# Chapter I
# TMDL DEVELOPMENT: HISTORY, DEVELOPMENT, MODELS, BACTERIAL SOURCE TRACKING METHODS, AND OBJECTIVES

## INTRODUCTION

Water is essential to every living organism. Water contaminated with chemicals, nutrients, and sediment and unnaturally high or low numbers of microorganisms can negatively affect the ecosystem of a single stream or entire watershed (VA DEQ 2004). Polluted water can spread a variety of diseases, many of which can be transmitted to humans, such as cholera and typhoid fever (CDC 2004). Recreational water-bodies, like the California coast-line, can become impaired (not safe for drinking, fishing, or recreating) because of bacterial counts that exceed current state standards, causing them to be closed during the summer months. Closing recreational areas can cause a dramatic and negative impact to businesses and lead to economic losses. Pathogenic organisms are the primary threat to the health and safety of the U.S. water supply (EPA 2004d). Tracking these organisms and mitigating their negative impacts to the natural environment is of the utmost importance.

Unfortunately, it is not yet practical to examine water for the hundreds of various pathogenic organisms that may be present. For this reason indicator organisms, which are easier to track but behave similar to the pathogenic organisms, are used. The most common group of indicator organisms is the fecal coliform group, which contains *Escherichia coli, Enterobacter aerogenes*, and *Klebsiella pneumoniae* (EPA 2004c). The coliform bacteria are ideal because they are found in the intestinal tract of humans and warm-blooded animals in large numbers (Madigan *et al.,* 2000). In addition, coliform bacteria die at a rate consistent with that of pathogens and behave in a similar fashion during water purification (Madigan *et al.,* 2000). If tests indicate that a water sample is coliform positive, it most likely has received fecal contamination. Although the fecal coliform and other tests are available to identify and monitor contaminants, it has only been recently that tests have been developed to determine the sources of contamination. Bacterial source tracking provides the means to test, identify, and track contamination to water-bodies. The 1972 Clean Water Act provided the impetus for the development of source identification methods, by requiring that states identify all impaired streams, identify the source of the impairment, and develop Total Maximum Daily Loads (TMDLs) for each impairment (VA DEQ 2004).

A TMDL is the amount of pollution a stream can receive without being negatively affected (VA DEQ 2004). This measurement must include contributions from point (wastewater treatment plants, industrial discharges) and non-point sources of pollution (agricultural runoff, storm runoff), background contributions (natural and seasonal conditions), and must also include a margin of safety (VA DEQ 2004). A TMDL is developed to establish the maximum load of a pollutant that will allow a waterbody to achieve the applicable water quality standard, and to set a target for implementation of control measures. A waterbody is considered impaired if it exceeds water quality standards 10% of the time during an assessment period. In Virginia, the bacterial standard for recreational water is 400 colony forming units (CFUs) of fecal coliform per 100 ml of water for a one time sample or 235 CFUs per 100 ml for *Escherichia coli*. A TMDL must be established for each type of impairment, so multiple TMDLs are possible for a single waterbody (e.g. fecal bacteria, nutrients, and sediments).

Water quality monitoring is costly and time consuming, so most states have been unable to adequately monitor their waterways (EPA 2004d). In 1972, section 303(d) of the Clean Water Act required states to identify waters that do not meet water quality standards, institute a schedule for developing TMDLs, develop a list of impaired waters, and establish TMDLs for each water on the 303(d) list. The EPA revised their regulations in July 2000, requiring states to develop implementation plans with each TMDL (VA DEQ 2004).

In 1997, the Virginia General Assembly enacted the Water Quality Monitoring Information and Restoration Act, section 62.1-44.19:4 through 19:8 of the Code of Virginia. This legislation required the Department of Environmental Quality (DEQ) to develop a list of impaired waters, to develop TMDLs for each impairment, and to develop an implementation plan for each TMDL. In 1998, DEQ and the Department of Conservation and Recreation (DCR) signed a Memorandum of Understanding (MOU) with the EPA to develop TMDLs, according to a schedule, for the 247 impaired waters listed on the 1998 303(d) list. These are due for submission in 2004 (VA DEQ 2004).

Most states failed to act on the provisions of the Clean Water Act until forced to do so by lawsuits brought about by private organizations. In Virginia, the American Canoe Association and the American Littoral Society filed a complaint against the EPA for failure to comply with the provisions of §303(d) of the Clean Water Act (ACA 2004). In 1999, the EPA signed a Consent Decree with the plaintiffs. The consent decree contained a TMDL development schedule through year 2010 (VA DEQ 2004). Over 26,000 streams have been added to the EPAs impaired list, with 48,809 impairments. Of those impairments listed, 5,578 are for fecal microorganisms. Since 1996, the EPA has approved only 9,586 submitted TMDL plans (EPA 2004d).

The Piedmont and South Central regions of this study represent a fraction of the TMDL development for the 2004 submission. Since 1998, 837 Virginia streams have been added to the 303(d) list. Of the 1,433 impairments listed, 634 are for microbial pathogens (EPA 2004d). Development of TMDL plans has lead to extensive water quality monitoring needed to support development of the TMDLs.

Water quality impairments can be divided in to four main categories: microbiological (bacteria, protozoa, viruses), biological (aquatic life), chemical (pesticides, nutrients) and physical (suspended solids, thermal pollution). Microorganisms are deposited into water via fecal matter. Fecal matter may enter water-bodies through storm runoff in urban and rural areas, livestock and wildlife defecating directly in streams, and by way of leaking sewer pipes. Illness can also occur by eating food washed with contaminated water (CDC 2004). The most common waterborne, disease causing, bacteria are *Campylobacter* spp, *Vibrio Cholera*, *Salmonella* spp, and *Shigella* spp (Madigan *et al.,* 2000). These bacteria are gram-negative, with varying oxygen requirements and cell shapes. *Campylobacter jejuni* is microaerophilic (requires 3-10% oxygen), with a curved rod shape. *C.jejuni* is the number one cause of acute gastroenteritis, worldwide, and is found on virtually all poultry carcasses produced in the United States (Madigan *et al.,* 2000). *Vibrio cholera*, the bacteria that causes cholera, is a motile rod with a single polar flagellum. *V. cholera* produces an enterotoxin that causes severe diarrhea, which often leads to dehydration (CDC 2004). Several *Salmonella* species cause gastroenteritis through improper handling of food. The Salmonellas are flagellated facultative anaerobes (can grow with of without oxygen). The most dangerous species is *Salmonella typhi,* which causes typhoid fever. High fever, weakness, stomach pain, headache, and loss of appetite characterize typhoid fever. The most troubling factor is that people can be asympotmatic carriers of this organism, making others sick but remaining healthy (CDC 2004). *Shigella* species are also facultative anaerobes with a rod shape. This organism is responsible for bacillary dysentery, which causes bloody diarrhea (CDC 2004). Without exception, the diseases caused by these organisms are more prevalent in undeveloped countries where sanitation is poor, and where much of the population is undernourished, making them more susceptible to illnesses. Fortunately, bacteria are easily killed by standard water treatment practices such as chlorinating, sedimentation, and filtration.

Hepatitis A and E, the Norwalk Virus, and the poliovirus can also be transmitted through fecal contamination of water. Hepatitis A is a hepatovirus with non-enveloped symmetrical RNA. As the virus spreads, it targets the liver causing jaundice. The Norwalk virus is a calicivirus, also with non-enveloped RNA. This virus produces acute gastroenteritis lasting 24 to 48 hours. The poliovirus is a picornavirus with a non-enveloped RNA strand. A patient may suffer from aseptic meningitis without progressing to fully developed polio (Baron 1991).

*Giardia lamblia* and *Cryptosporidium parvum* are the two most common waterborne protozoa responsible for human illness. *Giardia lamblia* is a flagellated protozoa that produces chlorine resistant cysts. Once these dormant cells reach the intestines, they germinate, and a foul smelling diarrhea results. *Cryptosporidium parvum* is commonly found in the gut of dairy cattle and is 14 times more resistant to chlorine than *Giardia*. This organism was the source of the 1993 waterborne disease outbreak in Wisconsin, that infected 400,000 people. Fortunately, advanced chlorination combined with appropriate sedimentation and filtration will remove both of these organisms from water (Madigan *et al.,* 2000).

Chemical contamination includes both nutrients and chemicals. Pesticides and nutrients from fertilizers and animal manure enter waterbodies through runoff from agriculture and urban practices. Over- application of pesticides on cropland and private lawns creates runoff during storm events. Agricultural application of animal manure on croplands, as a means to dispose of it, also creates a runoff problem (DCR 2004a). Nitrogen and phosphorus, also excreted in animal wastes, are applied to crop land to ensure optimal growth. Unfortunately, these nutrients may accumulate in the soil and are transported during rain events.

Physical impairments may include heavy sedimentation, extreme pH, and thermal pollution. Suspended solids cause turbidity, which reduces light penetration in water. This may interfere with photosynthesis of aquatic plants and microorganisms. Suspended solids can also coat rocks, plant roots, and stream beds, interfering with the growth of aquatic life. Solids may also carry toxic chemicals or nutrients. Extreme pH values can kill fish and plants, affect chemical reactions that take place in the water, and generally cause toxic conditions to all aquatic life. (Simpson *et al.*,2002). Although chemical and physical impairments can negatively affect the use of water and in some cases can be hazardous to human and animal populations, microbiological impairments present a more immediate threat.

TMDL DEVELOPMENT

In order to develop a TMDL, the Virginia DEQ recommends following certain guidelines. First, the Virginia is required to list impaired waters on the 303(d) list, as well as their reason for impairment, if known. Next, the waters are prioritized for TMDL development. Once a contractor is selected to develop a TMDL, data collection begins. The purpose of the data collection stage is to increase knowledge of the impairment and to identify the source of the contamination. Data collection is also important to obtain information for the TMDL model. As data collection continues and the TMDL is developed, public meetings are held (a total of 3) in order to alert stakeholders and the public to the process. After the TMDL has been developed, and the third public meeting held, the TMDL is submitted to the EPA for approval. Next, the TMDL is presented to the State Water Control Board (SWCB) for adoption as a regulation, and is incorporated into the appropriate basin-wide Water Quality Management Plan (WQMP). Development of the implementation plan begins with public input and finally, the TMDL is implemented (VA DEQ 2004)

TMDL MODELS

Total Maximum Daily Loads are allocated using computer based models, or representations of the watershed. Many models are available. In order to choose, a series of questions must be asked, such as: what is the geographic extent, what data is available, what additional data is required, cost, what level of accuracy and precision is needed and why? Non point source (NPS) models are used to estimate and determine water quality impacts to water-bodies. NPS models are based on large geographic areas, and may include parameters such as temperature, sediment, nutrients, Biological Oxygen Demand, bacteria, and toxins. There are three types of NPS models: Screening, Simulation, and Distributed Process based models. Screening models do not specify exact concentrations but provide risk potentials. This model is simple and relies on general data. The simulation model includes specific routing and transport mechanisms and can be calibrated to measure concentrations. Simulation models can predict concentrations in various components (such as sources, flows, numbers of animals or septic fields) over time, given specific application rates. This type of model requires detailed data. The distributed process based model uses GIS data to estimate flows and uses site specific data (Oregon DEQ 2004).

TMDL IMPLEMETATION/BEST MANAGEMENT PRACTICES

A TMDL Implementation Plan includes ways to reduce whatever is creating the impairment. Best Management Practices (BMPs) are practices that have been determined to be the most effective and practical ways of preventing or reducing pollution. DCR recommends implementation of such BMPs as fencing to keep livestock out of streams, teaching farmers proper times and ways to apply manure, and teaching homeowners responsible pesticide and nutrient use at home. The BMPs chosen for each impairment will be specific to the cause of the impairment and the area involved (DCR 2004a, 2004b).

**OBJECTIVES**

Each sampling site was monitored once a month for one year. If standard fecal coliform values were exceeded 10% of the time through out the year, the sites impaired status was verified. At the same time, the sources of fecal contamination were also determined. As discussed in the TMDL section, this information and other site and environmental data were used to build a computer model to predict the TMDL value for each impairment. The objectives of this study were to:

1. Verify that each sampling site exceeded state bacterial count standards (using fecal coliform data). Considering that each site is on the State 303(d) list of impaired waterways, it is expected that each site will continue to exceed standards because there is a legitimate fecal pollution problem.
2. Compare the Discriminate Analysis and Logistic Regression statistical models for the classification of unknown isolates.
3. Determine the dominant source of fecal contamination for each sampling site and develop load averages for each tributary in the watershed using one year of measurements.

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