FECAL COLIFORM TMDL DEVELOPMENT: CASE STUDY AND RAMIFICATIONS

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The Commonwealth of Virginia needs to develop 648 TMDLs for 600 water bodies (VADEQ, 2000). Of the total 2,166 impaired stream miles in Virginia, 1,165 miles, or 54 percent, are impaired by fecal coliform. In 1999, researchers at the Biological Systems Engineering Department at Virginia Tech were contracted by the Virginia Department of Conservation and Recreation (VADCR) to develop TMDLs for nine impaired segments, including three stream segments in the North River watershed (Mostaghimi et al., 2000). In the following sections a description of the TMDL plan developed for Pleasant Run watershed is presented as a case study. The key lessons learned from these investigations and the ramifications of procedures developed are discussed in this article.

TMDL CASE STUDY: PLEASANT RUN

Background

Located in Rockingham County, Virginia, the Pleasant Run watershed (5,309 acres) is about two miles south-southeast of the city of Harrisonburg. Pleasant Run is a tributary of the North River. The North River is a tributary of the South Fork of the Shenandoah River, which in turn, is a tributary of the Potomac River. The Potomac River discharges into the Chesapeake Bay.

Water quality samples collected in Pleasant Run, over a five-year period by the Virginia Department of Environmental Quality (VADEQ) indicated that 84 percent of the samples violated the instantaneous water quality standard for fecal coliform. Virginia's instantaneous standard specifies that the fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the high frequency of water quality violations, Pleasant Run was assessed as not supporting the Clean Water Act's swimming use support goal and, therefore, was placed on Virginia's 1998 303(d) list of impaired waterbodies for fecal coliform (USEPA, 1998a; 1998b). The impairment starts at the headwaters and continues downstream to its confluence with North River, for a total of 6.30 stream miles.

In order to remedy the water quality impairment pertaining to fecal coliform, a TMDL plan was needed, taking into account all sources of fecal coliform. Upon implementation, the TMDL for Pleasant Run is expected to ensure that stream water quality be in compliance with the geometric mean standard for fecal coliform. The geometric mean standard specifies that the 30-day geometric mean concentration of fecal coliform shall not exceed 200 cfu/100mL.

Objectives

The objective of the project was to develop a TMDL plan for the Pleasant Run watershed. The following steps were taken to achieve the stated objective:

- Identified potential fecal coliform sources, including background sources, and estimated the magnitude of each source in cooperation with stakeholders;
- Quantified fecal coliform production from each source;
- Simulated attenuation of fecal coliform during transport from deposited locations to water bodies;
- Accounted for variations in precipitation, hydrology, and land-use in simulating fecal coliform deposition in streams;
- Estimated fecal coliform concentrations in waterbodies under present conditions;
- Explored multiple scenarios to reduce fecal coliform concentrations to meet the geometric mean standard;
- Selected a TMDL that can be realistically implemented and is socially acceptable; and
- Incorporated a margin of safety into the TMDL.

Source Assessment

Potential fecal coliform sources in the Pleasant Run watershed were assessed using multiple approaches, including information from VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Since there are no permitted point sources of fecal coliform in the Pleasant Run watershed, the fecal coliform load is entirely from non-point sources. The non-point sources of fecal coliform are mainly agricultural, such as land-applied animal waste and manure deposited on pastures by cattle. A significant fecal coliform load comes from cattle directly depositing in streams. Wildlife also contributes to fecal coliform loadings on pasture, forest, and stream. Extensive watershed reconnaissance was undertaken to identify different species of wildlife, determine population numbers, and assess habitat in the watershed. Non-agricultural non-point sources of fecal coliform loadings include failing septic systems and pet waste. Locations of the 338 unsewered households (with septic systems) were identified using 1999 E-911 digital data from Rockingham County. Each unsewered household was classified into one of three age categories (pre-1964, 1964-1984, and post-1984) based on USGS 7.5-min. topographic maps. It was assumed that septic system failure rates for houses in the pre-1964, 1964-1984, and post-1984 age categories were 40, 20, and 5 percent, respectively. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in production and practices, considering factors such as the fraction of time cattle are in confinement or in streams, as well as manure storage and spreading schedules (Mostaghimi et al., 2000). The potential fecal coliform sources and daily fecal coliform production rates for various sources in the watershed are listed in Table 1.

Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) model was used to simulate the fate and transport of fecal coliform bacteria in the Pleasant Run watershed (Bicknell et al., 1993; Donigian et al., 1994). Due to the short period of flow record available for Pleasant Run, the hydrology component of HSPF was calibrated for Linville Creek, a tributary of the North Fork of the Shenandoah River, which had a longer period of record. The Pleasant Run and Linville Creek watersheds have similar land-use characteristics.

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land-use characteristics of the watershed. Required weather data were obtained from the Dale Enterprise weather station located about 13 miles from the watershed. Since hourly data for other meteorological parameters (e.g. solar radiation, temperature) were not available at Dale Enterprise, daily data from Monterey (Virginia), Lynchburg Airport, and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF. The hydrology parameters were defined for every land-use category for each subwatershed within the Pleasant Run. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Donigian et al., 1995). These parameters were estimated by surveying representative channel cross-sections in each subwatershed. Values for other hydrologic parameters were estimated based on local conditions when possible, otherwise the default parameters provided within HSPF were used (Mostaghimi et al., 2000).

Fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct non-point sources in the model. Fecal coliform that is land-applied or deposited on land was treated as non-point source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct non-point source loading was applied to the stream reach in each subwatershed as appropriate. The non-point source loading was applied as fecal coliform counts to each land-use category in a subwatershed on a monthly basis. Fecal coliform was considered to die-off in land-applied sources, stored manure, and in the stream. Both direct non-point and non-point source loadings were varied by month to account for seasonal differences.

The hydrology calibration was performed using data from the Linville Creek watershed. The calibration period selected for the Linville Creek data was September 1, 1991 to March 1, 1996, and the validation period was September 1, 1986 to August 31, 1991. The HSPEXP decision support software (Lumb et al., 1994) was used to develop a calibrated HSPF data set for the Linville Creek watershed. The HSPEXP system provides guidance on parameter adjustment during the calibration process. The calibration of the HSPF hydrology parameters resulted in simulated flows that accurately matched the observed data for Linville Creek (Table 2). There was very good agreement between the observed and simulated stream flow indicating that the

Table 1. Potential fecal coliform sources and daily fecal coliform production by source in Pleasant Run watershed

Potential Source	Population in Watershed	Fecal coliform produced ($\times10^6$ cfu/head-day)*
Humans	1,067	1,950[a]
Dairy cattle		
Milk and dry cows	1,260	20,000[b]
Heifers [c]	1,260	9,200[d]
Beef cattle	760	25,800[e]
Pets	409	450[f]
Poultry		
Layers	24,000	136[g]
Broilers	99,000	89[g]
Turkeys	35,000	93[g]
Deer	169	347[h]
Raccoon	2	113[h]
Muskrat	244	25[h]

[a] Source: Geldreich et al. (1977)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[f] Source: Weiskel et al. (1996)
[g] Source: ASAE (1998)
[h] Source: Yagow (1999)
* colony-forming units/100 mL (milliliters) of water

Table 2. Linville Creek calibration simulation results (September 1, 1991 to March 1, 1996)

Parameter	Simulated (inches)	Observed (inches)	Percent Error
Summer plus winter stream flow	54.9	55.2	-0.5%
Summer[a] stream flow	7.6	7.5	0.01%
Winter[b] stream flow	20.2	21.5	-6.0%

[a] June – August
[b] December - February

model represented the hydrologic characteristics of the watershed very well. Percent error for each variable was within the criteria specified by HSPEXP (Mostaghimi et al., 2000). The calibrated data set was then used in the model to predict runoff for a different time period for Linville Creek to provide a basis for evaluating the appropriateness of the calibrated parameters. There was very good agreement between the observed and simulated stream flow, indicating that the calibrated parameters represent the characteristics of the watershed reasonably well for time periods in addition to the calibration period (Mostaghimi et al., 2000).

After the hydrologic calibration and validation were completed, the water quality component of HSPF was calibrated. The water quality component of HSPF was calibrated using three years of fecal coliform data collected in the watershed (Lumb et al., 1993). Based on the amounts of fecal coliform produced in different locations, monthly fecal coliform loads to different land-use categories were calculated for each subwatershed for input into the model. The fecal coliform content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal fecal coliform loading to streams by cattle was calculated for pastures adjacent to streams. Fecal coliform loadings to streams and the land surface by wildlife were estimated for deer, raccoon, and muskrat. Fecal coliform loadings to the land surface from failing septic systems were estimated based on the number and age of houses in the watershed. Fecal coliform contribution from pet waste was also considered (Mostaghimi et al., 2000). A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate of fecal coliform in the watershed (Mostaghimi et al., 2000).

After the model calibration process was completed, the contributions from the various sources in the Pleasant Run watershed were represented in HSPF to establish the existing conditions for the representative hydrologic period of about three years. The simulation results indicated nearly 93 percent of the mean daily fecal coliform concentration in the stream originates from cattle directly depositing in the stream, 5 percent from upland areas due to runoff, while the contributions from milking parlor wash-water and wildlife defecating in the stream accounts for the remaining 2 percent. The fecal coliform concentrations exceeded the 30-day geometric mean water quality standard more frequently during low flow periods and during the summer. During the summer, when stream flow was lower, cattle spent more time in streams, and, thereby, increased direct fecal coliform deposition to streams (Mostaghimi et al., 2000).

Margin of Safety

U.S. EPA recommends incorporating a margin of safety (MOS) in TMDL reports. While developing allocation scenarios to implement the TMDL, an explicit MOS of 5 percent was used. Hence, the maximum 30-day geometric mean target for the allocation scenario was 190 cfu/100 mL, 5 percent below the standard (200 cfu/100 mL). It is expected that a MOS of 5 percent will account for any uncertainty involved in the accuracy of the input data used in the model.

Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet the 30-day geometric mean standard, including a margin of safety, (190 cfu/100 mL) with no violations. The selected scenario is presented in Table 3.

Results clearly indicate that direct cattle deposits in the stream have a significant impact on fecal coliform concentrations. Non-point source loading from upland areas is a minor source of fecal coliform compared to cattle in streams. The selected allocation scenario requires a 25 percent reduction in fecal coliform loads from pervious, upland sources and a 10 percent reduction from wildlife loading. Further, complete exclusion of cattle from streams and elimination of direct wash-water discharge of the one milk parlor to the stream are required to meet the TMDL goal. The 30-day geometric mean fecal colifom concentrations resulting from the selected allocation scenario, as well as the existing conditions, are presented graphically in Figure 1.

Phased Implementation

An alternative scenario that requires less drastic changes in management practices and achieves smaller reduction in fecal coliform concentration in the stream was evaluated. The implementation of such a transitional scenario, or Phase I implementation, will allow for an evaluation of the effectiveness of management practices and the accuracy of model assumptions through data collection. Phase I implementation was developed for a maximum of 10 percent violations of the instantaneous standard (1,000 cfu/100 mL) based on monthly sampling frequency. Phase I implementation requires a 98.5 percent reduction in direct fecal coliform loading by cattle into the stream and elimination of direct discharge of wash-water from milking parlors into streams. Also, a 25 percent reduction in fecal coliform loadings from the pervious, upland areas is required. The Phase I implementation requires no reductions in wildlife contributions.

The phased TMDL implementation allows for the interim evaluation of the effectiveness of the proposed TMDL implementation while progressing toward compliance with Virginia's water quality standard. Phase I implementation allows for the evaluation of the effectiveness of management practices through stream monitoring on a monthly basis. Also, data collection during this phase allows for the quantification of uncertainties that affect TMDL development. By accounting for such uncertainties, the TMDL can be improved for the final implementation phase that requires full compliance with the 200 cfu/100 mL geometric mean water quality standard.

Table 3. Selected allocation scenario for the Pleasant Run TMDL

Percent reduction in loading from existing condition					
Direct wildlife deposits	Direct cattle deposits	NPS from pervious land segments	NPS from impervious land segments	Milking parlor wash-off	Percentage of days with 30-day GM > 190 cfu/100mL
10	100	25	0	100	0.0

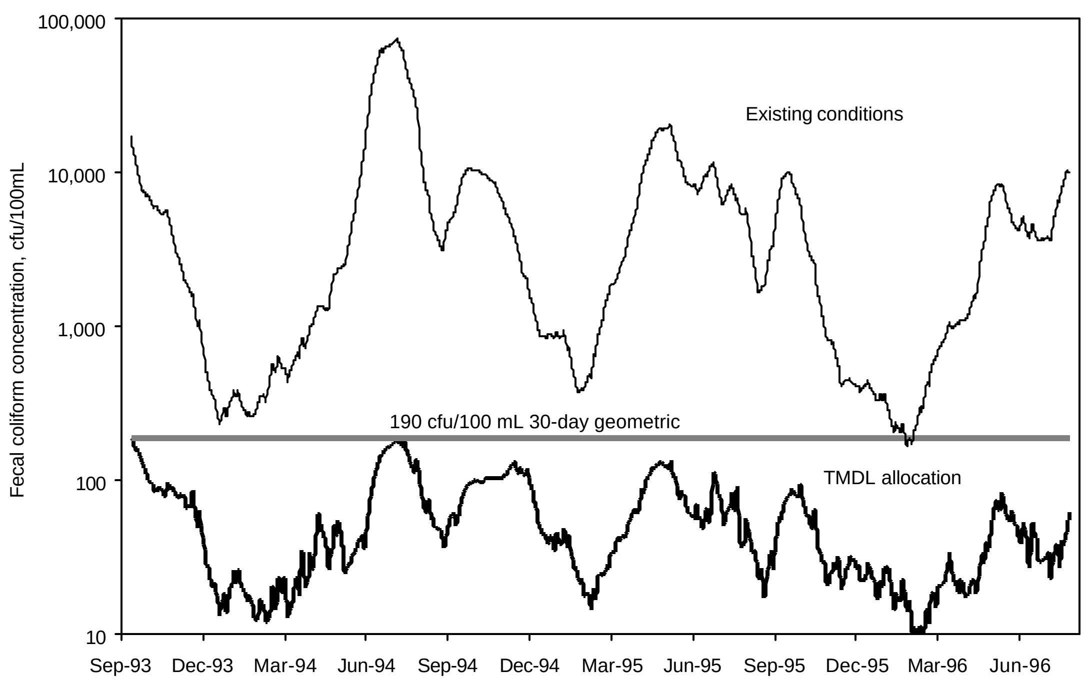

Figure 1. Successful TMDL allocation, 190cfu/100mL geometric mean goal, and existing conditions for Pleasant Run.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Three public meetings were organized for this purpose. The first public meeting was held to inform the stakeholders of the TMDL development process and to obtain feedback on animal numbers and other land-use activities in the watershed. The results of the hydrologic calibration as well as animal population and fecal production estimates were discussed in the second public meeting. The draft TMDL report was discussed at the third public meeting prior to submission of the report to U.S. EPA.

The U.S. EPA approved the TMDL plan developed for Pleasant Run in June 2000. A best management practice (BMP) implementation plan is being developed by the VADCR.

DISCUSSION

Lessons Learned

The following lessons were learned from the Pleasant Run study and six other TMDLs developed by the investigators:

- The existing data on stream flow and water quality may not be adequate for model calibration and validation for most Virginia watersheds. Virginia is currently discussing its strategy to collect adequate data for TMDL development and implementation.

- There is a high degree of uncertainty involved in the animal population and distribution data within watersheds. There is also an immediate need to develop improved methods for more accurate estimation of wildlife as well as domestic animal populations.
- There is a need for developing models that simulate the important hydrologic/water quality processes affecting the bacteria TMDLs. Most existing models are not able to consider temporal, spatial and economic efficacy of BMPs as related to bacteria TMDLs. Furthermore, guidance on model selection, application and interpretation of results is severely lacking.
- There is not enough guidance on the appropriate level of the Margin of safety (MOS) used in the TMDL plans. Most TMDL studies consider a 5-10 percent MOS to account for assumptions and uncertainties involved in the accuracy of the input data used in the model. This level may not be accurate for some investigations.
- The Pleasant Run TMDL, as well as all other fecal coliform TMDLs developed in Virginia, indicate that cattle in the stream is a consistent problem and that Virginia's fecal coliform standards may not be realistic for nonpoint sources. In some streams fecal coliform bacteria counts from wildlife alone resulted in violation of the standard, particularly during low flow conditions. As a result, many of these streams may not be able to attain current fecal coliform standards without some reductions in wildlife loadings. Fecal coliform TMDLs require drastic reductions in bacteria loadings from various sources. Such drastic reductions may be neither technologically possible nor socially acceptable to the landowners.

<u>Implications for State Water Quality Standards</u>

Currently, all waters in Virginia are designated as "primary contact" for the swimming use, regardless of their size, depth, location, water quality, or actual use. For a non-shellfish supporting water body to be in compliance with the Virginia fecal coliform standards for contact recreational use, two criteria are specified: 1) instantaneous (single sample), which specifies no violation of 1000 cfu/100 mL at any time, and 2) geometric mean, which specifies that the geometric mean of two or more water quality samples taken within a 30-day period shall not exceed 200 cfu/100 mL. The standards are to be met during all stream conditions and do not consider background fecal coliform levels in the stream, such as those contributed by wildlife.

The issues raised during TMDL development contributed significantly to the ongoing debate on water quality standards in Virginia. As a result of the TMDL studies, the Commonwealth of Virginia established an academic advisory committee to re-evaluate the suitability of its fecal coliform standards. Subsequently, the proposed amendments to the standards contain three criteria (fecal coliform, *E. Coli*, and entrococci) for primary contact recreation. The previous 200 cfu/100 mL geometric mean for fecal coliform remains the same, but was changed to apply to a calendar month rather than to a 30-day average. The instantaneous fecal coliform criteria (zero violation of 1000 cfu/100 mL) have been modified to match the U.S. EPA's coliform criterion of not more than 10 percent violation of the 400 cfu/100 mL. The proposed entrococci and *E. Coli* criteria geometric means are the same as the EPA's 1986 criteria. Public hearings will be held to discuss these draft amendments to the bacteria standards.

AUTHORS

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