

6 – ESTIMATED LOAD REDUCTIONS (ELEMENT B)

SWAT MODEL PERFORMANCE

As with the hydrology, a calibration period of up to two years was selected as per the project Quality Assurance Project Plan (QAPP). The selected period was the same for the hydrology calibration as for the bacteria calibration. Model performance for bacteria was evaluated on the basis of several criteria including:

- Comparisons of observed grab samples to daily model bacteria concentrations; and
- Long-term geometric mean comparisons.

Model performance was also evaluated using time series and overall geometric mean comparisons to observed data collected by TCEQ and/or H-GAC at several monitoring stations. There are data starting in 2010 at recently added monitoring stations, specifically 20722 and 20723. Because the model simulation period did not extend beyond 2009, these stations could not be used specifically for calibration. However, the data at these stations were used to give a general understanding of typical bacteria concentrations at those two locations and parameters in the model were adjusted to match the general trends observed at those stations.

Results from the modeling are presented in Table 12 for the calibration period and Table 13 for the validation period. The results presented in these tables are for paired results, meaning that the simulated bacteria concentration was matched with an observed data point and the geometric means were calculated using those data. As can be seen from the table, there are some stations where the model matched very well, such as Station 16373. Other stations, such as 12147, did not match as well on a paired basis. This is not unexpected for bacteria simulations.

A plot of the geometric mean for the entire calibration period compared with observed data is shown in Figure 16. The minimum and maximum values presented on the plot are the minimum and maximum geometric means calculated for 2001, 2002, 2003, 2004 and 2005. This figure demonstrates that while the errors at some individual stations are fairly high, the model does capture the variability observed in the watershed and matches overall trends fairly well.

Finally, time series plots of simulated bacteria concentrations over time compared with observed data points are included in Figure 17. These figures demonstrate the wide variability on a day-to-day basis that was observed in the bacteria concentrations in the San Bernard River and its tributaries.

Table 12 – Bacteria Simulation Performance – Calibration Period (concentrations in cfu/dL)

Station	Number of Samples	Observed Geometric Mean	Modeled Geometric Mean	Error ¹
16373	16	303.3	301.9	2%
17420	9	317.0	91.6	-74%
12147	18	412.5	753.3	225%
15272	12	428.3	229.2	-48%

1. Error is calculated as observed concentration minus the modeled value divided by the observed value.

Table 13 – Bacteria Simulation Performance – Paired Dataset for Validation Period (concentrations in cfu/dL)

Station	Number of Samples	Observed Geometric Mean	Modeled Geometric Mean	Error ¹
16370	16	78.1	366.9	370%
16373	9	295	301	2%
12147	18	282.4	918.1	225%

1. Error is calculated as observed concentration minus the modeled value divided by the observed value.

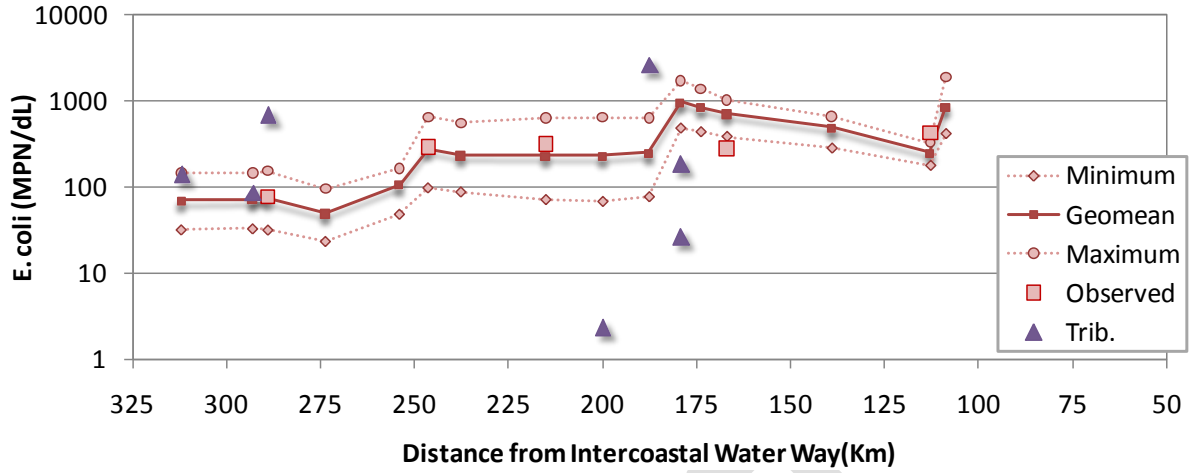
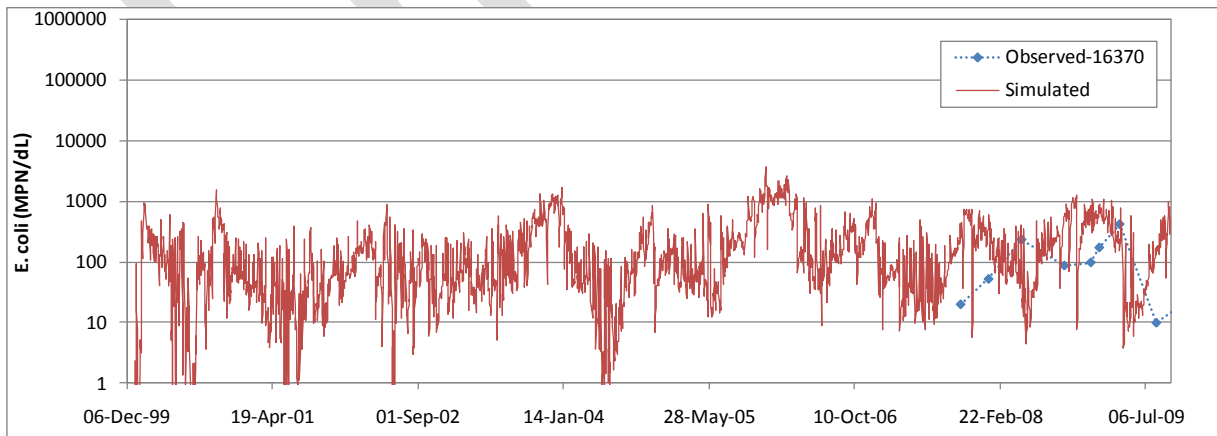
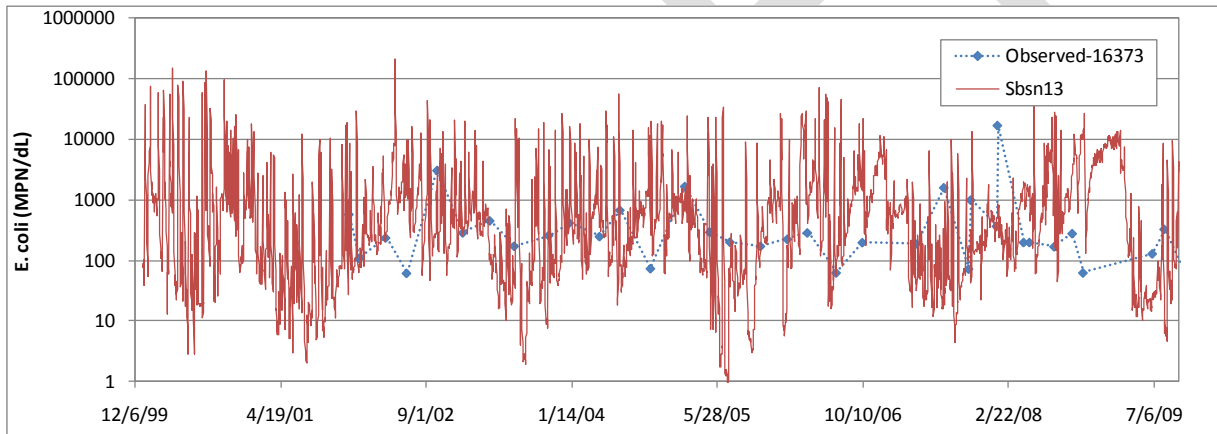


Figure 16 – Geometric Mean Comparison



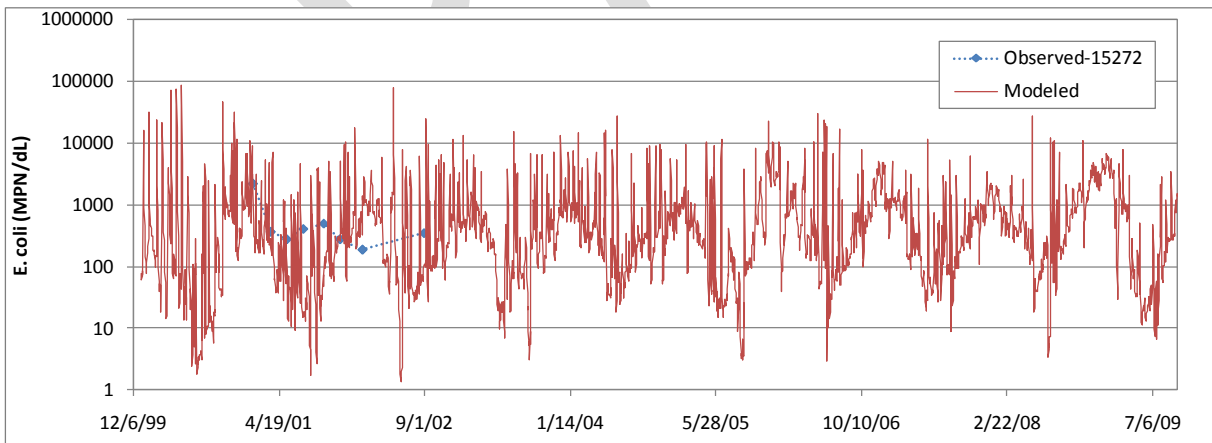
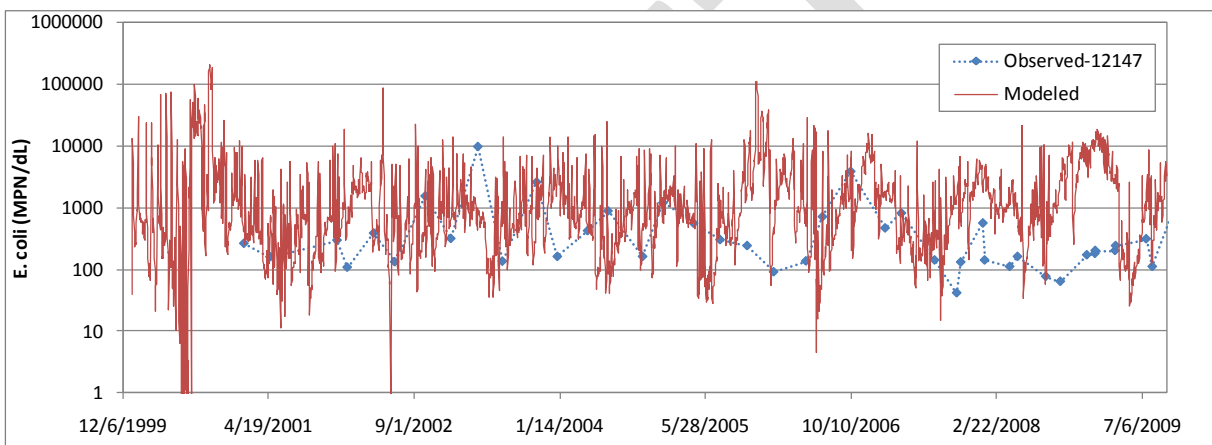
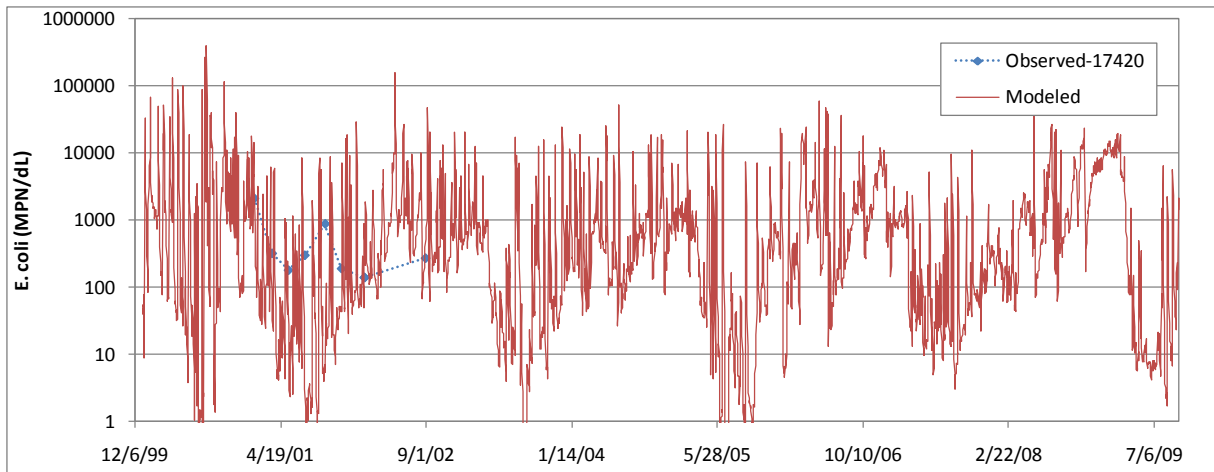
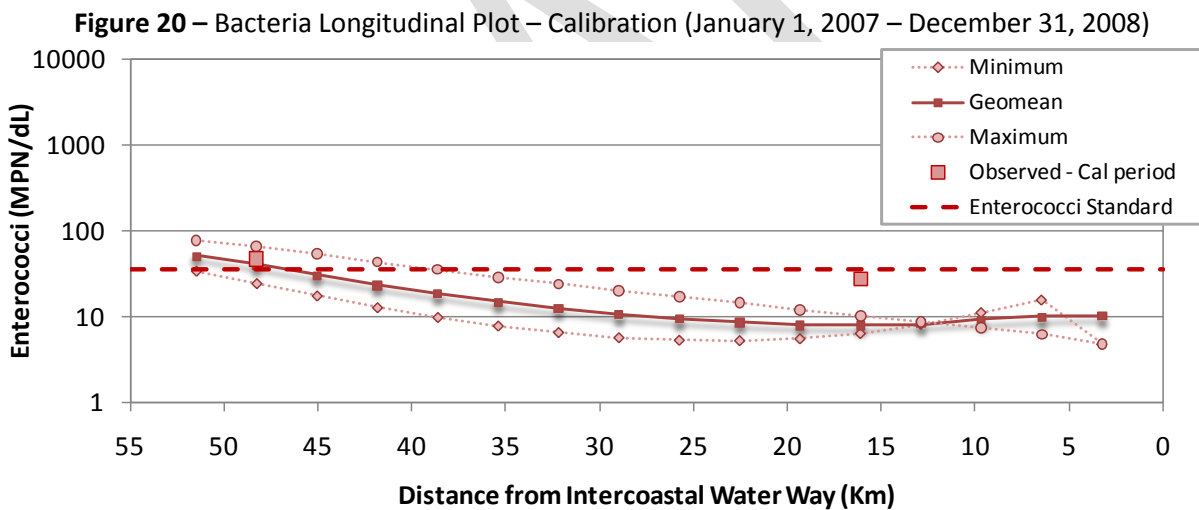


Figure 17 – Time series plots of Bacteria Calibration

TIDAL PRISM MODEL PERFORMANCE

The model performance for the tidal prism for bacteria was evaluated by comparing the observed enterococci to modeled enterococci at all available stations along the main stem of the stream on an overall geometric mean basis as well as by comparing individual grab samples to simulated values.

A longitudinal plot of the modeled and observed geometric mean concentrations for the calibration period is presented in Figure 20 for the calibration period and Figure 21 for the validation period. The maximum and minimum concentrations presented in the longitudinal plot are the maximum/minimum geometric means for each year of the calibration time period. The validation time period was not long enough to calculate geometric means for more than one year; therefore, only the geometric mean was plotted on the graph. Time series plots for each of the stations are also presented in Figure 22 for the calibration period and Figure 23 for the validation period. Segment 2 exhibits small changes in concentration that reflect the tidal fluctuation in the San Bernard River. The peaks observed in the data are related to rainfall events which cause runoff from the watershed to reach the tidal segment of the San Bernard River, carrying with it elevated concentrations of bacteria. While it can be seen that the model does overestimate in some segments and underestimates in others, overall it captures the bacterial levels in San Bernard River.



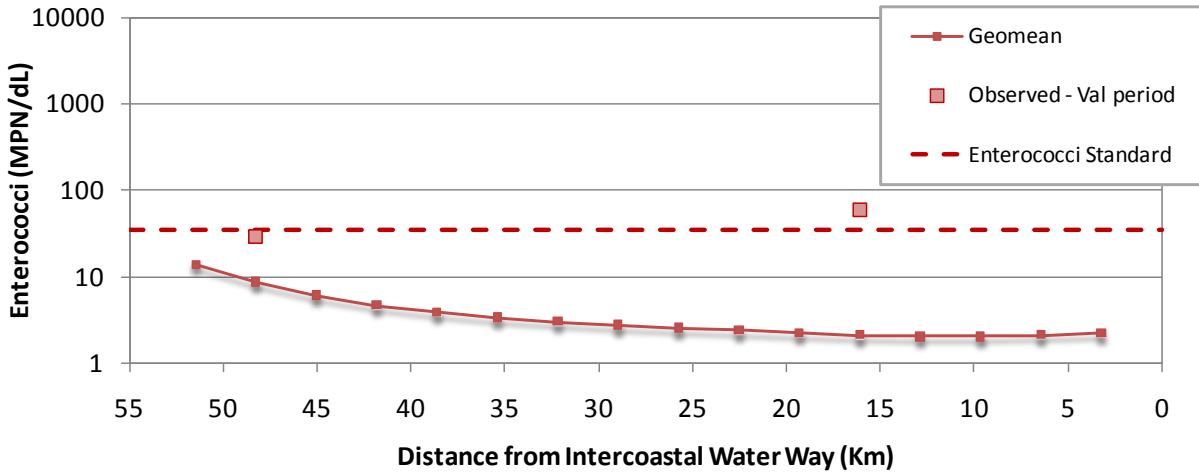


Figure 21 – Bacteria Longitudinal Plot – Validation (January 1, 2009 through September 30, 2009)

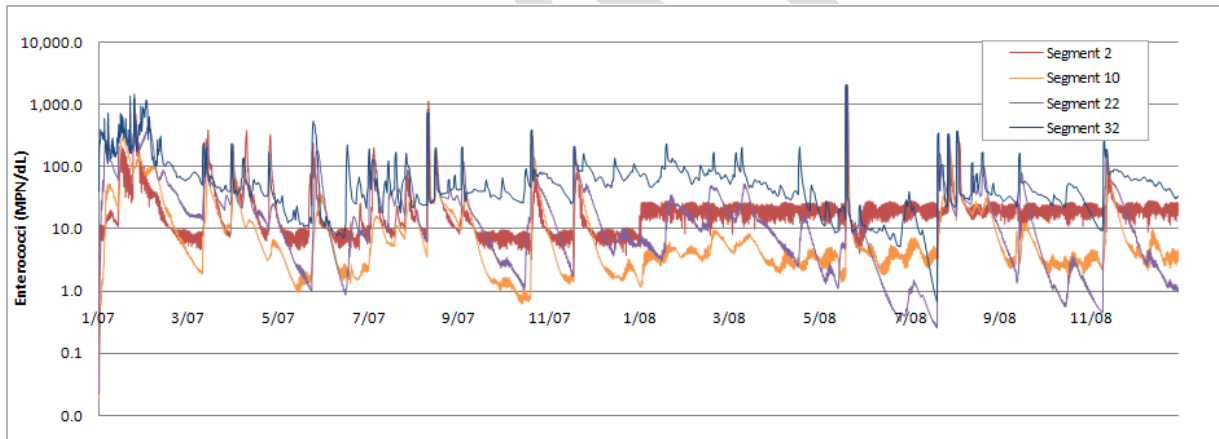


Figure 22 –Time Series Plots – Calibration Period

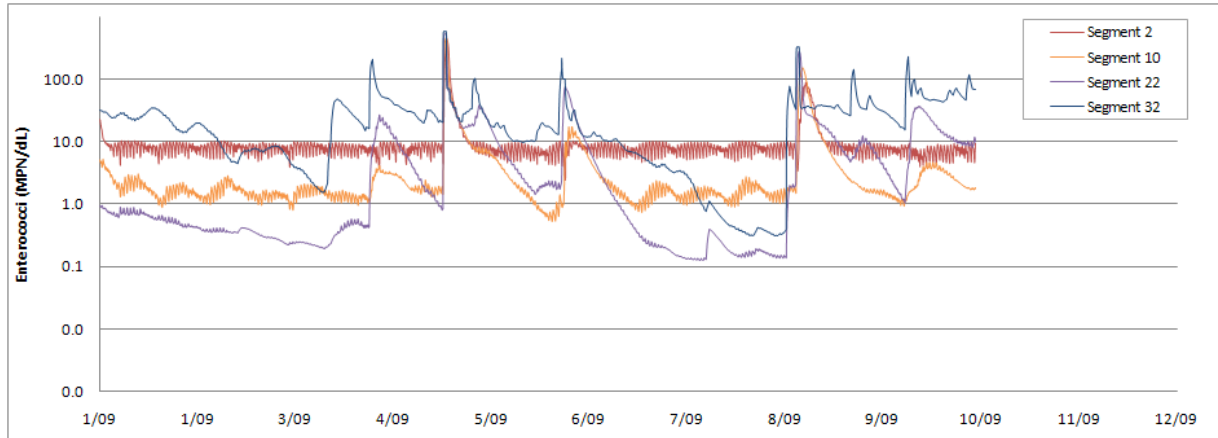


Figure 22 –Time Series Plots – Validation Period

BACTERIA SOURCE ANALYSIS

There are several potential sources of bacteria in the San Bernard River Watershed. These include permitted sources, such as wastewater treatment facilities that do not completely disinfect their effluent and sanitary sewer overflows. Other sources, such as livestock, wildlife, domestic pets, and failing on-site sewage facilities (septic systems) are not permitted but may also contribute to bacteria loading in the San Bernard River.

To explore the impact of each of these sources, several scenarios were run using SWAT with each source eliminated. The change in the in-stream concentrations of bacteria indicate how significant an impact each of the sources have on the San Bernard River. Since the majority of these changes occur in the watershed, the SWAT model was the only tool used to evaluate the sources in the River. The results of the analysis are presented in Figure 1.

The figure demonstrates that all bacteria sources in the watershed play a role in maintaining the bacteria levels in the River. This is an important finding as it suggests that improving water quality in the River can be achieved in multiple ways. It is important to note that these scenarios are used as a tool to understand the watershed; it is not expected that any of the source elimination scenarios would be physically implemented in the watershed.

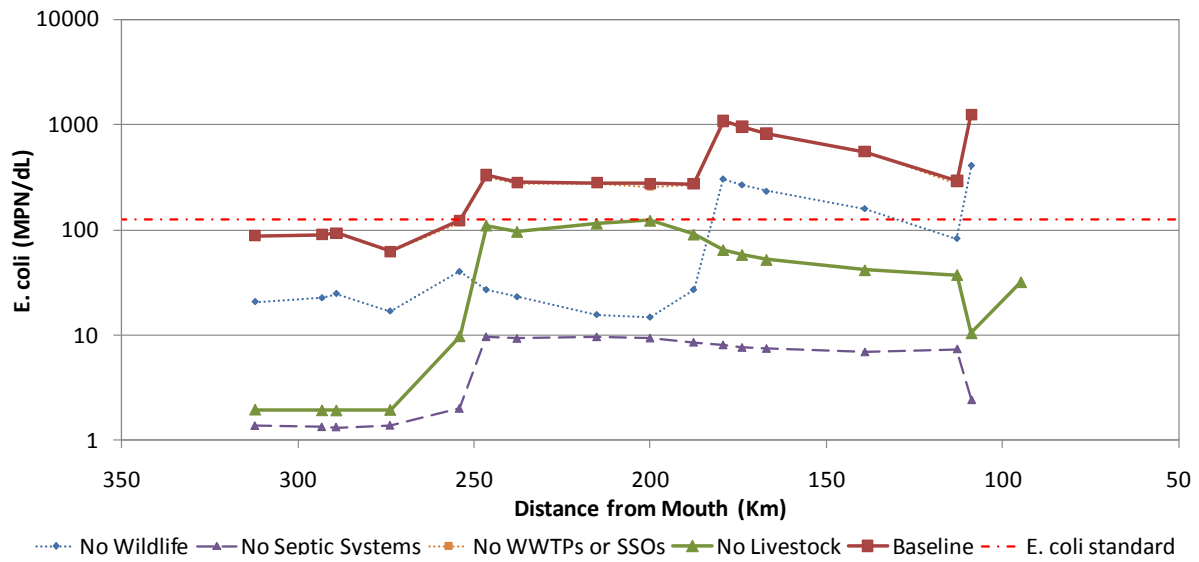


Figure 1 – Bacteria Source Analysis – SWAT Model

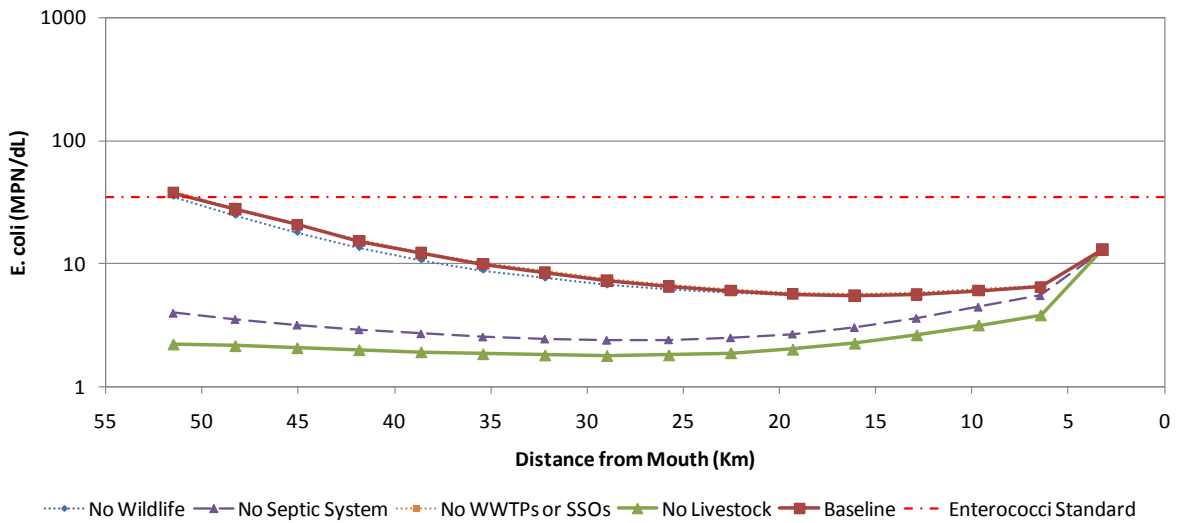


Figure 2 – Bacteria Source Analysis – Tidal Prism Model

The figures demonstrate that all bacteria sources in the watershed play a role in maintaining the bacteria levels in the River. This is an important finding as it suggests that improving water quality in the River can be achieved in multiple ways. It is important to note that these scenarios are used as a tool to understand the watershed; it is not expected that any of the source elimination scenarios would be physically implemented in the watershed.

A summary table of the reductions based on each source is presented in Table 1 for the SWAT model and Table 2 for the Tidal Prism model.

Table 1. Summary of *E. coli* Concentrations and Percent Reduction from Baseline Condition – SWAT Model

Subbasin	River Km	Baseline	No WWTPs or SSOs		No Wildlife		No Septic Systems		No Livestock	
		<i>E. coli</i> (MPN/dL)	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction	(MPN/dL)	Percent Reduction
1	312.09	87.8	87.2	-1%	20.7	-76%	1.4	-98%	2.0	-98%
7	293.11	90.4	90.1	0%	22.5	-75%	1.3	-99%	1.9	-98%
8	289.04	93.6	93.4	0%	24.7	-74%	1.3	-99%	1.9	-98%
10	273.77	62.1	62.0	0%	16.8	-73%	1.4	-98%	2.0	-97%
11	254.09	122.9	117.6	-4%	40.0	-67%	2.0	-98%	9.8	-92%
13	246.50	332.2	318.8	-4%	26.9	-92%	9.6	-97%	110.7	-67%
16	237.75	282.3	272.6	-3%	23.0	-92%	9.3	-97%	96.3	-66%
17	215.14	279.0	273.1	-2%	15.5	-94%	9.6	-97%	115.3	-59%
21	200.00	274.8	256.6	-7%	14.7	-95%	9.4	-97%	122.9	-55%
23	187.65	272.8	268.6	-2%	26.8	-90%	8.5	-97%	90.8	-67%
26	179.27	1085.0	1079.6	0%	305.9	-72%	8.0	-99%	64.7	-94%
28	173.90	956.8	953.8	0%	268.7	-72%	7.6	-99%	58.1	-94%
30	166.97	818.5	817.1	0%	233.3	-71%	7.4	-99%	52.1	-94%
31	139.05	554.9	554.7	0%	159.3	-71%	6.9	-99%	41.6	-93%
35	112.85	291.8	273.9	-6%	82.8	-72%	7.4	-97%	37.5	-87%
34	108.76	1246.9	1246.9	0%	412.1	-67%	2.4	-100%	10.5	-99%

Table 2. Summary of Enterococci Concentrations and Percent Reduction from Baseline Condition
 – Tidal Prism Model

River KM/Segment	Baseline	No WWTPs or SSOs		No Wildlife		No Septic Systems		No Livestock	
	ci (MPN/dL)	ci (MPN/dL)	Percent Reduction	ci (MPN/dL)	Percent Reduction	ci (MPN/dL)	Percent Reduction	ci (MPN/dL)	Percent Reduction
32.00	37.8	38.4	2%	35.1	-7%	4.0	-89%	2.2	-94%
30.00	27.7	27.8	0%	24.6	-11%	3.5	-87%	2.2	-92%
28.00	20.8	20.6	-1%	17.9	-14%	3.2	-85%	2.1	-90%
26.00	15.3	15.6	2%	13.5	-12%	2.9	-81%	2.0	-87%
24.00	12.2	12.5	2%	10.7	-12%	2.7	-78%	1.9	-84%
22.00	10.0	10.2	2%	8.8	-11%	2.6	-74%	1.9	-81%
20.00	8.4	8.7	3%	7.6	-10%	2.5	-71%	1.8	-79%
18.00	7.3	7.5	3%	6.7	-8%	2.4	-67%	1.8	-75%
16.00	6.5	6.7	3%	6.1	-6%	2.4	-63%	1.8	-72%
14.00	6.0	6.2	3%	5.8	-4%	2.5	-58%	1.9	-69%
12.00	5.6	5.8	3%	5.6	-1%	2.7	-52%	2.0	-64%
10.00	5.5	5.6	3%	5.5	1%	3.0	-44%	2.3	-59%
8.00	5.6	5.8	3%	5.8	3%	3.6	-36%	2.6	-53%
6.00	6.0	6.2	2%	6.2	4%	4.5	-26%	3.2	-48%
4.00	6.5	6.6	2%	6.7	3%	5.5	-15%	3.8	-41%
2.00	13.0	13.0	0%	13.0	0%	13.0	0%	13.0	0%

Several other key findings are as follows:

- **Wastewater treatment plants:** It was assumed that the discharge associated with WWTPs would be 126 MPN/dL for the baseline condition, which is the current water quality standard for E. coli. SSOs were assigned a concentration of 500,000 MPN/dL which is consistent with dilute sewage concentrations. The source elimination scenario eliminated all bacteria in the effluent discharge. In practice, the concentrations associated with the discharges will vary based upon a wide range of factors such as plant condition, plant maintenance, and occurrence of rainfall. However, it is clear from the modeling that wastewater treatment plants do play a small role in maintaining the elevated bacteria concentrations in the current baseline model.
- **Septic systems:** Septic systems proved to be a significant factor in the elevated concentrations observed in the San Bernard River. This scenario assumed that all malfunctioning septic systems were fixed and therefore no discharge of bacteria occurred. The difference in bacteria concentrations with and without failing septic systems is striking and suggests that there is a significant impact from the systems on the San Bernard River.
- **Livestock:** The modeling suggests that bacteria runoff from livestock manure is another key factor that maintains the elevated bacteria in the San Bernard River. It is clear that livestock are another key factor in maintaining the bacteria concentrations in the San Bernard River. Livestock have more impact on the upper reaches of the watershed than other locations. It is important to note that the livestock (and wildlife) estimates for some subbasins were calibrated higher than what would be predicted based on the animal census data to match the in-stream bacteria levels.
- **Wildlife and domesticated animals:** Wildlife and domesticated animal loading in the watershed is another key source of bacteria in the region. Eliminating their contributions does not permit the San Bernard to meet water quality standards.

BMP SCENARIO EVALUATION

After evaluating the impact of each bacteria source on the San Bernard River watershed, the next step was to evaluate some specific BMPs that could be implemented in the watershed to improve water quality. The following section outlines some potential BMP solutions.

BMP SCENARIO 1 - VEGETATIVE FILTER STRIPS

One type important management practice (BMP) for water pollution in agricultural areas is a vegetative filter strip. Vegetative filter strips (VFSs) are also known as buffer strips, riparian zones, protection strips, and streamside management zones. Filter strips are located adjacent to the stream to help protect water quality of the stream or lake. These strips are used to minimize the effect of agricultural uses, grazing, and urban activity around the watershed. Filter strips prevent bacteria, sediments, organics, nutrients, pesticides, and other contaminant loadings from entering the streams and thus improving water quality.

SWAT models VFSs with two approaches: one that receives modest flow densities and one that receives concentrated flows. The VFS channel geometry is defined as a trapezoidal with 8:1 side slope; the required inputs for waterways are length, width, depth, and slope. In SWAT, the VFS functionality is simulated in two sections; section 1 represents the bulk of the VFS area receiving the lower flows (i.e., is more diffuse) and section 2 receives about 25% to 75% of the field runoff (the “headwaters” of the VFS that receives more concentrated flow). One important point to note is that in VFSs, bacteria are assumed to be sorbed and captured within the sediment and the soluble particles are captured on the runoff.

The VFSs were applied to agriculture (AGRR), hay (HAY), rangeland shrub (RNGB), and rangeland grassland/herbaceous (RNGE) land uses. The filter strip was assumed to start at the beginning of the simulation period. Several other key variables were specified for the VFS:

- VFSRATIO is the ratio of field area to filter strip (ha^2/ha^2), ranges from 0 ha^2/ha^2 to 300 ha^2/ha^2 with 40 ha^2/ha^2 to 60 ha^2/ha^2 being common values, the values tested in the model were 45 ha^2/ha^2 and 55 ha^2/ha^2 . These values indicate the density
- The VFSCON variable refers to the fraction of the HRU that drains the most concentrated 10% of the filters strip area, value of 50% was used per SWAT guidance.
- VFSCH is the fraction of the flow of the most concentrated 10% of the filter strip; this value was set to 0% per SWAT guidance (Waidler et al, 2011).

Once all the variables were set, the edits were extended to all the subbasins containing the desired land uses for all the different slopes.

The results of the analysis are presented in Figure 3. A summary of the concentrations in tabular form are presented in Table 3 as well. As the figure demonstrates, vegetated filter strips implemented in the watershed could have a very significant impact on the in-stream concentrations of bacteria. It is important to note that the middle portion of the River is just above the water quality standard when the most significant improvements are observed, indicating that some additional efforts will be required to reduce failing septic systems, improve wastewater treatment or otherwise exclude cattle/wildlife from the streams.

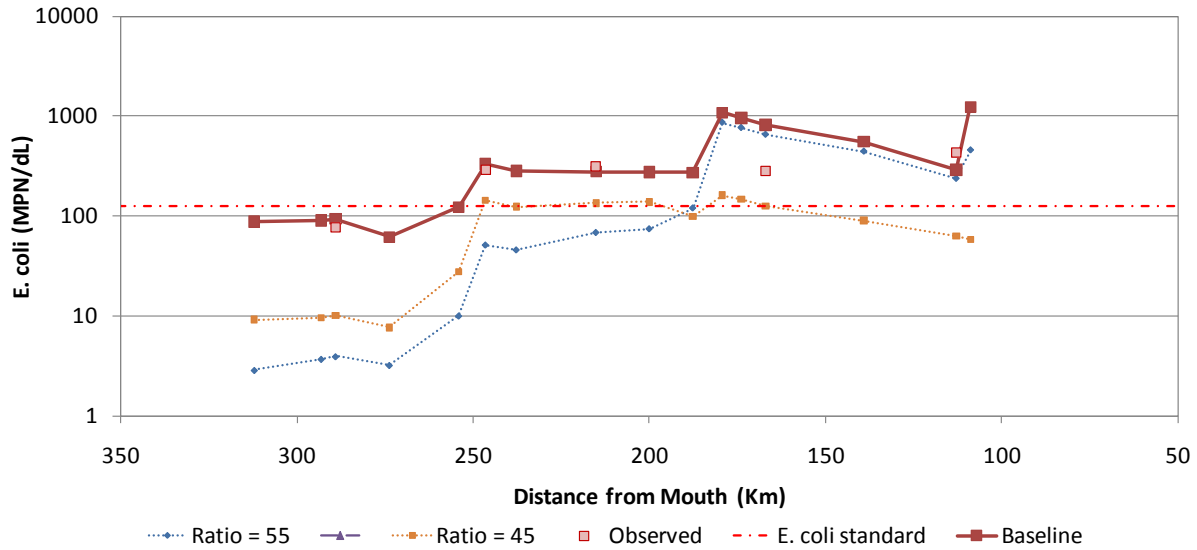


Figure 2 – Vegetated Filter Strip Results

Table 3. Summary of *E. coli* Concentrations and Percent Reduction from Baseline Condition – Vegetated Filter Strip Results

Subbasin	River Km	Baseline	Ratio of filter are to filter strip = 45		Ratio of filter are to filter strip = 55	
		<i>E. coli</i> (MPN/dL)	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction
1	312.09	87.8	9.2	-90%	2.9	-97%
7	293.11	90.4	9.5	-89%	3.7	-96%
8	289.04	93.6	10.2	-89%	3.9	-96%
10	273.77	62.1	7.7	-88%	3.2	-95%
11	254.09	122.9	27.6	-78%	10.0	-92%
13	246.5	332.2	144.2	-57%	51.3	-85%
16	237.75	282.3	124.2	-56%	45.9	-84%
17	215.14	279.0	135.1	-52%	68.5	-75%

Subbasin	River Km	Baseline	Ratio of filter are to filter strip = 45		Ratio of filter are to filter strip = 55	
		<i>E. coli</i> (MPN/dL)	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction
21	200	274.8	138.8	-49%	74.5	-73%
23	187.65	272.8	99.5	-64%	120.2	-56%
26	179.27	1085.0	162.1	-85%	860.9	-21%
28	173.9	956.8	147.1	-85%	762.6	-20%
30	166.97	818.5	125.4	-85%	652.3	-20%
31	139.05	554.9	90.2	-84%	443.0	-20%
35	112.85	291.8	62.9	-78%	237.4	-19%
34	108.76	1246.9	58.2	-95%	455.9	-63%

It is interesting that the more concentrated filter strips (those with a ratio of filter area to filter strip of 45 ha²/ha²) result in lower concentrations near the mouth of watershed when compared with the less concentrated filter strips (those with ratio of filter area to filter strip of 55 ha²/ha²). This may be related to the flatter land near the mouth of the watershed which may not respond as well to the filter strips. In the upper watershed, a less concentrated filter strip could potentially result in a longer flow path along the filter strip and thus remove additional bacteria from stormwater runoff.

BMP SCENARIO 2 - GRASSED WATERWAYS

Grassed waterways are another type of best management practice (BMP) for bacterial water pollution. Grassed waterways are strips of grass seeded in areas where water concentrates or flows off a field. These patches are planted with strong roots grass to carry water across a land. These waterways provide benefits such as reducing the flow velocity, trap sediment and bacteria, absorb chemicals and nutrients from the runoff water, and provide enhancements to wildlife.

SWAT models grassed waterways as a trapezoidal channel. SWAT simulates the channel as broad and shallow with side slopes of 8:1. The reduction of sediments, bacteria and nutrients are calculated in a similar fashion to the way the model simulates sediment and organic nutrient loss for subbasin tributary channels. The main inputs are width and length. Grassed waterway is simulated on an HRU basis, meaning that they can be varied by land use.

The grassed waterways were applied to the same land uses as VFSs, agriculture (AGRR), hay (HAY), rangeland shrub (RNGB), and rangeland grassland/herbaceous (RNGE) land uses. The grassed waterways were assumed to be in place at the beginning of the simulation period. The following key variables were used to simulate grassed waterways

- GWATN: SWAT requires a Manning’s N used for overland flow, under the variable GWATN. The Manning’s n selected was 0.35 to represent the overland flow.
- GWATSPCON is a linear parameter for the sediments in the waterways, the default value of 0.005 was used for the variable.
- GWATL is the length of the grassed waterway is entered under the GWATL variable. The length was varied between 5, 25 and 50 km in length. This default is the length of a single side of a squared HRU.
- GWATD is the depth of the channel from top of the bank to the bottom in meters. If a depth is not selected the program sets the depth as 3/64 of GWATW. For the 5 and 25 m long channels, a value of 1 m was used. For the channel with 50 m in length, a value of 2 m was used.
- GWATW is the average width in meters of the grassed waterway. For the evaluation of the alternative widths of 100 meters were used.
- GWATS is the average slope of the channel in meters. The default value of 0.005 was used for the slope. If the slope is not entered SWAT calculates the slope as 75% of the HRU slope.

Results from the analyses are presented in Figure 3. A tabular summary of the results are presented in Table 4. As shown, there is some reduction in bacteria concentrations when the BMPs are implement. The results suggest that implementing grassed waterways in the San Bernard River watershed will result in an improvement in water quality; however, the impact of these BMPs will not be as significant as the vegetated filter strips.

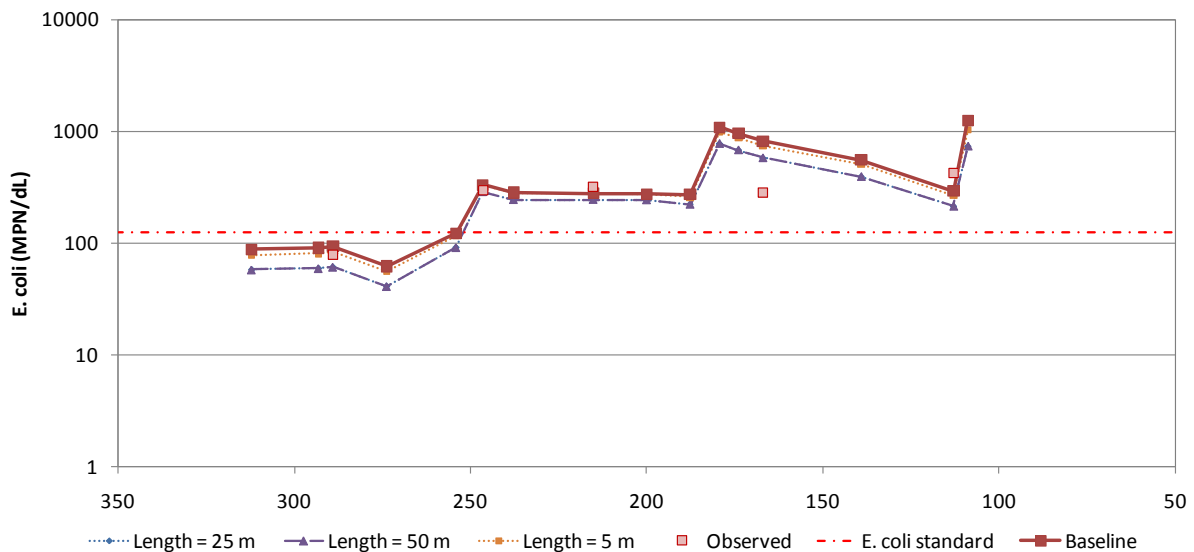


Figure 3 – Grassed Waterway Results

Table 4. Summary of *E. coli* Concentrations and Percent Reduction from Baseline Condition – Grassed Waterway Results

Subbasin	River Km	Baseline	Waterway length = 5 m		Waterway length = 25 m		Waterway length = 50 m	
		<i>E. coli</i> (MPN/dL)	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction	<i>E. coli</i> (MPN/dL)	Percent Reduction
1	312.09	87.8	78.4	-11%	57.8	-34%	57.8	-34%
7	293.11	90.4	80.7	-11%	59.4	-34%	59.4	-34%
8	289.04	93.6	83.2	-11%	61.1	-35%	61.1	-35%
10	273.77	62.1	55.6	-11%	41.1	-34%	41.1	-34%
11	254.09	122.9	116.7	-5%	91.4	-26%	91.4	-26%
13	246.5	332.2	329.9	-1%	287.9	-13%	287.9	-13%
16	237.75	282.3	280.2	-1%	244.9	-13%	244.9	-13%
17	215.14	279.0	277.0	-1%	245.6	-12%	245.6	-12%
21	200	274.8	273.0	-1%	243.6	-11%	243.6	-11%
23	187.65	272.8	258.5	-5%	222.5	-18%	222.5	-18%
26	179.27	1085.0	991.1	-9%	774.5	-29%	774.5	-29%
28	173.9	956.8	871.5	-9%	679.6	-29%	679.6	-29%
30	166.97	818.5	742.2	-9%	577.6	-29%	577.6	-29%
31	139.05	554.9	504.2	-9%	393.2	-29%	393.2	-29%
35	112.85	291.8	268.4	-8%	213.6	-27%	213.6	-27%
34	108.76	1246.9	1037.0	-17%	733.7	-41%	733.7	-41%

MODELING CONCLUSIONS

The SWAT and Tidal Prism modeling demonstrates that there are a number of ways in which to improve the water quality in the San Bernard watershed. Sources of the most concern in the watershed include on-site sewage facilities, livestock, and wildlife. Best management practices that help treat and prevent runoff from these sources from entering the waterways will be most useful in lowering bacteria levels in the watershed. Vegetated filter strips, or buffers would be effective across a broad spectrum of land uses in the watershed. The main source of concern is OSSFs and the outputs from these could be improved through repair and replacement of older systems found in the watershed. The modeling also demonstrated that significantly improving just one or two of the sources would help improve the overall water quality in the watershed. The two sources that would most significantly improve the water quality if they were at least partially eliminated would be OSSFs and livestock. A few of the subwatersheds in particular that contribute greater inputs should be prioritized.