et al., 2007; Zhongfu et al., 2010). Resuspension of bacteria-laden beach sands during recreation or due to wave action can act as an additional net source of bacteria to the local beach waters. Therefore, a clear understanding of all the factors affecting the bacteria movement, decay, and growth in lake waters is needed to develop reliable bacteria TMDLs for inland lake beaches.

This study presents an alternative approach to establish a bacteria TMDL for lake beaches under the condition where watershed bacteria contributions are limited and there is an alternative source of bacteria at the beach. To justify this new approach, we assessed the impacts of watershed fecal bacteria inputs to the lake on the fecal bacteria concentrations at the lake beach; used a near-shore beach volume model to develop a bacteria TMDL and determine load reductions needed to achieve water quality goals; and provided monitoring recommendations to support application of this approach.

MATERIALS AND METHODS

STUDY AREA

The study area is the 98-acre manmade Hickory Grove Lake (fig. 1), which is located in Hickory Grove Park, Story County, Iowa, a popular recreational area that annually serves more than 70,000 visitors. The lake is a component of the Iowa Ambient Watershed Monitoring and Assessment Program, which is administered by the Iowa Department of Natural Resources (IDNR) – Iowa Geological and Water Survey to assess the condition of Iowa's surface and groundwater resources. The lake is designated for primary contact recreation, aquatic life and human health uses, and was listed on the 2008 303(d) Impaired Waters Listing for elevated bacteria levels. The lake drains an area of 1,629 ha which is dominated by cultivated land cropped in corn and soybean rotations (83.3%), followed by urban (6.4%), pasture (3.2%), water (2.6%), forest (2.2%), rangeland (1.7%), and wetland (0.6%) land uses. The outflow of the lake flows into East Indian Creek, which is a tributary of the Skunk River.

A total area of 879 ha within the watershed is managed with subsurface tile drains, which is used to remove excess water from subsurface soils to improve crop productivity. The subsurface tile drainage system and other drainage infrastructure are managed within the context of the drainage district (fig. 1) per regulations established in Iowa Law (Story County, 2014). The subsurface tile drain network is one of the major flow paths to the lake and is estimated to represent approximately 75% of the discharge to the lake. Therefore, the outlet of the tile drain system here after is referred to as the lake inlet. A large detention basin is located on the east side of the lake which intercepts

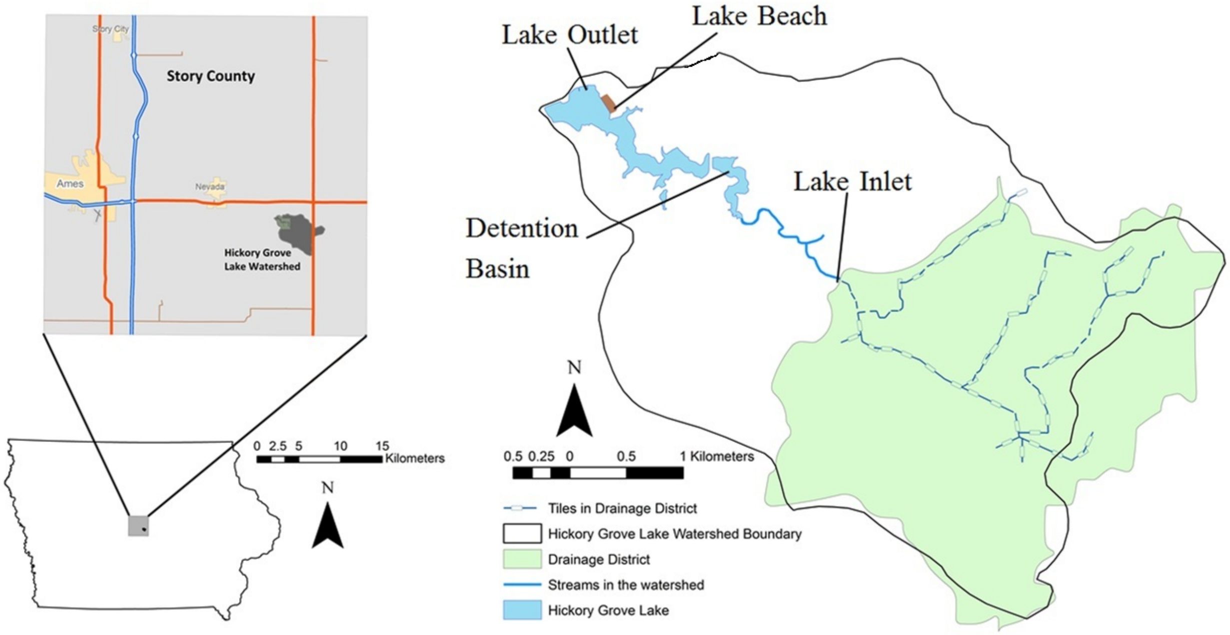

Figure 1. Location of the Hickory Grove Lake and the sampling locations in the watershed.

flow entering the lake from upland areas and allows for settling of sediment as well as decay and settling of bacteria.

SOURCES OF FECAL BACTERIA IN THE WATERSHED

The water quality in Hickory Grove Lake is dominated by non-point source pollution as there are no permitted point sources in the watershed that discharge to the lake. While the lake is listed on the 2008 303d list due to elevated bacteria levels, few areas in the watershed receive manure application. Field surveys conducted by the watershed coordinator confirmed that poultry manure is applied to fields (64.8 ha) to the north of the lake approximately every 2 to 3 years (Aaron Andrews, Watershed coordinator, personal communication, April 2012). Runoff from these manure amended fields can potentially transfer fecal bacteria to the lake.

Assessment of livestock populations in the watershed identified 10 to 12 cattle upstream of the lake inlet with continuous access to the stream. Studies have shown that livestock exclusion and fencing streams reduces FIB loadings by 46% to 52% (Meals, 2001) and FIB concentrations in waters by 57% to 66% (Line, 2003). Other animal sources include resident wildlife and migrating birds during spring and fall which may also contribute to increased bacteria levels in the lake. The park ranger estimated that there are approximately 50 resident geese present at the lake during the recreation season (Memorial Day to Labor Day) and that migrating geese through Iowa during each Spring and Fall range from 1,500 to 2,000 (Dustin Eighmy, Hickory Grove Park Ranger, personal communication, March 2011).

Optical brightener tests were conducted on samples collected from the lake inlet during low flow conditions to assess the potential bacteria contributions from the rural septic systems. Elevated optical brightener levels were detected in one of the three tests conducted (optical brighteners concentration – 19.1 µg/L and *E. coli* concentration – 135 orgs/100 mL on 4 August 2011), confirming the presence of a human source of fecal contamination. The Story County Environmental Health Department evaluated the septic systems in the watershed and identified eight unpermitted septic systems located within the watershed boundary.

WATER QUALITY MONITORING

Water samples at the lake beach, lake inlet, and lake outlet were analyzed for *E. coli* concentrations (fig. 1). The *E. coli* concentrations at the Hickory Grove Lake beach were monitored weekly during the recreational season (typically Memorial Day to Labor Day weekends) under Watershed Monitoring and Assessment Section by the Iowa DNR. The Iowa DNR routine monitoring protocols include collection of weekly water samples that are composited from three transects (left edge, center, and right edge) at three depths (ankle deep, knee deep, and chest deep) along the beach as described in McCurdy (2012). The water samples were collected in 125 mL Nalgene bottles and were analyzed within 24 h of collection using the Most Probable Number (MPN) method (APHA, AWWA, and WPCF, 2005).

The Water Quality Research Laboratory (WQRL) at Iowa State University monitored weekly *E. coli* concentrations at the lake inlet and the lake outlet during the recreational season from 2010 to 2012. In addition to weekly grab sampling, grab samples were also collected at the lake inlet and the lake outlet during rainfall-runoff events. The water samples were collected in 125 mL Nalgene bottles and were analyzed within 24 h of collection using the Membrane Filtration (MF) method (APHA, AWWA, and WPCF, 2005). In the MF method, 100 mL of water is passed through the membrane filter and the filter is placed on Modified mTEC Agar which is incubated at 44.5±0.2°C for 24 h. Both the MPN and MF are U.S. EPA approved methods for the determination of *E. coli* in water (U.S. Environmental Protection Agency, 1978).

The lake water and bottom sediments were also spatially sampled using a random sampling pattern to determine *E. coli* hotspots in the lake. First water samples were collected without disturbing bottom sediment. Next, sediment samples were collected from the top 2-3 cm of the lakebed using a Shallow Water Bottom Dredge Sampler (15 × 15 cm opening, Forestry Suppliers Inc., Jackson, Miss.). This monitoring design allowed for comparison of *E. coli* concentrations at the lake beach to the lake inlet and lake outlet during a range of flow conditions.

ANALYSIS OF MONITORING DATA

Linear regressions were used to describe the relationships between the *E. coli* concentrations at the lake beach with *E. coli* concentrations at the lake inlet and outlet, and rainfall amounts. These assessments were performed to evaluate the effects of event surface runoff and tile flow on the *E. coli* concentrations at the lake beach and to identify the significance of watershed bacteria loads on bacteria concentrations at the beach.

EFFECT OF PRECIPITATION ON *E. COLI* CONCENTRATIONS AT THE LAKE BEACH

The average annual precipitation in the Hickory Grove Lake Watershed is approximately 939 mm. The year 2010 was a wet year with a total annual precipitation about 1082 mm and years 2011 and 2012 were dry years with total annual precipitations 751 and 559 mm, respectively. During the wet year of 2010, the lake inlet flowed year round, whereas during the dry years of 2011 and 2012, flow at the lake inlet ceased by late summer. Because of this, rainfall was used as a proxy to evaluate relationship between runoff from the watershed and *E. coli* concentrations at the lake beach. Relationships between beach bacteria levels and precipitation amounts were examined from 2004 to 2012 to help determine if the upland watershed areas are contributing to beach bacteria levels. Relationships between rainfall amounts and *E. coli* concentrations at the lake beach are shown in figure 2; for correlation purposes bacteria levels were only used if precipitation occurred the day prior to or the day of sample collection. A conservative estimate of the time of concentration for the Hickory Grove Lake Watershed (3.5 h) was estimated from the USDA NRCS Velocity Method (NRCS, 2010), therefore a 24 h antecedent rainfall amount would be optimal to estimate the effects of watershed contributions on beach bacteria concentrations. A R^2 value of 0.0053 was observed between beach bacteria concentrations and rainfall amounts indicating no obvious association. High *E. coli* concentrations at the beach were observed during periods of little or no rainfall and vice versa. Analysis of Variance (ANOVA) performed on the linear regression relationship between rainfall and *E. coli* concentrations at the lake beach (null hypothesis: slope is equal to zero) obtained a p-value of 0.48. The t-test failed to reject the null hypothesis at an α-value of 0.05; therefore, there is insufficient evidence to conclude that there is a relationship between rainfall and lake beach *E. coli* concentrations. Flow was monitored at the lake inlet from 2010 to 2012 and the regression analysis between streamflow and *E. coli* concentrations at the lake inlet obtained an r^2 value of 0.23, indicating no relationship.

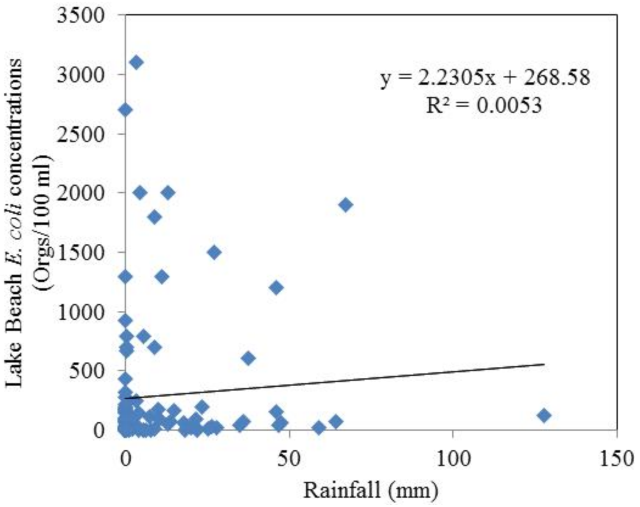

Figure 2 Relationships between rainfall and *E. coli* concentrations at the Hickory Grove Lake beach from 2004 through 2012.

COMPARISON OF *E. COLI* CONCENTRATIONS AT THE LAKE INLET TO THE LAKE BEACH

This analysis includes two parts, a visual examination of the *E. coli* concentrations at the lake beach and lake inlet followed by a linear regression analysis. Figure 3 presents the *E. coli* concentrations measured at the lake inlet and at the lake beach from 2010 to 2012. The samples at the lake inlet were collected every Thursday and following rainfall events while the lake beach samples were collected every Monday during the recreation season. The IDNR single sample mean (SSM) and geometric mean (GM) standards for recreational use lakes are 235 orgs/100 mL and 126 orgs/100 mL, respectively. The Hickory Grove Lake is considered impaired if the *E. coli* concentrations at the lake beach exceed the IDNR GM standard represented by the solid line in figure 3. The *E. coli* concentrations at the lake beach exceeded the IDNR GM standards several times during the recreational season between 2010 and 2012 which led to beach closures. This analysis again demonstrates the lack of agreement between the *E. coli* concentrations entering the lake and the *E. coli* concentrations at the beach. For example, on 9 August 2010 the *E. coli* concentration at the lake inlet was 3,217 orgs/100 mL exceeding the IDNR SSM and GM standards, whereas the *E. coli* concentration at the lake beach was only 120 orgs/100 mL. There were other times (e.g., 22 July 2010) when the beach was impaired due to elevated bacteria levels while the *E. coli* concentrations at the lake inlet were below the IDNR water quality standards.

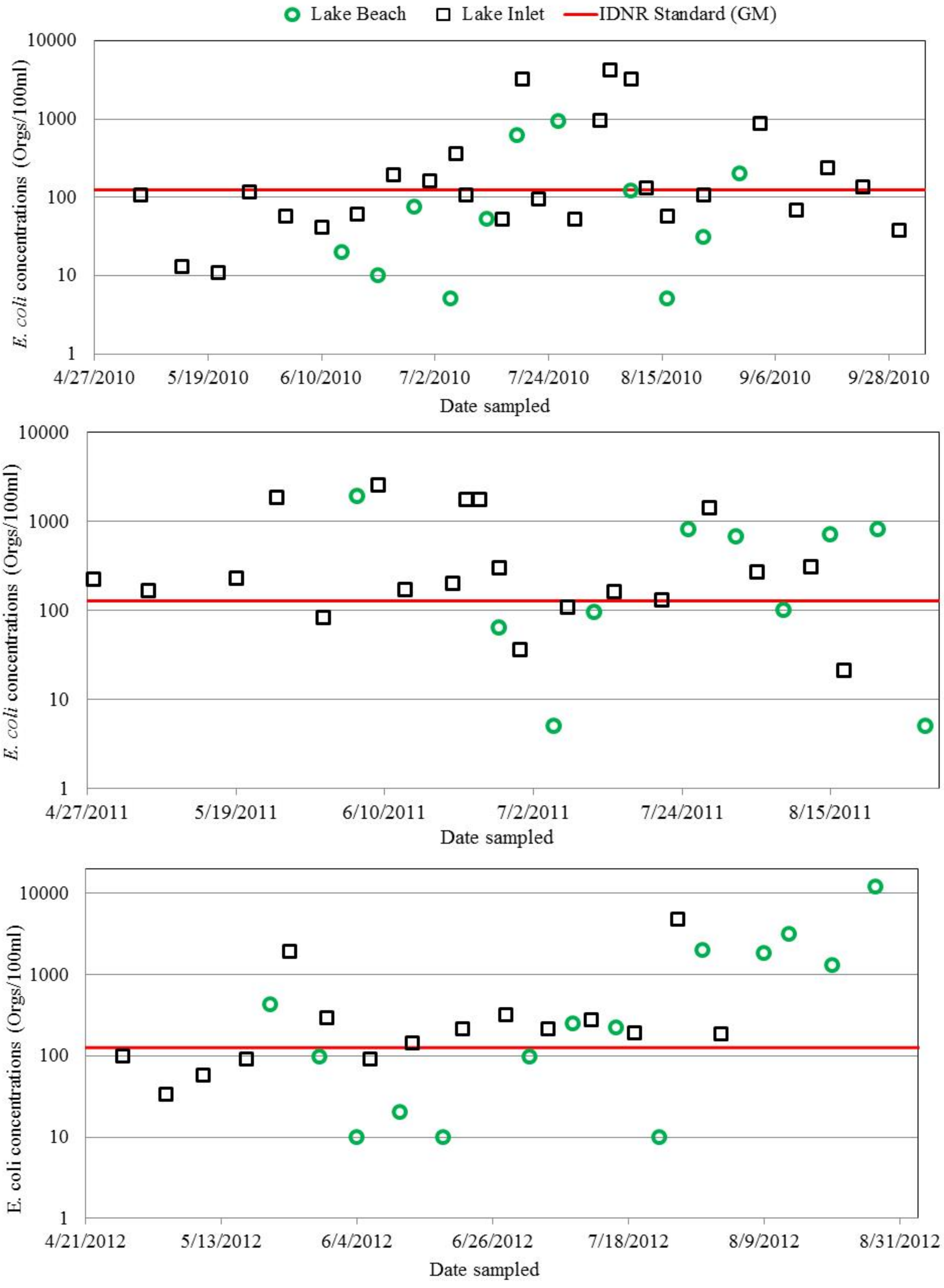

Figure 3. ***E. coli*** **concentrations at the Hickory Grove Lake beach and at the lake inlet during the years 2010, 2011, and 2012.**

The estimated residence time of Hickory Grove Lake is 77 days, and in that case natural decay of *E. coli* will dominate over the in-lake microbial transport processes. Limited information is available for this site regarding in-lake mixing and microbial dynamics, which would be needed to better inform potential transport time between *E.*

coli concentrations at the lake inlet and the lake beach. In the Hickory Grove Lake watershed the time of concentration is short, 3.5 h, so that watershed microbes can be quickly transported to the lake. In the simplest case, if we were to assume a well-mixed lake, we would expect to see relationships in the *E. coli* concentrations at the lake inlet and at the lake beach.

While residence time should be certainly considered in the development of future sampling schemes, the increased frequency of elevated *E. coli* levels at the beach occurring during times of no flow at the lake inlet also makes a strong case that the hot spots at the beach are not related to watershed activities. Several of the beach impairments in 2011 and 2012 primarily occurred towards the end of the recreational season when flow had ceased at the lake inlet, the primary source of flow into the lake. Flow at the lake inlet ceased by early August in 2011 and by late July in 2012 due to low annual precipitation amounts. The samples collected from the lake beach exceeded the water quality standards during the dry periods. For example, the *E. coli* concentration at the lake beach was 12,000 orgs/100 mL in third week of August 2012, but all contributing flow from the watershed had ceased by the last week of July 2012 (fig. 3).

To confirm the observed lack of relationships, the dataset was examined for linear correlations between the *E. coli* concentrations at the lake beach and at the lake inlet over three years, from 2010 to 2012 (R-squared value = 0.0018). As shown in figure 4 there was no clear and consistent relationship between *E. coli* concentrations at the two locations. This figure includes data points when flow was not present at the lake inlet. ANOVA performed on the linear regression relationship between *E. coli* concentrations at the lake beach and lake inlet (null hypothesis: slope is equal to zero) obtained a p-value of 0.81. The t-test failed to reject null hypothesis at an α-value of 0.05, therefore there is insufficient evidence to conclude that there is a relationship in the *E. coli* concentrations between lake inlet and lake beach.

COMPARISON OF *E. COLI* CONCENTRATIONS AT THE LAKE OUTLET TO THE LAKE BEACH

The *E. coli* concentrations at the lake outlet and the lake beach were also analyzed to examine any relationships between the two sampling locations. The lake outlet is an overflow spillway where the discharge from the lake is controlled by the depth of water in the lake and the elevation of spillway. The lake outlet sampling location was approximately 400 m northwest of the lake beach. Figure 5 shows the *E. coli* concentrations at the lake beach and at the lake outlet from 2010 through 2012. An R-squared value of 0.0033 indicates poor fit between the lake beach and the lake outlet *E. coli* concentrations. Again, the regression analysis was unsuccessful in relating the overall lake bacterial water quality with the *E. coli* concentrations at the lake beach. ANOVA performed on the linear regression relationship between *E. coli* concentrations at the lake beach and lake outlet (null hypothesis: slope is equal to zero) obtained a p-value of 0.74. The t-test failed to reject null hypothesis at an α-value of 0.05, therefore there is insufficient evidence to conclude that there is a relationship in the *E. coli* concentrations between lake inlet and lake outlet.

SPATIAL SAMPLING

Water samples were collected from around the lake to determine the presence of *E. coli* hot spots in the lake and to see if the lake inlet bacteria concentrations are representative of concentrations throughout the lake. The resident geese congregate mainly at four locations in the lake (fig. 6) and samples were collected from around these areas and from randomly selected locations in the lake. Spatial sampling of the lake was conducted to determine the extent of the *E. coli* in the lake, when elevated bacteria concentrations at the beach were observed in fall 2011, but not at the lake inlet (fig. 6). The beach monitoring by IDNR at the lake beach on 22 August 2011 detected *E. coli* concentrations of 790 orgs/100 mL, whereas the *E. coli* concentrations at the lake inlet were only 21 orgs/100 mL. Figure 6 shows the *E. coli* spatial sampling at Hickory Grove Lake on 30 August 2011; bacteria were detected only in the samples collected at the beach and the *E. coli* counts observed were less than 35 orgs/100 mL. The *E. coli* concentrations at the lake beach on 29 August 2011 were only 5 orgs/100 mL. The fluctuation of *E. coli* concentrations at the lake beach over the 9 day period (22-30 Aug. 2011) could be due to the time lag between sampling periods or natural decay processes. Regardless, the spatial

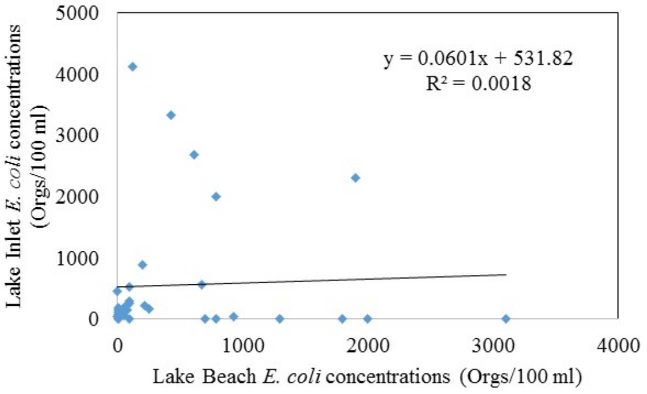

Figure 4. Relationships between *E. coli* concentrations at the Hickory Grove Lake beach and at the lake inlet.

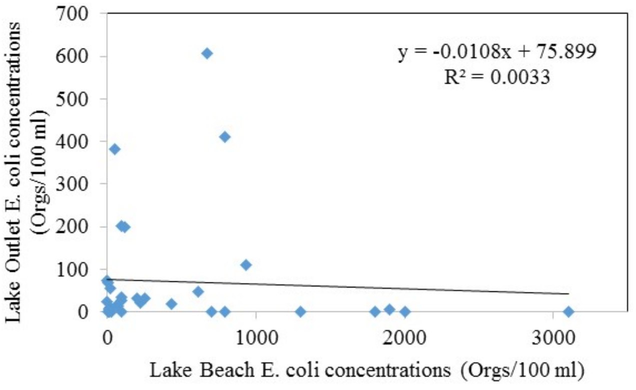

Figure 5. Relationships between *E. coli* concentrations at the Hickory Grove Lake beach and the lake outlet from 2010 through 2012.

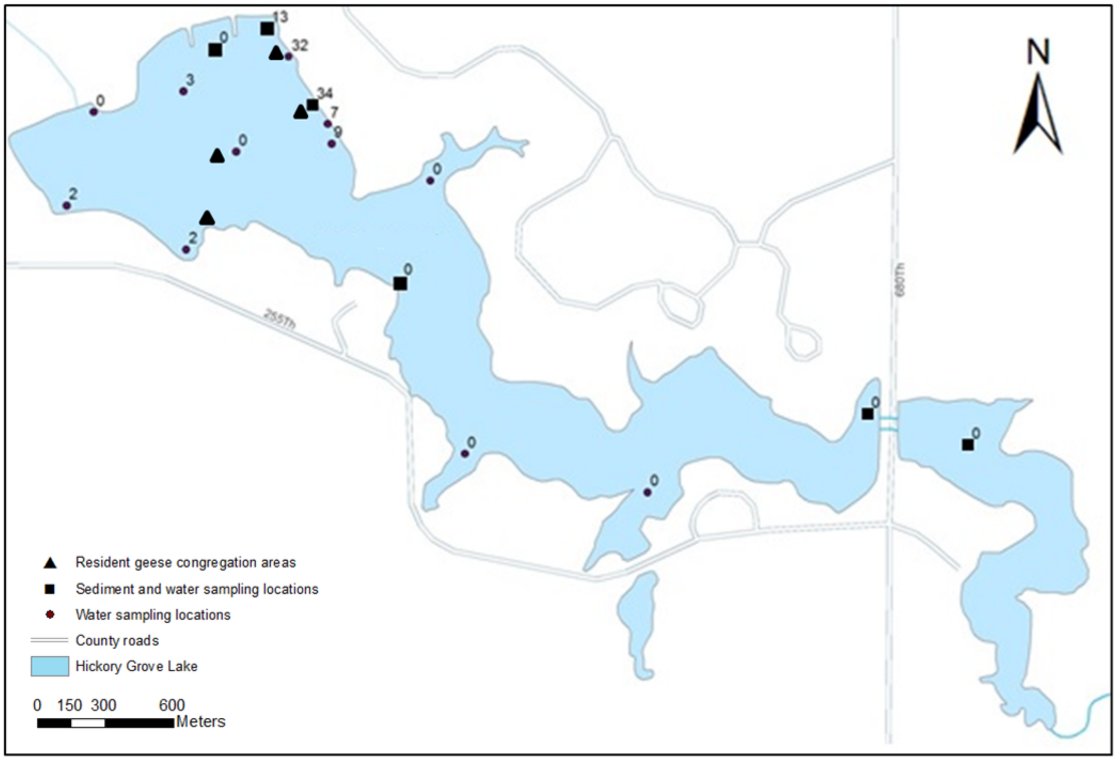

Figure 6. *E. coli* spatial sampling in Hickory Grove Lake on 30 August 2011. Values shown on the map are the *E. coli* concentrations in water samples (orgs/100 mL)

sampling provided useful information regarding the concentrations of bacteria throughout the lake. Spatial sampling was able to identify hotspots in the lake and from this it was hypothesized that the primary source for fecal bacteria at the lake beach was resident geese.

During the spatial sampling in the fall of 2011, sediment samples were collected along with water samples from the lake bottom at six locations (fig. 6). *E. coli* levels were only detectable at two locations (at the beach and at a secondary location on the north end of the lake where geese are also frequently observed). The sediment samples collected at the beach averaged 39 orgs/g (assuming soil bulk density at the lake beach as 1.3 g/cm^3), whereas the water sample collected at the same location had averaged 16 orgs/100 mL. The sediment samples collected from the detention basin did not have detectable levels of *E. coli*.

The regression relationships between the lake beach *E. coli* concentration and the rainfall amounts, the lake inlet and lake beach *E. coli* concentrations; and the lake outlet and the lake beach *E. coli* concentrations were used to support the hypothesis that migratory birds are the primary source of bacteria leading to beach water quality impairments. In all cases, poor relationships were observed indicating watershed bacteria inputs do not significantly affect the bacteria concentrations at the Hickory Grove Lake beach. The spatial sampling of the lake also indicated that bacteria were concentrated at the beach and other locations where resident geese frequently populate. Based on these observations, direct inputs from resident geese at the beach were identified as the major source contributing to beach bacteria impairments rather than watershed bacteria loads to the lake; therefore, a beach bacteria TMDL was developed using a near-shore beach volume model.

NEAR-SHORE BEACH VOLUME MODEL

Chapra (1997) developed a process-based equation to estimate bacteria concentrations in a waterbody during steady-state conditions. The bacteria concentrations in a waterbody were determined based on decay rates, bacteria loading rates, and diffusion rates of bacteria. This model assumes that the diffusion of organisms is equal in all directions.

$$C = \frac{w}{\pi HE} K_0 \sqrt{\frac{kr^2}{E}} \tag{1}$$

where C = concentration of FIB (mass/volume), w = rate of FIB loading (mass/time), r = radius or distance from the beach (length), H = depth of the lake corresponding with distance from the beach (length), E = diffusion of microorganisms in a waterbody (length^2/time), k = decay rate of microorganisms (1/time), and K_0 = first-order modified Bessel function of the second kind.

BEACH BACTERIA TMDL

The Near-Shore Beach Volume (NSBV) model was used to estimate the maximum allowable bacteria load to the Hickory Grove Lake beach. This method was previously applied at the George Wyth Lake, Iowa, a bacteria impaired beach, and the TMDL was approved by the U.S. EPA in December of 2008. The *E. coli* load to the lake beach was estimated by taking into account the number of geese at the beach, the time spent by geese at the beach, and the defecation by geese while on the waterbody. The daily bacteria load is approximately 4.9E+10 fecal coliform organisms per goose per day (USEPA, 2001). The IDNR estimates that the ratio of *E. coli* to fecal coliform is 0.92:1, based on the concentrations observed in waterbodies in Iowa (IDNR, 2008). Therefore, the bacteria load generated by the resident geese was estimated to be 4.51E+10 *E. coli* organisms per day per goose. Geese spend the majority of their time in or near the lake and defecate while on water, therefore it was assumed that at least 50% of the bacteria load generated by the geese is received by the lake (IDNR, 2008). Another assumption made in this study is that the geese spend equal time at four locations in the lake and therefore only one-quarter of the estimated *E. coli* load is received by the beach waters (Dustin Eighmy, Hickory Grove Park Ranger, Personal Communication, March 2011). The total bacteria load received by the beach waters was calculated as 2.82E+11 *E. coli* organisms per 50 geese per day.

The 2010 USDA Farm Service Agency aerial images were used to measure the dimensions (length and width) of the lake beach using ArcGIS 10.1 software. The beach volume was estimated as 4,243 m^3 (3.44 acre-ft) using 91.4 m (300 ft) as the beach length, 30.5 m (100 ft) as the beach width (floating buoys were located at 100 ft into the lake from the beach), and the depth of the lake at the buoys was assumed to be 3.05 m (10 ft) with the lake beach at a 5° slope. Parameters used in setting the bacteria TMDL are presented in table 1. Bowie et al. (1985) summarized decay rates for fecal coliform and *E. coli* at various temperatures for different waterbodies in the United States. The decay rates varied from 0 to 2 per day for various streams, estuaries, and lakes. An average decay rate of 1.6 per day at 20°C was used in this study, similar to the study at George Wyth Lake, Iowa (IDNR, 2008). The diffusion rate of microorganisms (E) varies widely with waterbody type, temperature of waterbody, and source of microorganisms. Therefore, in order to account for high uncertainty in E, randomly selected values within the specified range were used to characterize the allowable bacteria loads at the lake beach. The Monte Carlo simulations were performed on the NBSV model (1000 simulations) using the randomly selected E values.

The Monte Carlo model was calibrated by varying E so that the model output is within the observed *E. coli* concentrations at the lake beach. The maximum concentration observed at the lake beach during the 9 year monitoring period (2004-2012) was 3,100 orgs/100 mL, with an outlier of 12,000 orgs/100 mL on 27 August 2012. The minimum concentration observed at the lake beach during 9 year monitoring period was 5 orgs/100 mL. The minimum and maximum concentrations from the Monte Carlo model output were 42 orgs/100 mL and 3,814 orgs/100 mL, respectively. The mean concentration of the model output was 140 orgs/100 mL and about 12% of the Monte Carlo model output exceeded the SSM standard. The kurtosis and skewness of the model output were -1.11 and 6.15, respectively; these values indicate the model output had a rightly skewed distribution with a flatter peak. The model output is highly skewed and was widely spread around left side of the mean (140 orgs/100 mL); therefore, the majority of the output from the NBSV model was less than or around 140 orgs/100 mL. The daily allowable maximum bacteria load from geese was estimated as 1.87E+11 orgs/day, and the geometric mean bacteria load was estimated as 1.01E+11 orgs/day. The allowable bacteria loads represent the median loads from the 1000 simulations performed.

Table 1. NBSV parameter values used for setting the TMDL.

Parameter	Value	Units
H	3.048 (10)	m (ft)
E	86.39 - 0.86 (930 - 9.3E+8)	m^2/day (ft^2/day)
k	1.6	1/day
r	30.48 (100)	m (ft)
C	2.3E+6 (2.9E+9)	orgs/m^3 (orgs/acre-ft)

In this study, an implicit Margin of Safety approach was used in the TMDL development. This approach includes using conservative estimates of model parameters, bacteria loads received by the lake, and Monte Carlo simulations to reduce the uncertainties in the model output. The load allocation from the NSBV model for the SSM target is 1.87E+11 orgs/day and for the GM the target is 1.01E+11 orgs/day. The SSM and GM target loads were approximately equal to the daily loads generated by four and two resident geese, respectively. As few as five resident geese can elevate the *E. coli* concentrations at the beach above the water quality standard.

LIMITATIONS OF THE APPROACH

The method proposed here is recommended as an alternative for setting beach bacteria TMDLs in situations when the bacteria levels at an impaired beach do not appear to be related to watershed bacteria loads. Watershed activities may still have some impact on lake water quality, but in this case study, the overwhelming load to the beach from resident geese created a local hot spot with elevated *E. coli* concentrations which were not observed at the watershed outlet or other locations within the waterbody. In the case where a point source load is present in the watershed, additional consideration as to the applicability of the NSBV model approach would include: location of the point source in the watershed, proximity of the point source to the beach, and estimation of the potential of the point source fecal bacteria load reaching beach waters. A secondary compliance location could be set at the lake inlet and a TMDL could be developed for this location to address watershed bacteria inputs to the lake. A use attainability analysis would be required to identify the appropriate use of the inlet waters and identify the relevant water quality standards.

The near shore beach model requires several assumptions to define parameters which are not well known for Iowa lakes. Particularly the diffusion rate (E) is poorly defined in both the reference which introduces the model (Chapra, 1997) and other model applications in Iowa. Here we limited the range of acceptable values for E, to simulate bacteria concentrations observed at the Hickory Grove Lake beach. If more intensive spatial sampling at the beach area were to be adopted, a weighted concentration could be calculated and similarly used to set the range of acceptable diffusion rates. Another parameter which introduces high variability into the recommended load reductions is the definition of the near shore beach volume. A smaller beach volume might be more representative of the recreational waters entered by children but a larger volume (for example the distance from the shore to the buoys) encompasses the entire swimming zone. A smaller beach volume is the most conservative estimate for protection of public health. Monitoring of beach sediments indicates elevated *E. coli* concentrations occur in the beach sand (Hartz et al., 2007) and resuspension of these sediment-attached bacteria is completely neglected in this model. However, limited information on resuspension of beach sediments into swimming areas is currently available and defining the parameters needed to predict this process is difficult and could introduce additional uncertainty into the model.

MONITORING RECOMMENDATIONS AND ANALYSIS

Prior to applying the NSBV model for establishing a beach bacteria TMDL, the monitoring system should be first designed to clarify if there is a relationship between lake inlet bacteria concentrations (representing the watershed contributions) and the beach bacteria levels. This can be accomplished by collecting water samples at key locations in the watershed and in the lake during baseflow conditions and after storm events. Watershed time of concentration and the lake residence time should be considered when post-event sampling occurs. Time of concentration information is needed to identify post-event sampling times corresponding with influent from upland areas that are likely to contribute FIB to waterbodies. The lake residence time should be calculated to inform timing of post-event sampling that will occur at monitored lake-inlet locations and recreational beach areas. Monitoring recommendations are as follows:

- weekly beach water quality monitoring and post-event sampling;
- periodic spatial sampling of the lake;
- weekly and post-event grab sampling of the water quality at the lake inlet mixing zones; and
- weekly and post-event grab sampling of the water quality at the lake outlet.

Additionally, the collection of microbial source tracking data would be useful to confirm that the dominant source of bacteria at the beach originates from local waterfowl. In some cases pet waste may need to be considered as an additional load to the beach.

CONCLUSION

Identifying the sources of contamination and the degree of contaminant loads received by the waterbody are the first steps in the TMDL development process. The near shore beach volume model approach proposed here is a viable alternative for setting load reductions at bacteria impaired beaches, where the predominant source of *E. coli* is waterfowl. Efforts to deter resident geese from lake beaches include controlled goose hunt programs, geese relocation programs, mylar tape around the beach to deter geese, harrowing the beach to expose the existing bacteria to UV radiation, a PTO driven grooming machine to remove goose droppings, sonic deterrents, vegetation controls, and green lasers.

The NBSV approach would allow Clean Water Act Section 319 implementation funds to target the localized contributions from geese and increase the likelihood of achieving water quality improvements. The recommended modifications to current monitoring approaches could expedite the TMDL development process, but design of the monitoring system would be specific to the waterbody in which it is being applied. The NSBV model may not apply to larger or more complex watersheds, where bacteria concentrations at the lake beach are affected by the watershed bacteria loads.

Research indicates that bacteria adsorb to particles (Hartz et al., 2007), and their fate and transport from upland areas could be associated with sediment. Therefore, to obtain more accurate bacteria TMDLs future research is recommended to improve understanding of the relationships between sediment and bacteria transport in streams, and modify the existing NSBV equation to include the resuspension of bacteria attached to beach sediments into beach waters. Additional research is also needed to better define the diffusion parameter. If this approach were to be widely adopted by states, regional guidelines for model parameter selection based on lake properties would be useful.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Iowa Department of Natural Resources, grant #CRD0HA5GAnton100073, and ESD7149KAmen120137. The authors would like to thank Charles Ikenberry for insightful discussions; Aaron Andrews, Kendal Agee, Arndt Gossell, Kate Klavon, Danielle Koester, Nick Terhall, and Conrad Brendel for assistance with sample collection and analysis; and Jason McCurdy with the IDNR for beach sampling data.

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