INDIANA *E. COLI* CALCULATOR USER GUIDE

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INTRODUCTION

This document provides a thorough review of the use and background information for the Indiana *E. coli* Calculator. The first portion of the document describes the calculator's components and use. Appendix I provides background information on *E. coli* mechanics and how to understand them through a modeling lens. Appendix II is an annotated bibliography of the sources cited in Appendix I.

INDIANA *E. COLI* CALCULATOR

The Indiana *E. coli* Calculator (IEC) is a spreadsheet tool that estimates the *Escherichia Coli* (*E. coli*) contribution from multiple sources and calculates load reductions of best management practice (BMP) installations. The portions of the spreadsheet that calculate *E. coli* contributions are heavily based upon the Environmental Protection Agency's (EPA) Bacteria Indicator Tool (BIT). The BIT estimates the monthly accumulation rate of fecal coliform bacteria on four land uses (cropland, forest, built-up, and pastureland). The tool also estimates the direct input of fecal coliform bacteria to streams from grazing agricultural animals and failing septic systems. The IEC converts the fecal coliform values of the BIT to *E. coli* through a conversion equation based on Ohio water quality sampling results.

There are two versions of the IEC: a condensed version and an expanded version. The condensed version uses default values to reduce user input and improve ease of use. It consolidates all user input to one sheet. The expanded version allows users to edit all input values used to calculate the *E. coli* loads. In both versions the load reduction calculations are the same, the condensed version just offers fewer settings to change. There is a description of the Condensed *E. coli* Calculator later in this guide.

The IEC is based on a modeling study of 10 subwatersheds, composed of four land uses (cropland, forest, urban, and pastureland). BLUE text found throughout the spreadsheet presents valuable information and assumptions. RED text designates values that should be specified by the user. **BLACK** text usually presents information that is calculated by the spreadsheet or that should not be changed. The default versions of the IEC have all cells locked except those where user inputs are required.

Throughout the IEC users will find reasonable default starting values based on literature for certain quantities that may not be readily estimated. The default values are colored red like user inputs and may be edited. These values are reasonable starting points, but users should use local information if it is available.

The tool contains the following worksheets:

Worksheet Name	**Purpose**
Input	User entry of the distributions of urban land, forestland, cropland, and pastureland, septic system information, and agricultural animal distribution in up to 10 subwatersheds
Weather Data+*	Contains rainfall data for all counties in Indiana. This sheet supports automatic calculation of rainfall data in the Rainfall tab.
Rainfall+*	Lists rainfall values for each subwatershed and land use based upon county weather data.

Worksheet Name	Purpose
Animals+	Lists the number of agricultural animals in each subwatershed (beef cattle, dairy cattle, swine, chickens, horses, sheep, and other [user-defined]), and the densities of urban animals and wildlife by land use category (ducks, geese, deer, beaver, raccoons, and other [user-defined]).
Manure Application+	Calculates the fraction of the annual manure produced that is available for wash off based on the amount applied to cropland and pastureland in each month and the fraction of manure incorporated into the soil (for hog, beef cattle, dairy cattle, horse, and poultry manure).
Grazing+	Lists the days spent confined and grazing for beef cattle, horses, sheep, and other. Beef cattle are assumed to have access to streams while grazing.
Wildlife+*	Calculates the fecal coliform bacteria and *E. coli* produced by wildlife by land use category.
Cropland+*	Calculates the monthly rate of accumulation of fecal coliform bacteria and *E. coli* on cropland from wildlife, hog, cattle, and poultry manure.
Forest+*	Calculates the rate of accumulation of fecal coliform bacteria and *E. coli* on forestland from wildlife.
Urban+	Calculates the rate of accumulation of fecal coliform bacteria and *E. coli* on built-up land using literature values and animal contributions.
Pastureland+*	Calculates the monthly rate of accumulation of fecal coliform bacteria and *E. coli* on pastureland from wildlife, cattle, and horse manure, and cattle, horse, sheep, and other grazing.
Cattle in Streams+*	Calculates the monthly loading and flow rate of *E. coli* contributed directly to the stream by beef cattle.
Septics+	Calculates the monthly loading and flow rate of *E. coli* from failing septic systems.
Total Loads	Calculates the sums of all contributory sources of *E. coli* and provides various time-step delineations of the results.
NPS Reductions	Calculates the *E. coli* reductions achieved through up to 50 individual BMP installations.
Septic Reductions	Calculates the *E. coli* reductions achieved through up to 50 individual entries of septic systems repaired or removed.
Lists+*	Contains the base information used to create the drop-down lists used in the NPS Reductions and Septic Reductions spread sheets.
BMP List+*	Contains the list of BMPs with associated reduction efficiencies used in the drop-down menus in the NPS Reductions tab.
References+*	Contains all the values and literature citations referenced throughout the spreadsheet.

+ denotes tabs that are hidden in the default Condensed version of the spreadsheet

* denotes tabs that are hidden in the default Expanded version of the spreadsheet

The following information must be input by the user:

- Land use distribution for each subwatershed (urban, forest, cropland, and pastureland). The urban land use is further broken down into four sections: commercial and services, mixed urban, residential, and transportation/communications/utilities).
- Number and type of agricultural animals in each subwatershed
- Number of septic systems in the study area, the number of people served by septic systems in the study area, and an estimated failure rate of septic systems in the study area

Default values are supplied for the following inputs, but they should be modified to reflect patterns in the study watershed:

- Fraction of each manure type that is applied each month
- Fraction of each manure type that is incorporated into the soil
- Time spent grazing and confined by agricultural animals (and in stream for beef cattle only)

Literature values are supplied for the following inputs, but they may be replaced with user values if better information is available for the study watershed:

- Animal waste production rates and fecal coliform bacteria content
- Fecal coliform bacteria accumulation rates for built-up land uses
- Raw sewage fecal coliform bacteria content and per capita waste production
- Wildlife densities for urban and non-urban land uses
- BMP reduction efficiencies
- Rainfall values

SHEET DESCRIPTIONS

The remainder of this document describes the purpose and use of each worksheet within the IEC, as well as the input required by the user (if any). Sheets that require user input are labelled. The sheets are listed in the order they appear in the IEC. Note that some sheets are hidden in the default versions of the IEC.

INPUT (USER INPUT)

The Input sheet allows the user to enter most of the necessary information for the calculator on one sheet. The information is used throughout the calculator to return loads and reductions. On this sheet users will need to select a county to represent the study area's rainfall, enter land uses, estimate the number of septic systems, septic system users, and failure rate, and the number of agricultural animals in the study area.

In cell D17 the user should use the drop-down menu to select a county in Indiana that represents the study area. This county will be used to calculate rainfall volume on the study area used later in the tool.

The four land uses in the IEC are Urban, Forest, Cropland and Pastureland. These four land uses are adapted from much more detailed land use schemes by reassigning the detailed categories to the corresponding calculator categories. Use the table on page six as a guide for reassigning land use:

USGS Land Use/Land Cover Classification	IEC Land Use Classification
Low Intensity Residential	Urban
High Intensity Residential	
Commercial/Industrial/Transportation	
Quarries/Strip Mines/Gravel Pits	
Deciduous Forest	Forest
Evergreen Forest	
Mixed Forest	
Shrubland	
Orchards/Vineyards/Other	
Woody Wetlands	
Emergent Herbaceous Wetlands	
Grasslands/Herbaceous	
Pasture/Hay	Pastureland
Row Crops	Cropland
Small Grains	
Fallow	

Land use conversions do not need to follow the guide exactly. For example, if grasslands are used by livestock for pasture then it makes sense to classify them under pastureland instead of forest. Once the land uses have been re-classified, enter the values in the appropriate cells on the Land Use sheet. Total acres by subwatershed and land use category will be calculated automatically by the tool.

The user should input the estimated number of septic systems in cell B37. The user should put the estimated number of people served by septic systems in B38. The user should estimate the failure rate of septic systems in the watershed and input that value into cell B40. More information on how to obtain these numbers is given in the explanation for the "Septics" sheet (page 15).

Lastly, in the table titled Agricultural Animals, the user should input the distribution of farm animals in each subwatershed by animal type. Additional detail on this may be found in the description of the "Animals" sheet (page 7).

RAINFALL (USER INPUT)

This sheet reports average annual rainfall in inches, average annual number of rain days, and average annual days with run off for a selected county in Indiana. It then calculates an average annual volume of water input into the ten subwatersheds and individual land uses reported in acre-feet. User input for this sheet is taken from cell D17 on the "Inputs" sheet. No user input is required on this sheet.

WEATHER DATA

The sheet contains average annual rainfall in inches, average annual number of rain days, and average annual days with run off for each county in Indiana. The data is calculated from the years 1981-2013. This sheet is hidden in the default version of the IEC and provides the supporting information for the Rainfall sheet. No user input is required, but the values can be changed if a user has more accurate rainfall data.

ANIMALS (USER INPUT)

Fecal contributions from the animals listed in this worksheet are used to derive loading estimates for all land uses. Only manure from cattle, swine, and poultry is assumed to be collected and applied to cropland. Cattle manure is also assumed to be applied to pastureland. Horse manure is assumed to be collected and applied to pastureland only. Manure from cattle, horses, sheep and "other" agricultural animals is assumed to be contributed to pastureland in proportion to time spent grazing. Wildlife densities are provided for all land uses except urban and are assumed to be the same in all subwatersheds. Urban animals are estimated separately. An “other” category is provided for agricultural animals, wildlife, and urban wildlife to allow the user to include animals that are not already available in the IEC.

Many Watershed Management Plans (WMPs) have information on the amount and type of agricultural animals present in the watershed. In the absence of site-specific data, the number of agricultural animals present in each subwatershed can be determined using county-level data from the Census of Agriculture(https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/index.php). The total number of agricultural animals can be estimated for each subwatershed based on a ratio of subwatershed level pastureland to county-level pastureland area. For example, assume Subwatershed 1 is located entirely within County A and that County A contains 1000 acres of pastureland and 200 dairy cows. If Subwatershed 1 contains 100 acres of pastureland, this subwatershed is assigned [(200/1000)*100] = 20 dairy cows. Calculate the number of agricultural animals (dairy and beef cattle, swine, chickens, horses, sheep, and “other”) in each subwatershed and enter these values in the appropriate cells on the Animals sheet. Totals by subwatershed and animal type will be calculated automatically. Another possible resource is the online STEPL data input server (http://it.tetratech-ffx.com/steplweb/steplweb.html). The website can provide estimates for landuse, animals, septics, and other information by subwatershed or county.

The default densities of wildlife and urban animals are estimated based on the best available literature values. It is assumed that the densities of wildlife on each of the non-urban land use types (forest, cropland and pastureland) are the same across all subwatersheds. Enter the density for each form of wildlife (ducks, geese, deer, beaver, raccoons, and “other”) on each land use type in animals per square mile. The wildlife densities per acre will be calculated automatically. To calculate animal inputs to the Urban land use, enter the estimated number of animals per square mile in the table labelled “Urban Animals”.

MANURE APPLICATION (USER INPUT)

This sheet contains calculations regarding the land application of waste produced by agricultural animals in the study area. Application of hog manure, cattle manure, horse manure, and poultry litter are considered. The information is presented based on the monthly variability of waste application. The annual production of manure is calculated and then applied each month using the information in this sheet. It is assumed that cattle manure is applied to both cropland and pastureland using the same method. Hog manure and poultry litter are assumed to be applied only to cropland. Horse manure is assumed to be applied only to pastureland.

For each of the four major manure sources (hogs, cattle, horses, and poultry), users may specify the fraction of the annual manure produced that is applied each month (January through December) and the fraction of the manure applied that is incorporated into the soil, or they may utilize the default values. The fraction of manure available for wash off each month for each type of manure will then be calculated automatically. Note that the equation used to calculate the fraction available for runoff can be updated if necessary.

GRAZING (USER INPUT)

This sheet contains information relevant to cattle, horses, sheep, and "other" animals grazing on cropland and pastureland in the study area. Dairy cattle are assumed to be kept only in feedlots. Therefore, all their waste is used for manure application (divided between cropland and pastureland). Beef cattle are assumed to be kept in feedlots or allowed to graze (depending on the season). When they are grazing, a certain proportion is assumed to have direct access to streams. The grazing time spent in streams represents a combination of the number of animals with stream access and the percent of time these animals spend contributing waste directly to the streams. Beef cattle waste is therefore applied as manure to cropland and pastureland, contributed directly to pastureland, or contributed directly to streams (referred to by the tool as Cattle in Streams). In the Total Loads sheet, direct deposition loading is added to pastureland loading. Horses are assumed to be either kept in stables or allowed to graze. Horse waste is therefore either applied as manure to pastureland or contributed directly to pastureland; horse manure is not applied to cropland. Sheep are assumed to be allowed to graze year-round. Sheep waste is therefore contributed only directly to pastureland. The purpose of the "other" animal category is to allow you to define the grazing patterns of an agricultural animal not available in the default information. To use this category, you must be sure to enter the number of "other" animals in each subwatershed (on the Animals sheet) and to specify a fecal coliform bacteria production rate for this animal (on the References sheet). "Other" animal waste is contributed directly to pastureland only while grazing.

For cattle, horses, sheep, and "other," enter the fraction of time spent confined each month (from 0, never confined, to 1, always confined). The fraction of time and the number of days per year spent grazing will be calculated automatically. The fraction of time grazing spent in pasture will be calculated automatically.

WILDLIFE

This sheet calculates the total fecal coliform bacteria produced by wildlife each day per acre on cropland, pastureland, and forest. This calculation is performed by multiplying the density (animals per acre) of each type of wildlife on each land use by the rate of fecal coliform production for that wildlife type (count per animal per day). The number of fecal coliform bacteria produced is then summed across all wildlife types for each land use to obtain a total wildlife fecal coliform production rate and an *E. coli* production rate (count per acre per day), which will be used in subsequent sheets.

To use the "other" wildlife category, you must be sure to enter the number of "other" animals in each subwatershed (on the Animals sheet) and to specify a fecal coliform bacteria production rate for this animal (on the References sheet). No user input is required on the Wildlife sheet.

CROPLAND

This sheet calculates the total fecal coliform bacteria and *E. coli* applied to each acre of cropland by month. The sources of fecal coliform bacteria for cropland are wildlife, hog manure application, cattle manure application, and poultry litter application. No user input is required on the cropland sheet. Chickens and hogs are assumed to be confined all the time, and their manure is applied only to cropland. Dairy cattle are also assumed to be confined all the time, and their manure is applied to both cropland and pastureland. Beef cattle are either kept in feedlots or allowed to graze, depending on the time of year and values input in the Grazing sheet. When they are grazing, a certain proportion is assumed to have direct access to streams (as specified in the Grazing sheet.) Beef cattle manure is therefore either applied to cropland and pastureland, contributed directly to pastureland during grazing, or contributed directly to streams (referred to by the tool as Cattle in Streams.)

Wildlife

The fecal coliform bacteria produced by wildlife per acre of cropland is determined for each month as follows:

1. The total wildlife population of each subwatershed is calculated (acres of cropland from the Land Use sheet multiplied by the cropland wildlife density from the Wildlife sheet.)
2. The total daily fecal coliform bacteria load generated by that population is calculated (acres of cropland from the Land Use sheet multiplied by the fecal coliform generated per acre of cropland from the Wildlife sheet).
3. The daily per acre accumulation rate of fecal coliform bacteria from wildlife is calculated by dividing the total load generated by the number of acres of cropland in each subwatershed.

Hog Manure

The fecal coliform bacteria from hog manure applied per acre of cropland is determined for each month as follows:

1. The number of hogs in each subwatershed (from the Animals sheet) is multiplied by the daily fecal coliform production rate per hog (from the References sheet) to obtain the daily hog fecal coliform production rate.
2. The daily rate is then multiplied by 365 to obtain the amount of fecal coliform produced by hogs per year.
3. The fecal coliform bacteria available for wash off is then calculated by multiplying the annual fecal coliform produced by the amount applied and available for wash off in each subwatershed in each month (from the hog manure section of the Manure Application sheet).
4. The monthly total is then divided by the number of days in each month to obtain the daily accumulation rate.
5. Finally, the daily accumulation rate is divided by the number of acres of cropland in each subwatershed to obtain the daily per acre load of fecal coliform bacteria from hog manure.

Cattle Manure

The fecal coliform bacteria from cattle manure applied per acre of cropland is determined for each month as follows:

1. The number of dairy and beef cattle in each subwatershed (from the Animals sheet) is multiplied by the daily fecal coliform production rate per dairy and beef cow (from the References sheet) to obtain the daily dairy and beef cattle fecal coliform production rates.
2. The daily dairy fecal coliform production rate is then multiplied by 365 to obtain the amount of fecal coliform produced by dairy cattle and available for application as manure per year. The

daily beef fecal coliform production rate is multiplied by 365 minus the days spent grazing (from the cattle section of the Grazing sheet) to obtain the amount of fecal coliform produced by beef cattle and available for application as manure per year. (The fecal coliform bacteria produced by beef cattle while grazing is assumed to be delivered directly to pastureland.) The total fecal coliform load from cattle manure application is the sum of the dairy and beef cattle loads.

3. The fecal coliform bacteria available for wash off is then calculated by multiplying the annual fecal coliform produced by the amount applied and available for wash off in each subwatershed in each month (from the cattle manure section of the Manure Application sheet).
4. The monthly total is then divided by the number of days in each month to obtain the daily accumulation rate.
5. Finally, the daily accumulation rate is divided between cropland and pastureland and the portion applied to cropland is divided by the number of acres of cropland in each subwatershed to obtain the daily per acre load of fecal coliform bacteria from cattle manure.

Poultry Litter

The fecal content of the litter is considered here, even though litter is the combination of manure and bedding. As such, the fecal coliform bacteria produced by chickens and applied to cropland is estimated from the rate of manure production per chicken and the bacteria content of that manure, rather than from the bacteria content of the combined manure and bedding.

The fecal coliform bacteria from poultry litter applied per acre of cropland is determined for each month as follows:

1. The number of chickens in each subwatershed (from the Animals sheet) is multiplied by the daily fecal coliform production rate per chicken (from the References sheet) to obtain the daily poultry fecal coliform production rate.
2. The daily rate is then multiplied by 365 to obtain the amount of fecal coliform produced by chickens per year.
3. The fecal coliform bacteria available for wash off is then calculated by multiplying the annual fecal coliform produced by the amount applied and available for wash off in each subwatershed in each month (from the poultry litter section of the Manure Application sheet).
4. The monthly total is then divided by the number of days in each month to obtain the daily accumulation rate.
5. Finally, the daily accumulation rate is divided by the number of acres of cropland in each subwatershed to obtain the daily per acre load of fecal coliform bacteria from poultry litter.

The total accumulation rate of fecal coliform bacteria and *E. coli* from cropland is calculated as the sum of the accumulation rates from wildlife and hog, cattle, and poultry manure applications.

FOREST

The wildlife population is the only bacteria contributor to forest considered. No user input is required on the Forest sheet. The fecal coliform bacteria produced by wildlife per acre of forest is determined for each month as follows:

1. The wildlife population of each subwatershed is calculated (acres of forest from the Land Use sheet multiplied by the forest wildlife density from the Wildlife sheet).

2. The total daily fecal coliform bacteria load generated by that population is calculated (acres of forest from the Land Use sheet multiplied by the fecal coliform generated per acre of forest from the Wildlife sheet).
3. The daily per acre accumulation of fecal coliform bacteria from wildlife is calculated by dividing the total load generated by the number of acres of forest in each subwatershed.

URBAN (USER INPUT)

Urban land loadings are based on two components: a base load defined by land use and animal loading. To calculate the Urban base load the Urban land use category is subdivided into four categories:

- Commercial and Services
- Mixed Urban or Built-Up
- Residential
- Transportation, Communications, and Utilities

Urban base loads are calculated as follows:

1. The percentage breakout of these categories is specified by the user in the Urban sheet. The acres of each urban category in each subwatershed are calculated by multiplying the total urban acres (from the Land Use sheet) by the percentage breakouts specified by the user.
2. A daily per acre fecal coliform bacteria loading rate is calculated for each built-up category using literature values. The loading rates provided in Horner (1992) and presented in the References sheet are applied as follows:

Urban Category	Fecal Coliform Loading Rate (count/acre/day)
Commercial and Services	Commercial
Mixed Urban or Built-Up	Average of road, commercial, single-family low-density, single-family high-density, and multifamily residential
Residential	Average of single-family low-density, single-family high-density, and multifamily residential
Transportation, Communications and Utilities	Road

3. A weighted average built-up fecal coliform bacteria accumulation rate is calculated for each subwatershed based on the individual Urban land use categories present and their corresponding accumulation rates.

Not all feces will be deposited in areas that wash to a water body, or they may be incorporated into the soil, and not all feces are produced at the same time. Therefore, urban animal feces are calculated by defining the fraction of feces available for wash off each month and multiplying that fraction by the volume of manure produced by animals in urban areas. These two values are assumed and may be changed by the user. Urban feces wash off is calculated by multiplying the fraction of feces produced each month by the fraction of feces available for wash off. The number of urban animals in each subwatershed is derived from the acreage and density of urban animals.

Urban Animals include ducks, geese, pigeons, deer, dogs, gulls, raccoons, and rats. An "other" option is available if desired. The mean loading rates are calculated based on literature values and estimated urban population density.

PASTURELAND

This sheet calculates the total fecal coliform bacteria applied to each acre of pastureland by month. The sources of fecal coliform bacteria for pastureland are wildlife, cattle and horse manure application, and beef cattle, horse, sheep, and "other" animal grazing. No user input is required on the Pastureland sheet. It is assumed that dairy cattle are confined all the time and their manure is applied to both cropland and pastureland. Beef cattle are assumed to be kept in feedlots or allowed to graze, depending on the season. When they are grazing, a certain proportion of the cattle is assumed to have direct access to streams (as specified on the Grazing sheet.) Beef cattle manure is therefore applied to cropland and pastureland, contributed directly to pastureland during grazing, or contributed directly to streams (referred to by the tool as Cattle in Streams.) Horse manure that is not deposited in pastureland during grazing is assumed to be collected and applied to pastureland. Sheep and "other" animal manure that is not deposited in pastureland during grazing is assumed to be collected and treated or transported out of the watershed and is tabulated in the last column of the Pastureland sheet (FC collected; EC collected).

Wildlife

The fecal coliform bacteria produced by wildlife per acre of pastureland is determined for each month as follows:

1. The wildlife population of each subwatershed is calculated (acres of pastureland from the Land Use sheet multiplied by the pastureland wildlife density from the Wildlife sheet).
2. The total daily fecal coliform bacteria load generated by that population is calculated (acres of pastureland from the Land Use sheet multiplied by the fecal coliform generated per acre of pastureland from the Wildlife sheet).
3. The daily per acre accumulation rate of fecal coliform bacteria from wildlife is calculated by dividing the total load generated by the number of acres of pastureland in each subwatershed.

Cattle Manure

The fecal coliform bacteria from cattle manure applied per acre of pastureland is determined for each month as follows:

1. The number of dairy and beef cattle in each subwatershed (from the Animals sheet) is multiplied by the daily fecal coliform production rate per dairy and beef cow (from the References sheet) to obtain the daily dairy and beef cattle fecal coliform production rates.
2. The daily dairy fecal coliform production rate is then multiplied by 365 days to obtain the annual amount of fecal coliform produced by dairy cattle and available for application as manure. The daily beef fecal coliform production rate is multiplied by 365 days minus the days spent grazing (from the cattle section of the Grazing sheet) to obtain the annual amount of fecal coliform produced by beef cattle and available for application as manure. (The fecal coliform bacteria produced by beef cattle while grazing is assumed to be delivered directly to pastureland; see

below.) The total fecal coliform load from cattle manure application is the sum of the dairy and beef cattle loads.

3. The fecal coliform bacteria available for wash off is then calculated by multiplying the annual fecal coliform produced by the amount applied and available for wash off in each subwatershed in each month (from the cattle manure section of the Manure Application sheet).
4. The monthly total is then divided by the number of days in each month to obtain the daily accumulation rate.
5. Finally, the daily accumulation rate is divided between Cropland and Pastureland and the portion applied to Pastureland is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation of fecal coliform bacteria from cattle manure.

Horse Manure

The fecal coliform bacteria from horse manure applied per acre of pastureland is determined for each month as follows:

1. The number of horses in each subwatershed (from the Animals sheet) is multiplied by the daily fecal coliform production rate per horse (from the References sheet) to obtain the daily horse fecal coliform production rate.
2. The daily rate is then multiplied by 365 days minus the days spent grazing (from the horse section of the Grazing sheet) to obtain the amount of fecal coliform produced by horses and available for application as manure per year. (The fecal coliform bacteria produced by horses while grazing is assumed to be delivered directly to pastureland; see below.)
3. The fecal coliform bacteria available for wash off is then calculated by multiplying the annual fecal coliform produced by the amount applied and available for wash off in each subwatershed in each month (from the horse manure section of the Manure Application sheet).
4. The monthly total is then divided by the number of days in each month to obtain the daily accumulation rate.
5. Finally, the daily accumulation rate is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation of fecal coliform bacteria from the application of horse manure.

Beef Cattle Grazing

The fecal coliform bacteria from beef cattle manure deposited during grazing per acre of pastureland is determined for each month as follows:

1. The number of beef cattle grazing is calculated by multiplying the number of beef cattle per subwatershed (from the Animals sheet) by the fraction of time spent grazing (from the Grazing sheet).
2. The fecal coliform load delivered directly to pastureland is calculated by multiplying the number of cattle grazing by the fraction of time spent in pasture (as opposed to in streams, from the Grazing sheet) and by the rate of fecal coliform bacteria production per beef cow (from the References sheet).

3. Finally, the daily grazing beef cattle fecal coliform production is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation rate of fecal coliform bacteria from beef cattle grazing.

Horse Grazing

The fecal coliform bacteria from horse manure deposited during grazing per acre of pastureland is determined for each month as follows:

1. The number of horses grazing is calculated by multiplying the number of horses per subwatershed (from the Animals sheet) by the fraction of time spent grazing (from the Grazing sheet).
2. The fecal coliform load delivered directly to Pastureland is calculated by multiplying the number of horses grazing by the rate of fecal coliform bacteria production per horse (from the References sheet).
3. The fecal coliform load in manure collected for application is calculated by subtracting the number of horses grazing from the total number of horses and multiplying by the rate of fecal coliform bacteria production per horse (from the References sheet).
4. Finally, the daily grazing horse fecal coliform production is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation rate of fecal coliform bacteria from horse grazing.

Sheep Grazing

The fecal coliform bacteria from sheep manure deposited during grazing per acre of pastureland is determined for each month as follows:

1. The number of sheep grazing is calculated by multiplying the number of sheep per subwatershed (from the Animals sheet) by the fraction of time spent grazing (from the Grazing sheet).
2. The fecal coliform load delivered directly to Pastureland is calculated by multiplying the number of sheep grazing by the rate of fecal coliform bacteria production per sheep (from the References sheet).
3. The fecal coliform load in manure collected for disposal is calculated by subtracting the number of sheep grazing from the total number of sheep and multiplying by the rate of fecal coliform bacteria production per sheep (from the References sheet).
4. Finally, the daily grazing sheep fecal coliform production is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation rate of fecal coliform bacteria from sheep grazing.

Other Animal Grazing

The purpose of the “other” animal category is to allow you to define an agricultural animal not available in the default information. To use this category, you must be sure to enter the number of “other” agricultural animals in each subwatershed (on the Animals sheet), to enter the time spent grazing (on the Grazing sheet), and to specify a fecal coliform bacteria production rate (on the References sheet in cell B25).

The fecal coliform bacteria from “other” animal manure deposited during grazing per acre of pastureland is determined for each month as follows:

1. The number of “other” animals grazing is calculated by multiplying the number of “other” animals per subwatershed (from the Animals sheet) by the fraction of time spent grazing (from the Grazing sheet).
2. The fecal coliform load delivered directly to pastureland is calculated by multiplying the number of “other” animals grazing by the rate of fecal coliform bacteria production per “other” animal (from the References sheet).
3. The fecal coliform load in manure collected for disposal is calculated by subtracting the number of “other” animals grazing from the total number of “other” animals and multiplying by the rate of fecal coliform bacteria production per “other” animal (from the References sheet).
4. Finally, the daily grazing “other” animal fecal coliform production is divided by the number of acres of pastureland in each subwatershed to obtain the daily per acre accumulation rate of fecal coliform bacteria from “other” animal grazing.

The total accumulation rate of fecal coliform bacteria from pastureland is calculated as the sum of the accumulation rates from wildlife, cattle and horse manure applications, and beef cattle, horse, sheep and “other” grazing.

CATTLE IN STREAMS

This sheet contains information related to the direct contribution of beef cattle *E. coli* bacteria to streams. Cattle hours spent in stream per month are calculated using the number of cattle per subwatershed and time spent grazing. No user input is required on this sheet. It is assumed that only beef cattle have access to streams when grazing. The fraction of grazing time spent in streams is specified on the Grazing sheet.

1. The number of beef cattle grazing is calculated by multiplying the total number of beef cattle (from the Animals sheet) by the fraction of time spent grazing (from the Grazing sheet).
2. Cattle Hours in Stream per month is calculated by multiplying the # of grazing cattle by Grazing time Spent in Streams (from the Grazing sheet) multiplied by 24 and then by the number of days in the month.
3. The fecal coliform bacteria loading rate (count/hr.) is calculated by multiplying the number of beef cattle in streams by the fecal coliform production rate per beef cow (from the References sheet.)
4. The beef cattle waste flow rate is calculated by multiplying the number of cattle in streams by the waste production rate per beef cow (from the References sheet) and an assumed beef cattle waste density of 62.4 pounds per cubic foot.

SEPTICS

This sheet contains information related to the contribution of failing septic systems to streams. The direct contribution of fecal coliform from septics to a stream can be represented as a point source in the calculator, which requires input of a flow rate (cfs) and a fecal coliform bacterium loading rate (count/hr.).

To estimate the contribution of fecal coliform bacteria from failing septic systems, the number of septic systems, the number of people served by septic systems, and the estimated rate of septic system failure in the study area must be entered. Population and septic tank data can be retrieved from the U.S. Census Bureau web site (https://www.census.gov/data/tables/time-series/dec/coh-sewage.html).

The estimated rate of septic system failure in the area of interest should be estimated based on local knowledge. From the preceding information, the average number of people served by each septic system, number of failing septic systems, and density of failing septic systems in the study area are calculated.

1. The number of failing septic systems in each subwatershed is calculated by multiplying the total area of each subwatershed (from the Land Use sheet) by the density of failing septic systems.
2. The number of people served by failing septic systems in each subwatershed is calculated by multiplying the number of failing septic systems by the average number of people served by each septic system.
3. The failing septic system flow rate is calculated by multiplying the number of people served by failing septic systems by an assumed daily waste flow of 70 gallons per person.
4. The fecal coliform bacteria loading rate from failing septic systems is calculated by multiplying the failing septic system flow rate by an assumed fecal coliform bacteria concentration of 6,300,000 counts per 100 mL of waste flow.

Note that the assumed value typical septic overcharge flow rate (J17) can be updated to represent more appropriate site-specific information.

TOTAL LOADS

The Total Loads sheet holds a variety of summations in various formats of the *E. coli* loads calculated from the previous worksheets. Each table or set of tables is labelled with a corresponding unit label. *E. coli* loading is also graphed on a monthly basis for each set of tables to allow the user to visually find trends.

Total E. coli Cells Generated per Year

The table Total *E. coli* cells generated per year sums the total load for each land use for an entire year.

1. The amount of fecal coliform in each land use for each month is calculated in the corresponding sheet (i.e. Cropland, Pastureland, etc.) in units of fecal coliform generated per acre per day.
2. The monthly totals of fecal coliform are then multiplied by the acreage of the land use in each subwatershed from the Land Use sheet to get the total daily fecal coliform per subwatershed.
3. The total daily fecal coliform per subwatershed is then multiplied by 365 days to get the total annual fecal coliform generated per subwatershed.
4. Finally, the conversion from fecal coliform to *E. coli* is calculated by using the equation: $E.Coli = 0.403 * Fecal\ Coliform^{1.028}$

E coli Loads per Day per Watershed

The table *E. coli* loads per day per watershed sums the total load for each land use and subwatershed generated in a single day (24 hours).

1. The amount of fecal coliform in each land use for each day is calculated in the corresponding sheet (i.e. Cropland, Pastureland, etc.) in units of fecal coliform generated per acre per day.
2. The result of the sum is multiplied by the landuse area from the input sheet.

3. Finally, the conversion from fecal coliform to *E. coli* is calculated by using the equation: $E.Coli = 0.403 * Fecal\ Coliform^{1.028}$

E. coli Count per 100mL of rainfall

E. coli Count per 100mL of rainfall divides the total *E. coli* generated per land use per subwatershed by the volume of rainfall per year. This number attempts to model loading to waterways in similar units used by water quality standards. The results are calculated as follows.

1. The total *E. coli* cells generated per year per land use per subwatershed is divided by the volume of rainfall calculated in the Rainfall sheet and converted to *E. coli* cells per 100mL.

E. coli Loads with Deterioration

Only living *E. coli* cells can make a person sick, so this sheet uses a basic decay equation to estimate the rate at which *E. coli* die off in freshwater. The calculator uses a single factor decay equation as recommended by Robert Thomann in Principles of Surface Water Quality Modeling and Control (1987). In his book Thomann argues that because there is little scientific consensus on multi-factor decay equations and little access to field results to verify accuracy, single factor decay equations may be used as simple models for decay. The single factor chosen to estimate decay in this calculator is temperature. Warm months and cold months are separated according to literature recommendations and assigned die-off rate constant values from literature. The decay equation used is: $N_t = N_0 * e^{(-kt)}$ where N_t is the number of *E. coli* cells at time *t,* N_0 is the number of *E. coli* cells at time 0, *t* is time in days, and *k* is the first order die-off rate constant. The *k* value used for warm months is 0.51 and for cold months is 0.36. Warm months are April through September, cold months are October through March.

The decayed loads are calculated as follows:

1. A monthly sum of the *E. coli* generated per land use is calculated from the supporting sheets.
2. The monthly sum is used as N_0 in the decay equation.
3. A die-off rate constant is chosen by month depending on average temperature. The *k* value used for warm months is 0.51 and for cold months is 0.36. Warm months are April through September, cold months are October through March.
4. Time (*t*) the number of days in each month, is input into the equation to finish the calculation.

NPS REDUCTIONS (USER INPUT)

The NPS Reductions sheet uses area percentages and BMP reduction efficiencies to calculate load reductions in a similar way to the Region 5 model for nutrients and sediment. In the Total Loads sheet, the total number of *E. coli* cells that are generated per year is calculated for each land use and in each subwatershed which are used as the starting point for the reduction calculation. The BMP reduction efficiency values come from Richkus 2016 and are used to calculate how much of the *E. coli* input into the BMP will be removed. Acres draining to BMP is used to calculate how much *E. coli* is input into the BMP based on the subwatershed and land use. Users should define the acreage draining to the BMP as the area of land that will drain to, and be treated by, the BMP.

1. The user selects a land use where the BMP has been installed (currently only urban, pastureland, and cropland have BMPs available for calculation).

2. Next the user selects the type of BMP that they wish to calculate the load reduction for. When a selection is made a reduction will appear in column D. A list of currently available BMPs with definitions can be found in Appendix I (page 21-22).
3. Next the user inputs the acres draining to the BMP as defined above.
4. Lastly the user must input the subwatershed where the BMP will be installed to calculate the percent reduction.

SEPTIC REDUCTIONS (USER INPUT)

The septic reductions sheet is based upon a stand-alone model created by the Wyoming Department of Environmental Quality that calculates the bacterial contribution of various types of residential sewage discharges to surface waters including straight pipe discharges or tank discharges, direct discharge or overland flow, and year round flow in receiving water or part-time flow. Part time residence is defined as being used 50% of the time. The model assumes an average of 2.5 persons per each single dwelling home, a daily per person discharge of 265 liters, and a raw, human sewage fecal coliform concentration of 6,300,000.

Instructions for using the Septic Reductions sheet are as follows:

1. The user should enter the number of septic systems removed or returned to good working order that are of the same type. All selectable elements should be the same when grouping systems to ensure accuracy.
2. Use the drop-down menu in column C to select for a straight pipe discharge or tank (indicating the system has a tank without a leach field).
3. Use the drop-down menu in column D to select whether the septic system directly discharges into surface waters or if there is overland flow. (note: overland flow measurement is in feet and needs to be between 1 and 500 feet. If a septic discharge is more than 500ft from surface water, the calculator assumes no surface connection)
4. Use the drop-down menu in column E to select if the septic system is used on a year-round basis or a part time basis.
5. In column F, if applicable, the user should enter the distance from the end of the discharge point to the surface water.
6. Lastly, use the drop-down menu in column G to select the subwatershed in which the septic system was removed from.

The following are the equations used to calculate the six variations of septic systems that are included in the IEC.

Straight Pipe Septic Coliform Equation:

$$Fecal\ Coliform\ Reduction = \frac{Avg\ \#\ of\ persons}{Household} * \frac{6{,}300{,}000\ organisms}{100\ mL} * 10 * \frac{265\ L}{person} * \frac{365\ days}{Year}$$

Septic Tank without Leach field:

$$Fecal\ Coliform\ Reduction = \frac{Avg\ \#\ of\ persons}{Household} * \frac{1{,}000{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{365\ days}{Year}$$

Straight Pipe Discharge with Overland Flow:

$$Fecal\ Coliform\ Reduction = \frac{Avg\ \#\ of\ persons}{Household} * \frac{6{,}300{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{365\ days}{Year} * \frac{(2.7 - \log Distance\ to\ water)}{2.7}$$

Septic Tank without Leach field with Overland Flow:

$$Fecal\ Coliform\ Reduction = \frac{2.5\ personAvg\ \#\ of\ persons}{Household} * \frac{1{,}000{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{365\ days}{Year} * \frac{(2.7 - \log Distance\ to\ water)}{2.7}$$

Straight Pipe Discharge to Seasonal Ditch:

$$Fecal\ Coliform\ Reduction = \frac{Avg\ \#\ of\ persons}{Household} * \frac{6{,}300{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{182\ days}{Year} * \frac{(2.7 - \log Distance\ to\ water)}{2.7} + \frac{Avg\ \#\ of\ persons}{Household} * \frac{6{,}300{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{183\ days}{Year}$$

Septic Tank without Leach field Discharge to Seasonal Ditch

$$Fecal\ Coliform\ Reduction = \frac{Avg\ \#\ of\ persons}{Household} * \frac{1{,}000{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{182\ days}{Year} * \frac{(2.7 - \log Distance\ to\ water)}{2.7} + \frac{Avg\ \#\ of\ persons}{Household} * \frac{1{,}000{,}000\ organisms}{100\ mL} * \frac{265\ L}{person} * \frac{183\ days}{Year}$$

LISTS

This sheet is for entirely functional purposes. It holds several lists used to format drop-down menus throughout the calculator. There is no user input required for this sheet.

BMP LIST

The BMP List sheet holds two tables. The tables contain BMP information and *E. coli* reduction efficiencies. There is no user input required for this sheet.

Optionally, a user may add BMPs to the top table (A2-H22) on this sheet to make them available to be used in calculations within the IEC. The user should be careful to use peer reviewed or reputable evidence to inform reduction efficiencies. The user will also need to update the named range for the land use within which the BMP will be used. Detailed instructions for updating a named range can be found here. To view named ranges within excel navigate to the formulas menu and select the “name manager” option in the “define names” menu. Within the Name Manager find the list titled “BMPList” and add new rows to the range as applicable to cover the new BMPs entered into the table.

REFERENCES

The data from the References sheet are accessed in the worksheets. Fecal coliform production rates for various animals are presented from several sources, and you may select the source you prefer or enter a value of your own in the “Best Professional Judgement” column. The spreadsheet is set up to use the ASAE and Mean values by default. If you prefer to use a different source, be sure to change the values in cells B9 through B23 on the References sheet. To use the “other” agricultural and wildlife animal categories, you must provide the number of “other” animals in each subwatershed (on the Animals sheet) and a fecal coliform bacteria production rate for this animal (on the References sheet). The References sheet also contains fecal coliform accumulation rates for five Built-up land use types. These numbers may also be changed if appropriate.

CONDENSED INDIANA *E. COLI* CALCULATOR

This is a condensed version of the *E. coli* Calculator that has simplified user inputs to increase ease of use. The total number of visible sheets has been decreased to four with user inputs only found on three sheets. There are no content changes between the tools, only visibility of different sheets. In the condensed version users may only change inputs of land use, agricultural animals, and septic system information.

In order to simplify user inputs, many input options in the calculator are hidden and assigned default values. These include “Manure Application” and “Grazing”. Inputs from “Animals”, “Urban” and “Septics” have been connected to the sheet “Inputs” in a consolidated manner to increase ease-of-use. If a user would like the additional functions, they should use the expanded version of the *E. coli* Calculator.

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APPENDIX I: BMP DEFINITIONS

CROPLAND:

Buffer – Forest (minimum 35 feet wide)

The forest buffer can be achieved by following the IN NRCS FOTG practices "Riparian Forest Buffer (391)" or "Saturated Buffer (604).

- https://efotg.sc.egov.usda.gov/references/public/IN/391_Riparian_Forest_Buffer.pdf
- https://efotg.sc.egov.usda.gov/references/public/IN/604_Saturated_Buffer.pdf

Buffer – Grass (minimum 35 feet wide)

The grass buffer can be achieved by following the IN NRCS FOTG practices "Contour Buffer Strips (332)" or "Saturated Buffer (604)".

- https://efotg.sc.egov.usda.gov/references/public/IN/332_Contour_Buffer_Strips.pdf
- https://efotg.sc.egov.usda.gov/references/public/IN/604_Saturated_Buffer.pdf

Water Control Structures

Water control structures follow the NRCS FOTG guidelines for "Structure for Water Control (587)".

- https://efotg.sc.egov.usda.gov/references/public/IN/587_Structure_for_Water_Control.pdf

Land Retirement

This practice can be achieved by removing land from row crop production and returning the land to a natural vegetative state.

PASTURELAND:

Buffer (minimum 35 feet wide) with Optimal Grazing

This is a combined practice with either "Contour Buffer Strips (332)" or "Saturated Buffer (604)" installed with "Prescribed Grazing (528)".

Contour Buffer Strips (332)

- https://efotg.sc.egov.usda.gov/references/public/IN/332_Contour_Buffer_Strips.pdf

Saturated buffer (604)

- https://efotg.sc.egov.usda.gov/references/public/IN/604_Saturated_Buffer.pdf

In conjunction with:

Prescribed Grazing (528)

- https://efotg.sc.egov.usda.gov/references/public/IN/528_Prescribed_Grazing.pdf

Alternative Water Supply

Alternative water supply can be achieved by following the IN NRCS FOTG practice "Watering Facility (614)"

- https://efotg.sc.egov.usda.gov/references/public/IN/614_Watering_Facility.pdf

Forest Buffer (minimum 35 ft wide)

The forest buffer can be achieved by following the IN NRCS FOTG practices "Riparian Forest Buffer (391)" or "Saturated Buffer (604).

- https://efotg.sc.egov.usda.gov/references/public/IN/391_Riparian_Forest_Buffer.pdf
- https://efotg.sc.egov.usda.gov/references/public/IN/604_Saturated_Buffer.pdf

Grass Buffer (minimum 35 ft wide)

The grass buffer can be achieved by following the IN NRCS FOTG practices "Contour Buffer Strips (332)" or "Saturated Buffer (604)".

- https://efotg.sc.egov.usda.gov/references/public/IN/332_Contour_Buffer_Strips.pdf
- https://efotg.sc.egov.usda.gov/references/public/IN/604_Saturated_Buffer.pdf

Grazing Land Management (rotational grazing with fenced areas)

This practice can be achieved by combining the IN NRCS FOTG practice "Fence (382) with "Prescribed Grazing (528)".

Fence (382)

- https://efotg.sc.egov.usda.gov/references/public/IN/382_Fence.pdf

In conjunction with:

Prescribed Grazing (528)

- https://efotg.sc.egov.usda.gov/references/public/IN/528_Prescribed_Grazing.pdf

Livestock Exclusion Fencing

The grass buffer can be achieved by following the IN NRCS FOTG practice "Fence (382)".

- https://efotg.sc.egov.usda.gov/references/public/IN/382_Fence.pdf

Prescribed Grazing

The grass buffer can be achieved by following the IN NRCS FOTG practice "Prescribed Grazing (528)".

- https://efotg.sc.egov.usda.gov/references/public/IN/528_Prescribed_Grazing.pdf

URBAN:

Due to the variability of urban best management practices the definitions of the practices included in the model are vague to allow users to incorporate professional best judgement. Each BMP is described with typical components, typical uses and desired effects.

Bioretention facility

Bioretention facilities are landscaped depressions or shallow basins used to slow and treat stormwater runoff. These systems normally include the following components: grass buffer strip, vegetation, shallow ponding area, mulch, engineered soils, sand bed, underdrain system. Bioretention basins are typically associated within small areas of land with residential usage or with parking lots where the islands become visually pleasing stormwater treatment centers.

Dry Detention

Dry detention basins temporarily pond run off to enable particulate pollutants to settle out and reduce maximum peak discharge. Dry detention basins usually treat areas larger than 10 acres and contain the following components: pretreatment forebay, side slopes, internal conveyance flow path, overflow and discharge area stabilization.

Extended Wet Detention

Extended wet detention basins permanently hold a base volume of water and temporarily hold a "storage" volume of water during rain events to enable particulate pollutants to settle out and reduce maximum peak discharge. Maintaining a base volume of water helps mitigate resuspension of deposited sediments in the holding area. Wet detention basins contain the following components: pretreatment forebay, side slopes, base holding volume, overflow and discharge area stabilization.

Infiltration Basin

Infiltration basins are designed to manage stormwater runoff by infiltrating water through permeable soils to groundwater. Infiltration basins do not release water except by infiltration, evaporation or emergency overflow during flood conditions. It is distinguished from a detention basin, sometimes called a dry pond, which is designed to discharge to a downstream water body (although it may incidentally infiltrate some of its volume to groundwater); and from a retention basin, which is designed to include a permanent pool of water. Infiltration basins usually treat areas larger than 10 acres and contain the following components: pretreatment forebay, side slopes, uncompacted soils, and emergency overflow area stabilization.

Infiltration Devices

Infiltration devices can be a wide range of engineered structures designed to infiltrate stormwater in an urban setting. They typically treat smaller areas, such as part of a parking lot. They typically include pretreatment, storage, and infiltration interface, and an emergency overflow. They are distinguished from bioretention by relying on engineered or physical processes to treat the water rather than biological or chemical processes.

Infiltration Trench

Infiltration trenches utilize the same principles as infiltration basins but are designed in a linear, trench design. Infiltration trenches do not release water except by infiltration, evaporation or emergency overflow during flood conditions. Infiltration trenches will typically treat smaller areas and contain the following components: pretreatment forebay, side slopes, uncompacted soils, and emergency overflow area stabilization.

LID (Low Impact Development) w/ Bioretention

Low-impact development (LID) is a term used to describe a land planning and engineering design approach to manage stormwater runoff as part of green infrastructure. LID emphasizes conservation and use of on-site natural features to protect water quality. LID with bioretention components (see above) typically treat small areas in developed urban areas or are used as part of a larger treatment system.

Sand Filter/Infiltration Basin

Infiltration basins that incorporate sand filters will have a section of the basin filled with sand that may or may not contain additives to promote chemical treatment. Sand provides a quick infiltration pathway as well as increased surface area for treating stormwater. Sand filters are typically added to infiltration basins as a pretreatment tool.

APPENDIX II: *E. COLI* CHARACTERISTICS

This appendix will review the current literature to understand the intricacies of modeling *Escherichia Coli* (*E. coli*) for urban and agricultural best management practices (BMPs) installed as part of nonpoint source implementation grants in Indiana. These estimated load reductions would be used to track the progress of projects in reducing the most common waterbody impairment in Indiana. This report will review the sources of *E. coli* in the environment, the mechanisms of transport through the environment, and the factors affecting deactivation or removal of *E. coli* from the environment. Next it will discuss the available research on the scientific understanding and ability to model the variables related to *E. coli* fate and transport, and lastly it will discuss the available models designed or used for modeling *E. coli* and their strengths and weaknesses.

Fecal contamination of water bodies can create risks of infection from a wide range of parasites, viruses, and bacteria. *E. coli* is used to indicate the presence of human and animal waste in the environment because of the ubiquitous nature of its colonization of the guts of warm-blooded mammals. *E. coli* is also easy to identify and sample for, and so has been chosen as the indicator of choice for fecal contamination of water in Indiana. Such indicator species can be referred to as a Fecal Indicator Bacteria (FIB) or Fecal Indicator Organism (FIO). The term Fecal Coliform (FC) refers to a larger suite of microorganisms that can indicate fecal contamination. These distinctions are important as they are referenced heavily by the literature in the following report.

SOURCES, TRANSPORT, AND FATE OF *E. COLI*

The presence of pathogens, including bacteria and viruses, in rivers and streams is one of the most common impairments of freshwater rivers and streams in the United States. The group of organisms of highest concern is called fecal indicator bacteria because they originate in the gastrointestinal tracts of warm-blooded mammals and their presence in waterways indicates contamination with fecal matter. Fecal contamination contaminates water with bacteria, parasites and viruses that can have significant health impacts on humans that come into contact with them. In order to facilitate water quality testing the Escherichia Coli (*E. coli*) bacterium has been designated as an indicator species in freshwater environments for the larger FIB group. Indiana has many miles of streams classified as impaired for *E. coli*, and many watershed management plans (WMPs) and Total Maximum Daily Loads (TMDLs) list reductions in *E. coli* loads as necessary for water quality improvement. However, Indiana does not currently have a method to calculate or model Escherichia Coli load reductions from agricultural and urban best management practice (BMP) installations to track the progress made by watershed groups implementing WMPs or TMDL requirements like it does with sediment, nitrogen, and phosphorous. In order to inform decisions made to find a method to model *E. coli* reductions this paper will discuss factors involved in *E. coli* deposition and transport, surface water quality modeling strengths and limitations as it relates to *E. coli*, availability of data related to modeling variables, existing *E. coli* modeling capabilities, and a review of neighboring state's policies related to *E. coli* modeling.

E. coli has been designated by the EPA as an indicator species for harmful surface water pathogens that generally relate to fecal contamination (Hathaway, 2008). Sources of *E. coli* in the environment include biological waste from humans, domesticated animals, and wild animals. Sources of human *E. coli* are failing septic systems, combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), municipal separate storm sewer systems (MS4s), wastewater treatment plant (WWTP) sludge applied to farm fields, and non-sterile effluent from WWTPs. Domesticated animals produce manure which may be applied to the landscape as fertilizer, left on pastureland, concentrated and stored improperly at feedlots, or directly deposited in streams via direct animal access. Wild animals may be infected with fecal pathogens and can contribute to stream loads via direct deposition or landscape deposition.

Due to the varied types of possible inputs of *E. coli* into a system, *E. coli* prevalence in the environment is transient, and varies both spatially and temporally. This means that loads can increase or decrease without new inputs, and input types vary from traditional nonpoint source (NPS) pollutants. *E. coli* is inactivated by various environmental factors including sunlight, predation, sedimentation, filtration, temperature, moisture conditions, salinity, among others (Jones, 2010). The magnitude of effect of these variables is not well understood. *E. coli* can also establish naturalized populations given the proper circumstances, meaning loads can persist or even grow in certain environments absent of additional inputs (Gallagher, 2012). Lastly, *E. coli* is not deposited equally across the environment like many other NPS pollutants. Anthropogenic/livestock *E. coli* sources are generally described as "hotspots", think an actively grazed pasture, feedlot, CSO, WWTP, failed septic system, etc. This means that inputs from these variables spread from highly concentrated input areas and cannot be extrapolated to wide areas. Wild animal deposition and manure application to fields conforms to more traditional nonpoint patterns.

E. coli transport is an important factor in estimating loading. It is affected by direct deposition, transport to waterways, and resuspension. Direct deposition to waterbodies provides direct contact with fecal matter/effluent and is the most efficient introduction of *E. coli* to the waterbody. Sources include direct livestock access to streams, CSOs, SSOs, and non-sterile WWTP effluent. *E. coli* that is not directly deposited into waterbodies can still travel over and through the landscape to reach waterbodies. Bacterial detachment and transport via surface flow is generally analogous to soil erosion and transport, though bacteria have different transport characteristics such as lower specific gravity and small particle size. Contaminated sub-surface flow to tile lines can contribute to baseline pathogen loads, however large-scale precipitation events resulting in overland flow create large spikes in pathogen loading that dwarf baseline loads.

The last factor affecting *E. coli* loading in freshwater is resuspension. As mentioned earlier, sedimentation is a factor in deactivating *E. coli* where the bacterium adsorbs to soil particles and settle via gravity out of the water column. However, research indicates disturbing the streambed sediments via human or animal interaction, or high flow can re-suspend *E. coli*. The resuspension can create high loading where previously there was not. (Pandey, 2014; Bai, 2005; Bradshaw, 2016; Burton, 1987; Kiefer, 2012; Soupir, 2016)

CURRENT SCIENTIFIC UNDERSTANDING OF *E. COLI* VARIABLES

In order to model *E. coli* sources, fate and transport there needs to be an in depth understanding of the mathematical relationships of related variables. Following is a discussion of the literature that ties observed data to mathematical relationships that can be input into models. As described above, *E. coli* is deposited into the environment via the feces of warm-blooded mammals. Wildlife, livestock, and humans are all significant sources. *E. coli* can either be directly deposited into streams and rivers, or it is deposited on the landscape and can then be transported via various water pathways to a stream, river, or groundwater reservoir. Once in the waterway *E. coli* can settle out of the water column, be deactivated, or can propagate in the water column.

SOURCES

The sources of *E. coli* bacteria are varied, and have different loading rates, residency times, and even distribution over the landscape. All warm-blooded mammals can become sources of *E. coli*, and so all feces from these animals has the potential to be a source of the bacteria. The categories of sourcing can be broken down into three categories: human, domesticated animals, and wildlife. (O'Keefe, 2003)

HUMAN *E. COLI*

Human *E. coli* is released into the environment by runoff from impervious urban surfaces, leachate from sanitary sewers and septic systems, overflow from combined sewers during rain events, or even the discharge from inefficient wastewater treatment plants. *E. coli* is ubiquitous in the human gut, and close to 100% of the population have *E. coli*. Average human fecal *E. coli* concentrations have been estimated at 1×10^{10} cfu g^{-1} (Ferguson 2009).

Many older cities have combined storm and sanitary sewers. WWTPs of these combined sewer systems are often designed to treat only dry weather discharges of sewage. When a rain event occurs, stormwater combines with the human sewage and overflows at certain points, generally directly into surface waterways. Samples of urban water during storm events can have extremely high *E. coli* concentrations. Maximum concentrations from a study in Sydney, Australia were 620,000 cfu/100 mL during rain events (Birch, 2004) which is about 2500 times the Indiana water quality standard of 250 cfu/ 100 mL. Additionally, in Indiana some WWTPs are not required to totally disinfect discharge water outside of the recreation season, which can contribute to ambient *E. coli* concentrations. Bonadonna 2002, and Garcia-Aljaro 2005 have numbers on WWTP effluent.

Urban runoff typically has higher loading rates than mixed land use or agriculture. High urban fecal indicator bacteria (FIB) counts start in early summer and persist through to the fall. Samples taken of the initial run off surge (first flush) and final run off samples were similar, with peak loading rates in the middle of the runoff event. This pattern forms due to first flush contamination from impervious surfaces, and at the peak from leaking sewers and CSOs which taper off towards the end of the event (Paule-Mercado, 2016). However, humans in mixed or rural landscapes can still make up a significant percentage of the *E. coli* load source. Somarelli et al. (2015) found that in the summer during "cottage" season New York state, human *E. coli* went up from 11% in the spring to 22.9% in the summer indicating septic system effects. Septic systems are a significant contributor of human *E. coli* to rural streams and rivers. In Indiana it is estimated that a single failing system on average discharges 76,650 gallons of untreated wastewater per year (Lee, 2005). The Indiana State Department of Health estimates that there are 200,000 failing septic systems in Indiana which equates to 15.3 billion gallons of raw sewage being released into the environment annually (Lee, 2005).

DOMESTIC ANIMAL *E. COLI*

Domesticated animal sources by volume are mainly related to agriculture, although studies have shown urban animal populations of dogs, cats, rats, and pigeons are sources as well (O'Keefe, 2003; Hackett, 2003). Domestic animal *E. coli* loading rates are influenced by population density, volume of manure produced, pathogen prevalence and shedding intensity, animal age and behavior, and catchment characteristics. Concentrated populations produce more manure per unit area, and that manure must be disposed of. Separate species produce different amounts of manure per animal. Infection rates differ between species and population densities. Shedding rates differ temporally and usually increase soon after infection before decreasing to a steady-state level in infected individuals. Younger individuals typically have higher shedding rates and defecate more often, while older individuals produce more feces but defecate less often and have lower shedding rates. Animal behavior plays a large role in deposition location; cattle, for example, congregate in waterways if given access, whereas indigenous species typically do not spend large amounts of time close to waterways (Ferguson, 2009).

Sources from animal production can be categorized in to two groups: grazing operations and feeding operations, each with their own unique challenges. Traditional animal husbandry grazes animals over large areas. The number of animals per unit area are limited by food availability. Estimates from Australia show a density of 500 cattle, 500 sheep, 5000 pigs, 3 horses, or 2 goats per square kilometer under grazing conditions (Ferguson, 2009). *E. coli* has been shown to persist on grass blades for 5-6 months (Avery, 2004) and in the soil for over 60 days (Oliver, 2005). Pasture design and animal behaviors significantly affect where manure is deposited. Cattle specifically will spend large amounts of time in waterways if given access (Brown, 2014). Direct deposition of manure to waterways is the most efficient transport pathway for *E. coli* loading from animals.

Animal feeding operations utilize modern practices to increase the number of animals that can be held per unit area. With increased animal population density manure accumulates and cannot be left to degrade like it would be in a pastoral setting. In addition, the proximity of animals can increase the transmission rates of fecal-transmitted pathogens. US Dairy cattle have a mean *E. coli* concentration of $8.4*10^4$ cfu g^{-1}, US sheep have a mean *E. coli* concentration of $4.1*10^6$ cfu g^{-1}, and US pigs have a mean *E. coli* concentration of $9.7*10^5$ cfu g^{-1} (Geldreich, 1962). The average volume of cattle manure deposits range from 920 g to 3 kg (Ferguson, 2009), Pigs produce 2.7 kg, and sheep 1.13 kg by wet weight per day (Geldreich, 1962). Manure is usually gathered and stored nearby the feeding operation before operators spread the manure as fertilizer and soil amendments on nearby fields. This process is effective when done properly, however, manure improperly spread on fields can infiltrate into groundwater, discharge to waterways via tile drainage systems, or it can run off the field via surface runoff in rain events. Manure storage lagoons are also susceptible to being flooded, or to breaking open and releasing the stored sludge into the environment.

WILD ANIMAL *E. COLI*

Wild animal deposition is the last major source of *E. coli* in waterways. Estimating the number and distribution of animals, volume of fecal matter produced per animal per day, and amount of *E. coli* bacteria per unit volume of fecal matter is a significant challenge with wild animals. The data also likely varies significantly from location to location and temporally.

Estimates of wildlife density are constantly fluctuating and the most up to date estimates would come from natural resources departments tasked with counting species numbers. Manure volumes for common wildlife in Australia can be found in table 1. Loading rates of fecal coliforms and *E. coli* in feces of wild animals can be found in table 2. A study conducted in New York found that geese were the dominant source of *E. coli* in the watershed using genetic analysis of *E. coli* bacteria. Geese were found to be the source of 44-73% of the *E. coli* in each watershed while Deer contributed 10.5-18.4% (Somarelli, 2005).

TABLE 1: MANURE PRODUCTION RATES FOR WILDLIFE ANIMALS (FERGUSON, 2009)

Animal	Country	Manure (kg animal^{-1} d^{-1})	Reference
Kangaroos	Australia	0.2	M. Roberts, personal communication
Pigs (feral)	Australia	6.2	(Australian Water Technologies, 2002a)
Deer	Australia	1	Similar to sheep (Australian Water Technologies, 2002a)
Rabbits	Netherlands	0.019–0.078	(Medema, 1999)
Dogs (feral)	Australia	0.5	(Australian Water Technologies, 2002a)
Mallard duck	Netherlands	0.035–0.355	(Medema, 1999)
Hedgehog	Netherlands	0.003–0.014	(Medema, 1999)

TABLE 2: MEAN CONCENTRATIONS OF FECAL COLIFORMS AND E. COLI IN FECES OF WILDLIFE ANIMALS (FERGUSON,

Animal	Country	*n*	Fecal coliforms, cfu g^{-1}	*E. coli*, cfu g^{-1}	Reference
Eastern grey kangaroo	Australia	25	—	5.8×10^5 SD 5.3×10^5	(Davies et al., 2005)
Rodents (mice)	United States	—	3.3×10^5	1.2×10^{5}*	(Geldreich, 1978)
Chipmunk	United States	—	1.48×10^5	5.6×10^{4}*	(Geldreich, 1978)
Rabbits	United States	—	20	16*	(Geldreich, 1978)
Duck	United States	—	3.3×10^7	8.0×10^6	(Geldreich et al., 1962)
Duck	United Kingdom	—	—	3.3×10^7	(Jones and White, 1984)
Geese	United States	—	3.2×10^4–1×10^6	—	(Weiskel, Howes, and Heufelder, 1996)
Seagulls	United Kingdom	—	—	1.3×10^8	(Jones and White, 1984)

*Equation used to converted fecal coliform count to *E. coli* count (Virginia Department of Environmental Quality, 2003).

TRANSPORT

For *E. coli* bacterium that are not deposited directly into a waterway, they must be transported to the water in some way. The general method of conveyance is water flowing through various media. Bacteria transport by surface runoff is affected by surface texture, soil wetness, vegetation, slope, and distance to the waterway. *E. coli* have also been shown to move through soil utilizing macropores and tile drainage systems.

Soils have a significant effect on the transport of *E. coli* bacteria. Soil texture influences *E. coli* retention and transport. Soils with higher clay content have reduced drainage, which helped retain *E. coli* bacteria in the soil matrix. Clay particulates also have an electrical charge, which helps bacteria sorp to the soil surface and stay in the soils (Balkhair, 2017). The level of saturation also affects the transport of *E. coli* through a soil. Unsaturated soils retained more bacteria than saturated soils (Balkhair, 2017) (Dorner, 2006). *E. coli* survives longer in wet/saturated soils with *E. coli* concentrations decreasing to 0 within 50 hours at 4% soil moisture but persisting 168 hours at 57% soil moisture (Gallagher, 2012). The effect of tile drains on *E. coli* transport has been shown to be negligible in studies conducted by Fraser and Walker in 1998 and 1990 respectively.

E. coli that has not infiltrated into the soil can be moved across the landscape with surface flows. Several variables influence the number of bacteria to survive transport across the soil surface. Steeper slopes and proximity to a waterway increase the number of bacteria surviving the transport process. Rough surface textures and vegetation can inhibit the transport of *E. coli* (Fraser, 1998). Although the bacteria have been shown to survive for 5-6 months on grass in pastures (Avery 2004). Several studies have shown that higher *E. coli* loads are correlated with high suspended sediment, suggesting that bacteria attach themselves to soil particles and are transported with the sediment (Bai, 2005; Mallin, 2002; Mohanty, 2013; Paule-Marcado, 2016). This also means that areas susceptible to erosion may also be larger sources of *E. coli*.

Urban areas are defined by a high concentration of impervious surfaces that reduce infiltration rates and increase the speed that water moves through the landscape. Rooftops, roads, and other paved areas collect rain and convey that water to sewers which are the main transport pathways for water through urban landscapes. These urban conveyances can be collectors of feces from urban animals and humans, and sewers have been shown to serve as hospitable environments for *E. coli* to survive. They also significantly reduce the amount of time it takes for water to move through the watershed to the destination river or stream. The large impervious surface area and expedient transport exacerbate the already high bacterial loading from urban areas.

FATE

Fecal contamination risks to human health include infection by various organisms. These organisms are dangerous to human health in so far as they have the capacity to infect a human through bodily contact or ingestion of contaminated water. If the organisms die, become inactivated, or are filtered from the water the risk of infection is significantly reduced. *E. coli* is adapted to the warm, sheltered conditions of mammal intestines and does not survive indefinitely in the environment. Several factors influence the rate of decay of *E. coli* concentrations in the environment and in the water column. Exposure to UV radiation, moisture, temperature, predation, nutrient availability, vegetation, and sedimentation all affect *E. coli* fates.

Like most bacteria, *E. coli* is susceptible to ultraviolet (UV) radiation from the sun (Olilo, 2016). Water depths of 15-45cm and minimal vegetative coverage have been shown to reduce *E. coli* in constructed wetlands (Hathaway, 2008) through exposure to UV radiation. Moisture also plays a role in *E. coli* survival. *E. coli* die off quickly in soils with low moisture content and persist in wet or saturated environments (Gallagher, 2012; Balkhair, 2017; Dorner, 2006). Temperature was been shown to be the dominant factor in *E. coli* survival in a 2012 study by Gallagher. *E. coli* was observed to propagate in water between 25 and 30 degrees Celsius. Like many organisms, bacteria have natural predators that are present in soil and water. Protozoa feed on bacteria and predation has been found to be a determining factor in *E. coli* concentration declines (Davies, 2000). Even so, *E. coli* has also been shown to survive on the surface of vegetation for months in cattle pastures (Avery, 2004).

As was discussed above in the transport section, *E. coli* bacteria frequently adsorb to soil particles in water. When the flow slows down these particles settle out over time and take the *E. coli* to the bed sediments. *E. coli* has been shown to persist in stream and lakebed sediments where it is protected from sunlight, predation, and has access to nutrients (Kiefer, 2012). However, bacteria can be re-suspended if the sediment is disturbed by large rain events, animal activity, or human activity (Pandey, 2014; Soupir, 2016).

BEST MANAGEMENT PRACTICE REDUCTIONS OF *E. COLI*

In order to model load reductions of various BMPs there needs to be an understanding of how effective various practices are at removing bacteria from water inputs. As discussed previously, exposure to UV radiation, moisture, temperature, predation, nutrient availability, vegetation, and sedimentation all effect *E. coli* longevity in the water column.

WETLAND TREATMENT SYSTEMS

These BMPs are characterized by wetland environments constructed for treating wastewater or stormwater inputs. They may be vegetated, open water, or have both types. Studies show a range of removal efficiencies from -45% to 98% (negative values mean the BMP output more of the pollutant than it took in). The Minnesota Stormwater Manual (MSM) reports a median value of 75% reduction based on five studies compiled by the International BMP database (Leisenring, 2012). On an individual storm basis one study found that the efficiency spanned from -260% to 98% in three different storm events. The exact reason for negative values is unknown, although it is hypothesized that sediment with adsorbed bacteria may be washed out of the BMP in intense storm events leading to negative loading (Tilman 2011).

In 2004, Birch et al conducted a study on a constructed wetland complex designed to remove sediment, nutrients, heavy metals, and fecal coliform from residential stormwater. Reductions in fecal coliform were between 83% and 99% for moderate storm events (~1mm/hr.) but decreased to 26% for the most extreme rain event (~4mm/hr.). The author suggests that the source of decreased effectiveness during heavy rain events is likely due to increased inputs from sewage overflows. Additionally, even with high removal rates the outflow concentrations still measured at 5,500 CFU/100 ml during two rain events and up to 220,000 CFU/100 ml during the most severe rain event. During three of the four rain events fecal coliform counts were several magnitudes higher than the recommended level for secondary contact.

DETENTION AND RETENTION PONDS

Detention and retention ponds are open water ponds built to allow sediment to settle out of suspension, and to provide water storage capacity to limit flooding. These ponds are usually not vegetated, except possibly around the edges. Bacteria removal efficiencies range from -5% to 98% in 5 different studies collected by Tilman et al, and the MSM uses a median value of 70% for wet retention ponds.

Hathaway et al tested various urban methods of removing pathogens including wet and dry detention basins, wetlands, bioretention areas, and proprietary devices. Removal efficiencies for the two dry detention basins were 5% and 14%, wet pond removal efficiency was 18%, removal efficiency for the two wetlands in the study were 92% and 22%, and the bioretention practice had a 71% removal efficiency. The three proprietary methods tested increased *E. coli* concentrations. The most effective practices (wetlands and bioretention) had a substantial amount of sun exposure which the author suggests contributed to increased *E. coli* die-off. The dry detention basins were observed to stay most for extended periods after rainfall, possibly providing a hospitable environment for reproduction and reducing effectiveness.

Mallin et al (2002) studied three wet detention basins over a 29-month period to determine the efficacy in reducing fecal coliform. The ponds drained mainly residential and commercial areas, and a golf course. The shapes of the basins varied as well as the distance between inlets and outlets. Both basins tested for fecal coliform showed significant reductions between inflow and outflow. The authors attribute the reductions to two major factors: a large, in-pond area with a diverse aquatic plant community and residence time from inlets and outlets being at opposite ends of the system. They also discuss the finding that the fecal coliform was the parameter most influenced by rainfall.

Biofiltration/filtration

Biofiltration BMPs collect stormwater runoff and then infiltrate it through a vegetated medium like sand, compost, soil, or a combination of those to filter out pollutants. Bio retention removal rates range from -68% to 99%, and the MSM uses a median value of 35% removal (Tilman, 2012).

Another aspect of filtration BMPs are amendments to the soil medium which can provide additional removal benefits. Sand filters with amendments ranging from granular activated carbon, zeolite, iron oxide, and various other metals have produced reductions from 0.41-3.44 log10. Incorporating wood chips into the soil medium produced 0.14-1.16 log10 reductions (Peng 2016). Peng also explores various coatings to be applied to the media as well as the impacts of biofilm formation and vegetation on bacterial removal. Drinking water treatment systems already use sand mediums with chemical coatings that help improve the removal of pathogens. There is a possibility that these coatings could be used in bio infiltration BMPs.

Mohanty et al (2013) examined the effect that iron oxide coated sand (IOCS) had on bacterial removal and remobilization. They found under laboratory conditions that 100% and 50% IOCS removed 99% of E Coli and less than 0.03% of bacteria remobilized during the draining process. They also tested the IOCS filters with water containing natural organic matter and showed that the sand filters remobilized 50% of the injected *E. coli* in the presence of organic matter.

Vegetated Buffers, Filter Strips, and Swales

In 2016 Olilo published a literature review of vegetated filter strips and the literature available on their role in removing *E. coli* from agricultural runoff. He concludes that while there are some plot level studies published, the body of work does not exist to be able to extrapolate the effects of filter strips to non-plot level landforms, nor to validate models of their function in the landscape.

Livestock Riparian Access Control

Limiting access of livestock to streams and riparian areas limits the amount of near and direct deposition of manure into the stream. Decreasing the amount of time livestock spend in the stream can be achieved through exclusion, or by providing the benefits the animals seek from the stream outside of the riparian area. Exclusion via fencing is most effective, however providing shade and water in upland areas can also limit livestock time spent in streams (Brown, 2014). As cited by Tilman 2011, a study by Collins et al., from 2004 showed that a 22-35% decrease in bacteria concentration with exclusion of livestock from riparian areas.

Manure Management

Manure Management encompasses many practices that intend to treat, store, and apply manure in a way that limits the potential for surface water bacterial contamination. Several manure application methods were tested including surface and subsurface application. Subsurface applications were observed to have the lowest bacterial concentrations but with the variability in all four treatments it was not statistically significant (Tilman, 2011).

STRENGTHS AND CHALLENGES IN MODELING

For the purposes of this report, any model chosen to model *E. coli* load reductions must fit the following criteria. First, the model needs to be as accurate as possible. Second, the model needs to be accessible to inexperienced model users. Third, it needs to be flexible and be able to process data quickly using baseline computer systems. The perfect model will balance complexity, data availability, number of assumptions, and ease of use as discussed below.

The first factor to consider is complexity or simplicity. Complexity is not a single yes or no choice, but rather a spectrum of choices. The more complex a model is the more variables it can consider. The more simplistic a model is the more assumptions are made. There are a lot of factors that can influence how much complexity is built into a model including availability of data, good or poor understanding of the processes being modelled, computing power, and time available to run the model.

The more closely a model resembles real world processes the more accurate the results will be. However, this generally leads to an increase in complexity of the model. More complex models take longer to build, require more computing power and time to run, and may require more data for calibration and testing purposes. Additionally, the modeler must have a good mathematical understanding of the processes they are working with to be able to create accurate digital facsimiles. Simpler models use assumptions, simplified mathematical processes, or even ignore certain variables altogether to reduce model build time, computing time, or due to a lack of data. There is a give and take relationship between accuracy and complexity of the model that will need to be decided.

Real world data is used heavily in modeling. It is used during the design and calibration phases. During the design phase a lack of data may requires modelers to use proxy values or assumptions which introduces possibility for error. Poor quality data can also affect the calibration phase when modelers compare model results with real world observations and use the differences to make changes to the model to improve accuracy. In both scenarios poor quality, low resolution, or missing real-world data can have significant effects on the ability of a model to be accurate.

When a modeler lacks a full understanding of the processes being modeled, they must make assumptions to complete the project. Assumptions may be right or wrong, but they always introduce the possibility of error into the process. When working with highly complex processes like *E. coli* fate and transport there are many unknowns and relatively poor scientific understanding of the processes involved. Many assumptions need to be made to accommodate the lack of data and defined processes.

Lastly, an effective model is one that is useable. There is a wide range of technical proficiency in the potential user base. The model interface needs to be easy to learn, or build upon existing, known interfaces (like Excel). The amount of time a user spends prepping the model to be run should also be taken into consideration. A model that takes two hours to run once compared to a model that takes five minutes to run will be perceived as much less useable. Lastly, the software to run the model should be pre-existing, free, or open source. Installation of new software can be a large barrier to some workers within certain government agencies.

UNIQUE CHALLENGES TO MODELLING *E. COLI*

E. coli, unlike sediment, nitrogen, or phosphorous, are living creatures. *E. coli* can reproduce and die so that *E. coli* loads can increase or decrease without any external input. We understand what parameters affect the growth and decay of these bacteria, but we do not fully understand how or how much they effect the growth or decay. Additionally, *E. coli* inputs are not ubiquitous in the environment, and the magnitude of inputs is partially unknown and highly variable.

EXISTING *E. COLI* MODEL OPTIONS

Aside from the Indiana *E. coli* calculator there are several other options for modeling *E. coli* with varying levels of detail, complexity, and accuracy. The following models were found through a literature review and have been used in scientific studies of *E. coli* modeling.

THE BACTERIA INDICATOR TOOL (BIT)

The BIT was developed by the EPA in 2000. It is based in Excel and uses simple equations to perform loading calculations making the model user friendly and accessible. The model was designed to provide an estimate of total loading to a watershed and can calculate loads for up to 10 subwatersheds. The model uses land uses, number of animals, acres of manure application, and septic system data to calculate loads. Users may customize most of the values used in the excel sheet giving this model significant flexibility.

There are several weaknesses with BIT. Since the model was designed to calculate total loads it does not have any options to add BMPs to get reductions. The model itself is almost 20 years old at the time of writing this, so the data used in the calculations is now 30 to 40 years old and may be out of date. BIT also uses fecal coliform units, not specifically *E. coli*, which would need to be converted if possible. Lastly, there are significant gaps in the model's capability to model transport variables, and some of the more complex variables associated with *E. coli* fate discussed earlier in this document.

Overall, the BIT is user friendly and accessible, but it does not provide the exact function desired and there are significant questions about the accuracy of the results.

BACTERIAL SOURCE LOAD CALCULATOR (BSLC)

The BSLC was developed at the Virginia Tech between 1999 and 2005. It is Excel based, although it uses Excel Visual Basic for Applications (VBA) which is an internal programing application that allows users to code their own Excel functions. Using Excel VBA requires an intermediate to expert knowledge of Excel and may be a limiting factor to some users. The Commonwealth of Virginia used BSLC for several *E. coli* TMDLs (Zeckoski, et al. 2005). Unfortunately, neither the source code nor a copy of the excel file were found despite extensive searches of the internet. I was unable to look at the functionality of the model to determine if it would be suitable for our needs.

SPREADSHEET TOOL FOR ESTIMATING POLLUTANT LOADS (STEPL)

STEPL was created by Tetra Tech in partnership with the EPA. The current update (STEPL 4.4) was published on March 15, 2018. As the name implies STEPL is Excel based although it is much more complex than BIT. STEPL uses VBA to create a graphic user interface (GUI) that makes use of the model easier. The EPA's website has links for model download, training materials, and supporting documentation. Users may download simple excel sheets or there is an additional software install that increases functionality and customization.

STEPL uses local data at the county level to determine manure application months. In the simple form It is capable of calculating loads for 10 watersheds, and uses land use, number and type of animal, septic systems and illegal wastewater discharges, soils data, and irrigation data as inputs. Users may also define custom values to be used by the model instead of the default options. STEPL has built in BMPs to calculate load reductions. There are urban and agriculture BMP options and a variety of BMP combinations may be programmed into the tool.

I have encountered a lot of bugs and unexpected shutdowns during my minimal experimentation with STEPL. While there a lot of BMPs preprogrammed, not all BMPs are available and new GI and LID innovations are not included. I was also unable to get *E. coli* load reductions to manifest when I input BMPs with test data. I could be using the program wrong, but I'm not sure *E. coli* reductions are available with all BMPs. Kentucky reports that they are unable to use STEPL for *E. coli* reductions. Lastly, full program functionality requires software to be installed which would limit governmental partners.

SOIL AND WATER ASSESSMENT TOOL (SWAT/SWAT+)

SWAT is a small watershed to river-basin scale model first developed by Texas A&M University in 2000. Unlike the previous models discussed, SWAT is a standalone program that utilizes GIS inputs to build the hydrologic and geomorphologic portions of the structure. SWAT has recently undergone an update and the new version is called SWAT+. There are multiple versions of SWAT to be compatible with various GIS software including QGIS and ArcMap (QSWAT+ and ArcSWAT+ respectively). SWAT is heavily used in the industry and has significant documentation.

SWAT+ is complex and requires intermediate proficiency with GIS software and intermediate understanding of computer systems. SWAT+ uses GIS elevation raster datasets to create subwatersheds, rivers, and floodplains. Then it uses land use data to create sub parcels with like characteristics forming hydrologic response units (HRUs). SWAT+ uses local data, including soil, meteorological, and elevation, and is highly customizable. Older versions of SWAT have been used to calculate *E. coli* loads, but the updated SWAT+ does not have bacterial modules available yet. The creator, Dr. Raghavan Srinivasan, has said in a webinar that they will be available in 1-2 years.

While SWAT+ is powerful and detailed, it is also complex and would require significant training. It also requires installation of the SWAT+ software, as well as GIS software if that is not preexisting. SWAT+ is compatible with QGIS, an open source GIS software, but that has a learning curve as well. Additionally, there is evidence that SWAT is still somewhat inaccurate despite the level of complexity when used to calculate bacterial loads (Bergion 2017).

OTHER MODELS CITED BY RESEARCH PAPERS THAT HAVE BEEN USED TO MODEL *E. COLI* LOADS

The following models have been used in studies of *E. coli* loading but have been separated out due to a lack of applicability. They are either highly complex, difficult to use, have little supporting information, or are not supported as accurate by the literature.

WATFLOOD

First conceptualized in 1972 and most recently updated in 2019, WATFLOOD is a collection of programs designed for hydrological forecasting. On a large scale WATFLOOD looks to operate similarly to SWAT in that is uses digital elevation models (DEMs), local weather data, and gridded land cover settings to model hydrological data. Unlike SWAT it does not use a visual interface like a GIS program. WATFLOOD will have many of the same challenges as SWAT due to complexity, lack of user-friendly interface, and heavy use of intensive programming. I was unable to test out the program for myself as it requires an installation which I am not allowed to execute. There is some documentation available on the WATFLOOD website.

A study by Sarah Dorner in 2006 used WATFLOOD to create a transport model fecal pathogen loads for a watershed in Ontario, Canada. She found that WATFLOOD performed reasonably well in predicting *E. coli* loads, although it was spotty in certain seasons and during high precipitation events. The author goes into detail about confounding factors and possible sources of error within the mechanics and calibration of the model. It also looks like the authors had to write several add-ons to the base WATFLOOD code to accommodate pathogen transport.

MWASTE

MWASTE was designed to simulate waste production and bacterial loading in run off from the application of animal waste to land. It simulates fecal coliform or fecal streptococci. It uses hydrologic information created using the CREAMS hydrologic model. CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was chosen because it was widely available in the field offices of the Soil Conservation Service who funded the development. MWASTE can only calculate one animal species at a time, so if multiple species need to be modeled multiple iterations of modeling will need to be completed. This model has not been validated according to the documentation found (Moore, 1989).

COLI

COLI is another model designed to simulate runoff from agricultural lands that have been applied with manure. The model has more of a statistical focus to it and outputs minimum and maximum concentrations of bacteria from a field that was recently applied with manure. The model was designed to incorporate three BMPs: waste storage, filter strips, and incorporation of manure into the soil. (Walker, 1990)

SEDMOD

SEDMOD is a menu-based application implemented entirely within the ArcGIS using the AML program language and raster modeling package (GRID). The model uses a grid and calculates flow and pollutants between grid cells. The flow is controlled by five parameters. The model does have significant weaknesses. The model assumes steady state conditions and does not consider environmental factors like temperature or rainfall therefore bacteria mass balance cannot be calculated. Stream processes like settling and resuspension are not addressed with this model. Several sources of FC are ignored including wildlife and septics (Fraser, 1998). This model is also not explicitly designed to calculate load reductions.

I have had significant difficulty in finding the source codes/downloadable models for BSLC, PPLM, MWASTE, and WATFLOOD.

OTHER STATES' APPROACH TO MODELING *E. COLI*

As part of the research used to develop the IEC twelve states were contacted and asked if they modeled load reductions of *E. coli* as part of project tracking and what processes they used to estimate those reductions. We received responses detailing a variety of approaches used to estimate progress in *E. coli* reductions.

The Minnesota Pollution Control Agency (MPCA) does not have an official tool or model that they use, rather they have published the Agricultural BMP Handbook for Minnesota and the Minnesota Stormwater Manual which provide estimates for load reductions for various agricultural and urban BMPs. In addition, they have had contractors use the Bacteria Source Load Tracker to calculate *E. coli* loads.

The Michigan Department of Environment, Great Lakes, and Energy have taken a slightly different approach to tracking progress. They do not model *E. coli* for grant projects or TMDLs and argue that since *E. coli* is not a conservative substance pre- and post-BMP installation monitoring is a more effective solution. They also inventory and track sources for future elimination using animal feeding operation permits, tillage surveys, sniffer dogs for failing septic systems, and DNA monitoring to identify animal sources (livestock, waterfowl, pets, etc.).

Wyoming Department of Environmental Quality has developed two spreadsheet models to estimate reductions in *E. coli* from septic systems and from non-channel livestock exclusion. The septic model was incorporated into the IEC.

Iowa, Kentucky, Colorado, Kansas, and Ohio do not track *E. coli* loading as it relates to BMP installations.

DISCUSSION OF INDIANA NPS PROGRAM PRIORITIES AND MODELING CAPABILITIES

The two limiting factors that determine what type of model will be used are accuracy and ease of use. Both measures operate on a spectrum and are generally inversely related. As accuracy increases ease of use decreases except for models that are both inaccurate and difficult to use.

Indiana watershed specialists are tasked with technical support of watershed groups and provide expertise on mapping and technical information. Modeling competency is low with current section employees and local watershed groups creating a challenge with adopting complex models. Training would be required for watershed specialists on the complex models to allow them to support local groups, and many local groups would request training as well. Federal and state IT protocols also restrict access to downloading and installing modeling software, and this has been a documented issue with software implementation in the past. A model that utilizes existing programming with "plug and chug" capabilities would have the most utility. An existing example would be the excel-based STEPL model.

Accuracy is the goal of any modeling effort. Smaller scale models introduce fewer assumptions than large scale models. Many of the complex models operate on a watershed scale which require data, like local historic rainfall data or land-use data, which may not be readily accessible for watershed groups. Limiting the scale used in the model may be a way to limit inaccuracy while maintaining ease of use (See the Region 5 nutrient and sediment model as an example).

CONCLUSION AND SUMMARY

The current understanding of *E. coli* generation, travel, and fate are evolving. There is a lack of a solid understanding of the variables effecting *E. coli* removal and deactivation. Modeling in this environment requires many assumptions which introduces error. Additionally, as modeling techniques improve, they become more complex and require more expertise and training to use effectively.

Based upon the data in this report BMP-scale, plug-and-chug, excel based models have acceptable error and assumptions, and are the most adoptable method to estimate *E. coli* reductions. Using excel as the base program allows the model to be disseminated widely across the state with few concerns about the need for specific training. Using a plug-and-chug style increases the ease of use for the end user. Watershed groups should be able to acquire a small set of parameters to input into the model which then provides a result in a quick and timely fashion. Lastly, operating on the BMP-scale limits the error involved with estimating the effects of large, watershed processes. On a small scale it can be assumed that the larger processes like subsurface flow have little to negligible effects on the result. The Indiana *E. coli* Calculator is an attempt to implement on the conditions set above to create a useful tool to estimate *E. coli* load reductions.

APPENDIX III: ANNOTATED BIBLIOGRAPHY

Avery, S.m., et al. 2004 "Fate of Escherichia Coli Originating from Livestock Faeces Deposited Directly onto Pasture." *Letters in Applied Microbiology*, vol. 38, no. 5, 2004, pp. 355–359., doi:10.1111/j.1472-765x.2004.01501.x. a. Escherichia coli from livestock faeces can survive on grass for at least 5–6 months, affording opportunity for pathogenic biotypes to contaminate animals, plants or water.

Bai, S., Lung, W., 2005. Modeling sediment impact on transport of fecal bacteria. Water Research 39 (2005) 5232–5240. Authors modeled the resuspension of fecal bacteria in tandem with sediment. It has been found that significant proportions of fecal bacteria in freshwater are attached to soil or soil particles in the water column.

Balkhair, Khaled S. 2016. "Modeling Fecal Bacteria Transport and Retention in Agricultural and Urban Soils under Saturated and Unsaturated Flow Conditions." *Water Research*, vol. 110, 20 Dec. 2016, pp. 313–320., doi:10.1016/j.watres.2016.12.023. Studied the transmission of *E. coli* through urban vs agricultural soils under saturated and unsaturated conditions.

Bergion, Viktor, et al. 2017. "Hydrological Modelling in a Drinking Water Catchment Area as a Means of Evaluating Pathogen Risk Reduction." *Journal of Hydrology*, vol. 544, 2017, pp. 74–85., doi:10.1016/j.jhydrol.2016.11.011. The authors used a SWAT model to estimate the effectiveness of four different BMPs on reducing *cryptosporidium* and *E. coli* in water discharges. The two treatments that showed statistically significant reductions of both Crypto and *E. coli* were vegetative filter strips and improved treatment at WWTPs.

Birch, Gavin F., et al. 2004. "Efficiency of a Constructed Wetland in Removing Contaminants from Stormwater." *Wetlands*, vol. 24, no. 2, 2 June 2004, pp. 459–466., doi:10.1672/0277-5212(2004)024[0459:eoacwi]2.0.co;2. This paper describes the study of a constructed wetland in Sydney, Australia and how effectively it reduced pollutants in stormwater. "Fecal coliform counts in the stormwater in this catchment are high (maximum: 620,000 cfu/100 ml), but mean removal efficiency was 76% (range 26% to 98%) during the four high-flow events monitored. Nevertheless, most samples from the outflow exceeded the Public Health criterion for secondary contact (e.g., boating) of 1000 cfu/100 ml."

Bradshaw, J. Kenneth, et al. 2016. "Characterizing Relationships among Fecal Indicator Bacteria, Microbial Source Tracking Markers, and Associated Waterborne Pathogen Occurrence in Stream Water and Sediments in a Mixed Land Use Watershed." *Water Research*, vol. 101, 13 May 2016, pp. 498–509., doi:10.1016/j.watres.2016.05.014. The primary objective of this study was to predict occurrence of waterborne pathogens in water and streambed sediments during dry-weather periods, when the probability that people will be recreating in a body of water is higher, using a simple statistical model that includes traditionally-measured FIB, environmental parameters, and source allocation using MST markers as predictor variables.

Brendel, Conrad, et al. 2017. "Relating Watershed Characteristics to Elevated Stream Escherichia Coli Levels in Agriculturally Dominated Landscapes: An Iowa Case Study." *Agricultural and Biosystems Engineering Publications*, vol. 9, no. 3, 2017, p. 154., doi:10.3390/w9030154. Paper discusses the relative significance of different land uses on the prevalence of *E. coli* in streams.

Utilizing data sets of AFOs, NPDES facilities, and vegetative cover the writers used GIS to analyze the correlations between *E. coli* concentrations and watershed land use.

Brown, Shannon B. et al 2014. "Predicting Time Cattle Spend in Streams to Quantify Direct Deposition of Manure" (2014). *Agricultural and Biosystems Engineering Publications*. 527. https://lib.dr.iastate.edu/abe_eng_pubs/527. Paper discusses the implications of increased data on the amount of time cattle spend in streams (and how much time they spend defecating in streams) to inform models trying to calculate the load of fecal coliform bacteria loading into streams as a result of land use. BIT is mentioned in this paper.

Burton, G. Allen, et al. 1987. "Survival of Pathogenic Bacteria in Various Freshwater Sediments." *Applied and Environmental Microbiology*, vol. 53, no. 4, Apr. 1987, pp. 633–638. Study discusses the longevity of bacteria in freshwater stream sediments and the factors effecting die-off.

Davies, C.m., and H.j. Bavor. 2000. "The Fate of Stormwater-Associated Bacteria in Constructed Wetland and Water Pollution Control Pond Systems." *Journal of Applied Microbiology*, vol. 89, no. 2, 2000, pp. 349–360., doi:10.1046/j.1365-2672.2000.01118.x. Tested the efficacy of constructed stormwater wetland and pond to determine bacterial load reductions.

Dorner, Sarah M. et al. 2006. "Hydrologic Modeling of Pathogen Fate and Transport". Environ. Sci. Technol. 2006, 40, 4746-4753. Paper describes the use of WATFLOOD model to predict the loads of pathogens on a watershed scale to streams. The model is characterized by surface flow, subsurface flow, and stream characteristics. Model was not very accurate in testing to observed values.

EPA Recreational Water Quality Criteria, 2012, "EPA estimated how the GI illness rate associated with the two GI illness definitions can be compared using the difference between (a) non-swimmer illness rates from the pre-1986 epidemiological data, and the (b) non-swimmer illness rates from the NEEAR study (U.S. EPA, 2011). The mean non-swimmer HCGI rate from pre-1986 epidemiological studies were 14 illnesses per 1,000 non-swimmer recreators, while the non-swimmer recreators mean NGI rate from the NEEAR study was 63 illnesses per 1,000 non-swimmer recreators. Thus, an illness rate of 8 HCGI per 1,000 primary contact recreators is estimated to be equivalent with an illness rate of approximately 36 NGI per 1,000 primary contact recreators (estimated translation factor of 4.5 NGI per HCGI4)." Illnesses derived from a 35CFU/100mL FIB in marine waters. Pg. 13-14.

Ferguson, Christobel M., et al. 2009. "Quantification of Microbial Sources in Drinking-Water Catchments." *Critical Reviews in Environmental Science and Technology*, vol. 39, no. 1, 25 Mar. 2009, pp. 1–40., doi:10.1080/10643380701413294. 1. Literature review of the sources of microbial contamination in freshwater. Has multiple lists of wildlife and animal sources.

Fraser, R. H. et al. 1998. Predicting Stream Pathogen Loading from Livestock using a Geographical Information System-Based Delivery Model. J. Environ. Qual. 27:935-945. doi:10.2134/jeq1998.00472425002700040030x. Paper discusses a GIS based model (SEDMOD) to be used to calculate bacterial loading by characterizing five key transport parameters: flow-path roughness, gradient, slope shape, stream proximity, and soil moisture. Model was found to be useful in predicting relative contributions of diverse livestock operations in a watershed.

Model does have significant weaknesses. Took variables affecting pathogen delivery from this paper.

Hackett, Tim, and Michael R. Lappin. 2003. "Prevalence of Enteric Pathogens in Dogs of North-Central Colorado." *Journal of the American Animal Hospital Association*, vol. 39, no. 1, 2003, pp. 52–56., doi:10.5326/0390052. Studied the prevalence of *E. coli* in dog feces in a park area to determine loading to a nearby stream.

Hall, Kimberlee K., et al., 2014. "Application of Multivariate Statistical Methodology to Model Factors Influencing Fate and Transport of Fecal Pollution in Surface Waters". J. Environ. Qual. 43:358–370 (2014) doi:10.2134/jeq2013.05.0190. Paper examines to use of multivariate statistical analysis to calculate *E. coli* loads for the purpose of creating more accurate TMDL rules.

Hathaway, J. M., et al. 2008. "Pathogen Removal Performance of Best Management Practices in Charlotte and Wilmington, North Carolina". World Environmental and Water Resources Congress 2008 Ahupua'a. Paper describes the project which tested water quality in the outflow of various urban BMPs to determine the efficacy in removal or inactivation of pathogens.

Holcomb, M. K. 2014 "The Challenges and Opportunities in Monitoring and Modeling Waterborne Pathogens in Water- and Resource-Restricted Africa: Highlighting the Critical Need for Multidisciplinary Research and Tool Advancement." *Master's Thesis Virginia Polytechnic Institute and State University*, 14 Nov. 2014. This thesis has a pretty decent overview of some of the available models to look at FIB and their short comings.

Jenkins, Michael B., et al. 2005 "Fecal Bacteria and Sex Hormones in Soil and Runoff from Cropped Watersheds Amended with Poultry Litter." *Science of The Total Environment*, vol. 358, no. 1-3, 31 May 2005, pp. 164–177., doi:10.1016/j.scitotenv.2005.04.015. Studied the effect of poultry litter on hormone and FIB levels before and after rain events with no significant difference found.

Jones, Jonathan et al. 2010 "Pollutant Category Summary: Fecal Indicator Bacteria" International Stormwater Best Management Practices (BMP) Database. 12/2010. An overview of the factors affecting fecal indicator bacteria fate and transport and a summary of studies conducted on removal of specific types of FIB.

Lee, Brad. et al. 2005 "Home & Environment Septic System Failure." *Purdue University Extension,* HENV-1-W. whitehouseinspections.net/yahoo_site_admin/assets/docs/how_to_use_a_septic_system_purdue.40161352.pdf. Purdue extension document that covers septic system failure in Indiana with estimates of discharge and failure rates.

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Mallin, Michael A., et al. 2002. "Pollutant Removal Efficacy of Three Wet Detention Ponds." *Journal of Environment Quality*, vol. 31, no. 2, Mar. 2002, p. 654., doi:10.2134/jeq2002.6540. Monthly inflow and outflow data were collected from three wet ponds in Wilmington, NC for a 29-month period. Two of the ponds experienced significant reductions in fecal coliform bacteria. The article goes in depth on the hypothesized factors of bacterial removal.

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Olilo, Casianes Owino, et al. 2016 “The Current State of Knowledge on the Interaction of Escherichia Coli within Vegetative Filter Strips as a Sustainable Best Management Practice to Reduce Fecal Pathogen Loading into Surface Waters.” *Energy, Ecology and Environment*, vol. 1, no. 4, 7 June 2016, pp. 248–266., doi:10.1007/s40974-016-0026-7. An overview of the strengths and limitations of current models to address the complexity of *E. coli* transport with significant back up data.

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Pandey, P. et al. 2015. “A neighborhood statistics model for predicting stream pathogen indicator levels”. *Environ Monit Assess* (2015) 187: 124 DOI 10.1007/s10661-014-4228-1. Paper discusses the use of a neighborhood statistical model to predict pathogen concentrations on a watershed scale. It used stream cross section, precipitation, and CAFO location to predict loads.

Paule-Mercado, M.a., et al. 2016. “Monitoring and Predicting the Fecal Indicator Bacteria Concentrations from Agricultural, Mixed Land Use and Urban Stormwater Runoff.” *Science of The Total Environment*, vol. 550, 16 Feb. 2016, pp. 1171–1181., doi:10.1016/j.scitotenv.2016.01.026. Studies the quantity of FIB as it relates to watershed land use and other transport variables (TSS, Turbidity, temp, etc.). Good explanation of FIB behavior in rain events. More short scale than long term though.

Peng, Jian, et al. 2016. “Indicator and Pathogen Removal by Low Impact Development Best Management Practices.” *Water*, vol. 8, no. 12, 16 Dec. 2016, p. 600., doi:10.3390/w8120600. Lots of data on various factors effecting the removal of *E. coli* in bio infiltration practices.

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