Total Maximum Daily Loads for Streams in the Elk River and Lower Kanawha River Watersheds,

West Virginia

Final USEPA Approved

TECHNICAL REPORT

May 2012

CONTENTS

TABLES

FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

7Q10	7-day, 10-year low flow
AD	acid deposition
AMD	acid mine drainage
AML	abandoned mine land
BEHI	bank erosion hazard index
BMP	best management practice
BOD	biochemical oxygen demand
BPH	Bureau of Public Health
CAIR	Clean Air Interstate Rule
CCC	criterion continuous concentration
CFR	Code of Federal Regulations
CMC	criterion maximum concentration
CSO	combined sewer overflow
CSR	Code of State Rules
DEM	Digital Elevation Model
DO	dissolved oxygen
DWWM	[WVDEP] Division of Water and Waste Management
EPT	Ephemeroptera, Plecoptera and Trichoptera
ERIS	Environmental Resources Information System
GIS	geographic information system
HSPF	Hydrologic Simulation Program - FORTRAN
LA	load allocation
LSPC	Loading Simulation Program – C++
MDAS	Mining Data Analysis System
MOS	margin of safety
MRPP	multiple responses of permutation procedures
MS4	municipal separate storm sewer system
MSTLAY	Moisture Storage and Transport in Soil Layers MDAS module
NADP	National Atmospheric Deposition Program
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NMDS	nonmetric multi-dimensional scaling
NOAA-NCDC	National Oceanic and Atmospheric Administration, National Climatic Data Center
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OOG	Office of Oil and Gas
OSR	WVDEP Office of Special Reclamation
POTW	publicly owned treatment works
RBP	rapid bioassessment protocol
SI	stressor identification
SMCRA	Surface Mining Control and Reclamation Act

STATSGO	State Soil Geographic database
TMDL	total maximum daily load
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WA	weighted averaging
WAB	Watershed Assessment Branch
WLA	wasteload allocation
WVDEP	West Virginia Department of Environmental Protection
WVDMR	[WVDEP] Division of Mining and Reclamation
WVSCI	West Virginia Stream Condition Index
WVU	West Virginia University

1.0 INTRODUCTION

1.1. Impairment Applicability

This technical report describes the pollutant sources and impairments of selected streams in Elk River and Lower Kanawha River watersheds for which total maximum daily loads (TMDLs) have been completed during the 2010 time period. A stream-by-stream listing of impairments covered by the scope of this TMDL effort is included in **Appendix A**.

The purpose of this document is to describe how TMDLs are developed and the step-by-step processes involved. A TMDL is the allowable amount of various pollutants, or load, which can be discharged into a stream while still maintaining an acceptable level of water quality for current and future human use and natural environmental functions.

Establishing the relationship between the instream water quality targets and source loads is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated computer modeling techniques. Ideally, the linkage is supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions. The sections that follow present the approaches taken to develop the linkage between sources and instream responses for TMDL development in the Elk River and Lower Kanawha River watersheds in West Virginia.

1.2. Water Quality Standards

According to Title 40 of the *Code of Federal Regulations* (CFR) Part 130, TMDLs must be designed to implement applicable water quality standards. The applicable water quality standards for metals, pH, dissolved oxygen, and fecal coliform bacteria in West Virginia are presented in **Table 1-1**.

Table 1-1. Applicable West Virginia water quality criteria

POLLUTANT	USE DESIGNATION				
	Aquatic Life				Human Health
	Warmwater Fisheries		Troutwaters		Contact Recreation/Public Water Supply
	Acute[a]	Chronic[b]	Acute[a]	Chronic[b]	
Aluminum, dissolved (µg/L)	750	750	750	87	--
Iron, total (mg/L)	--	1.5	--	1.0	1.5
Selenium, total (µg/L)	20	5	20	5	50

POLLUTANT	USE DESIGNATION				
	Aquatic Life				Human Health
	Warmwater Fisheries		Troutwaters		Contact Recreation/Public Water Supply
	Acute[a]	Chronic[b]	Acute[a]	Chronic[b]	
pH	No values below 6.0 or above 9.0	No values below 6.0 or above 9.0	No values below 6.0 or above 9.0	No values below 6.0 or above 9.0	No values below 6.0 or above 9.0
Dissolved oxygen	Not less than 5 mg/L at any time	Not less than 5 mg/L at any time	Not less than 6 mg/L at any time	Not less than 6 mg/L at any time	Not less than 5 mg/L at any time
Fecal coliform bacteria	**Human Health Criteria** Maximum allowable level of fecal coliform content for Primary Contact Recreation (either MPN [most probable number] or MF [membrane filter counts/test]) shall not exceed 200/100 mL as a monthly geometric mean based on not less than 5 samples per month; nor to exceed 400/100 mL in more than 10 percent of all samples taken during the month.				

[a] One-hour average concentration not to be exceeded more than once every 3 years on the average.

[b] Four-day average concentration not to be exceeded more than once every 3 years on the average.

Source: 47 CSR, Series 2, *Legislative Rules, Department of Environmental Protection: Requirements Governing Water Quality Standards*.

Numeric aquatic life water quality criteria for aluminum, iron, and selenium, such as those applicable here, require the evaluation of magnitude, frequency, and duration associated with the parameters of concern. Magnitude refers to the value of the criterion maximum concentration (CMC) to protect against short-term (acute) effects, or the value of the criterion continuous concentration (CCC) to protect against long-term (chronic) effects. Frequency indicates the number of water quality criteria exceedances allowed over a specified time period. West Virginia's water quality standards allow one exceedance of the aquatic life criteria every three years on average. Duration measures the period of exposure to instream pollutant concentrations. For CMC criteria, exposure is measured over a one-hour period; for CCC criteria, it is measured over a four-day period. In addition to these considerations, any technical approach must consider the form in which the numeric aquatic life criteria are expressed. For example, West Virginia's aquatic life criteria for iron are expressed in the total recoverable metal form, and the criteria for aluminum are expressed in the dissolved form.

Criteria for total fecal coliform bacteria are prescribed for the protection of the water contact recreation and public water supply human health uses. These criteria are presented as a geometric mean concentration, using a minimum of five consecutive samples over a 30-day period, and a maximum daily concentration that is not to be exceeded in more than 10 percent of all samples taken in a month.

The pH and dissolved aluminum impairments are related and are attributable to two separate nonpoint source categories. In certain watersheds with low buffering capacity, acidic precipitation decreases pH below the pH criterion. Decreased pH may in turn increase the portion of aluminum in solution and result in exceedances of the dissolved aluminum criterion. Dissolved aluminum and pH impairments have also been attributed to acidity and aluminum loading from abandoned mine land (AML) sources. The pH impairments with AML influences coincide with overlapping metals impairments. The TMDLs for pH impairments were developed using an approach where instream metals (iron and aluminum) concentrations were reduced for attainment of iron and aluminum water quality criteria, coupled with direct pollutant reductions to offset acid load from atmospheric deposition.

Because of the presence of selenium in coal and overburden and the prevalence of mining activity in proximity to observed exceedances of the selenium water quality criterion, the disturbances associated with the existing mining operations are assumed to be the cause of the selenium impairment. Nonpoint sources associated with surface disturbances (i.e., barren areas, unpaved roads, harvested forest, and oil and gas well operations) were considered to be negligible sources of selenium because these land disturbances typically do not disturb subsurface strata that contain selenium. Selenium TMDLs contain wasteload allocations (WLAs) for active mining sources located in the watersheds of selenium impaired streams.

The dissolved oxygen impairment of Little Five Mile Creek (WV-KL-7-A) is directly related to an animal confinement/feeding operation located within 50 meters of a stream monitoring location (KL-00083-0.8). The Little Five Mile Creek fecal coliform TMDL developed by WVDEP is an appropriate surrogate for the dissolved oxygen impairment for this stream.

All West Virginia waters are subject to narrative criteria that prohibit the presence of wastes in state waters that cause or contribute to significant adverse impacts to the chemical, physical, hydrologic, and biological components of aquatic ecosystems. This provision is the basis for “biological impairment” determinations. Biological impairment signifies a stressed aquatic community, and is discussed in detail in **Section 2.0**.

West Virginia’s water quality criteria are applicable at all stream flows greater than the 7-day, 10-year low (7Q10) flow. The approach or modeling technique for TMDL development must permit the representation of instream concentrations under a variety of flow conditions to evaluate critical flow periods for comparison with chronic and acute criteria. Both high-flow and low-flow periods were taken into account during TMDL development by using a long period of weather data that represented wet, dry, and average flow periods.

1.3. Physical Considerations in Developing the TMDL Approach

The TMDL development approach must also consider the dominant processes that affect pollutant loading and instream fate. The primary sources contributing to metals, pH, sediment and fecal coliform impairments include an array of point and nonpoint sources. Loading processes for nonpoint sources or land-based activities are typically rainfall-driven and thus relate to surface runoff and subsurface discharge to a stream. Permitted discharges might or might not be induced by rainfall, but they are represented by a known flow and concentration described in the permit limits.

Key instream factors that could be considered during TMDL development include routing of flow, dilution, transport of total metals, sediment adsorption/desorption, and precipitation of metals. The primary physical driving process is the transport of total metals by diffusion and advection in the flow. In addition, the chemical process of instream species transformation governs pH and the transport of dissolved aluminum. A significant instream process affecting the transport of fecal coliform bacteria is fecal coliform die-off.

Scale of analysis and waterbody type must also be considered when selecting the overall modeling approach. The approach should be able to evaluate watersheds of various sizes. The listed waters range from small headwater streams to large tributaries. Selection of scale should be sensitive to locations of key features, such as abandoned mines and point source discharges. At the larger watershed scale, land areas are aggregated into subwatersheds for practical representation of the system, commensurate with the available data. Occasionally, there are site-specific and localized acute problems that might require more detailed segmentation or definition of detailed modeling grids.

On the basis of the considerations described above, analysis of the monitoring data, review of the literature, and past pH, metals, sediment, and fecal coliform bacteria modeling experience, the Mining Data Analysis System (MDAS) was chosen to represent the source-response linkage for aluminum, iron, sediment, and fecal coliform bacteria. The MDAS is a comprehensive data management and modeling system that is capable of representing loading from the nonpoint and point sources and simulating instream processes. Acidic pH impairments were addressed in two ways. For streams with overlapping pH and metals impairments (where the impairments are primarily caused by historical mining sources), the TMDLs for pH impairments were developed using a surrogate approach where it was assumed that reducing instream metal (iron and aluminum) concentrations allows for attainment of pH water quality criteria. This assumption was then verified by applying the MDAS model. Stand-alone pH impairments (where the impairment results from acid precipitation and low watershed buffering capacity) were addressed by the Acid Deposition (AD) model within the MDAS. The AD model is composed of six modules: (1) the nitrogen soil transformation module, (2) the nitrogen stream module, (3) the sulfate adsorption/desorption module, (4) the sulfate stream module, (5) the soil chemical reaction module, and (6) the aqueous (stream) chemical reaction module. With the addition of acid deposition and reactive transport module, the MDAS has the capability of accurately simulating the pH of streams impaired by a combination of atmospheric deposition and acid mine drainage.

2.0 BIOLOGICAL TMDL DEVELOPMENT

One of the steps in developing a TMDL is analyzing the existing quantitative and qualitative water quality data available for the watersheds being considered for TMDL development. This analysis is conducted during the stressor identification (SI) process. All of the data are compiled, reviewed, and synthesized into summary tables. A collaborative effort is then conducted to review the data to determine the most likely stressors to the macroinvertebrate community in biologically impaired streams. The SI approach is discussed in further detail in the sections that follow.

The narrative water quality criterion of Title 47 of the *Code of State Rules* (CSR) 2 - 3.2.i. prohibits the presence of wastes in state waters that cause or contribute to a significant adverse impact on the chemical, physical, hydrologic, and biological components of aquatic ecosystems. Human activities such as mining, logging, agriculture, and residential development have caused significant biological degradation in West Virginia streams. West Virginia Department of Environmental Protection (WVDEP), through its benthic macroinvertebrate monitoring program, has identified streams across the state that do not meet the aquatic life use designations and are, therefore, considered *biologically impaired*. Support of the aquatic life designated use is determined based on established biomonitoring practices that evaluate the condition of the benthic macroinvertebrate community. Benthic macroinvertebrate communities are rated using a multimetric index developed for use in the wadeable streams of West Virginia. The West Virginia Stream Condition Index (WVSCI) is composed of six metrics that were selected to maximize discrimination between streams with known impairments and reference streams.

The biomonitoring data collected by WVDEP resulted in a total of 88 biological impairment designations, 44 in the Elk River, and 44 in the Lower Kanawha River. TMDL development requires that the causes of impairment, or stressors, to the biological community be identified so that pollutants can be controlled in each watershed.

2.1 Stressor Identification Overview

Biological assessments are useful in detecting impairment, but they do not necessarily identify the cause (or causes) of impairment. USEPA developed *Stressor Identification: Technical Guidance Document* to assist water resource managers in identifying stressors or combinations of stressors that cause biological impairment (Cormier, Sutter, & Norton, 2000). Elements of the SI process were used to evaluate and identify the primary stressors of the benthic community in the biologically impaired streams.

SI is a formal and rigorous method that identifies stressors causing biological impairment and provides a structure for organizing the scientific evidence supporting the conclusions. Accurately identifying stressors and examining the evidence supporting those findings are critical steps in developing TMDLs for biologically impaired waterbodies. The general SI process entails critically reviewing available information, forming possible stressor scenarios that might explain the impairment, analyzing those scenarios, and reaching conclusions about which stressor or stressors are causing the impairment. The process is iterative, usually beginning with a retrospective analysis of available data. The accuracy of the identification depends on the quality of data and other information used in the SI process. In some cases, additional data collection might be necessary to accurately identify the stressor(s). The conclusions determine those pollutants for which TMDLs are required for each of the biologically impaired streams. As a result, the TMDL process establishes a link between the impairment and benthic community stressors.

Figure 2-1 provides an overview of the SI process, which consists of three main steps. The first step is to develop a list of candidate causes, or stressors, which will be evaluated. This is accomplished by carefully describing the effect that is prompting the analysis and gathering available information on the situation and potential causes. Evidence might come from the case at hand, other similar situations, or knowledge of biological processes or mechanisms. The output of this initial step is a list of candidate causes and a conceptual model that shows cause-and-effect relationships.

The second step, analyzing evidence, involves analyzing the information related to each of the potential causes. All information known about the impaired waterbody is potentially useful in this step. The third step, evaluation of data, consists of analyzing the information in an organized approach to characterize the candidate causes. All available data are used to eliminate, to diagnose, and to compare the strength of evidence in order to identify the significant causes of biological impairment.

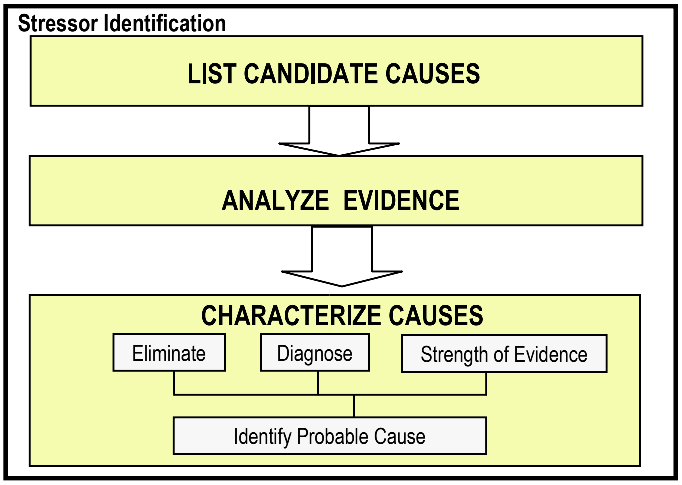


Figure 2-1. Stressor identification process

2.1.1. Linking Stressors to Sources in the Watershed

TMDLs were developed for the stressors (pollutants) identified through the SI process. Point and nonpoint sources of the significant stressors in each impaired watershed were identified and assessed during TMDL development. The relationship of the pollutant sources to instream water quality and biological condition was used as the basis of model development.

Source assessment needs depend on the pollutants identified in the SI process for each biologically impaired stream. In some cases, a single stressor is primarily responsible for the noted biological impacts. In other cases, multiple stressors and cumulative impacts might be responsible for the impaired condition. A variety of information was used to characterize pollutant sources in impaired watersheds, including landuse information, mining coverages and discharge data, water quality and biomonitoring data, non-mining point source data, TMDL source tracking information, literature sources, and other available data.

2.1.2. Technical Approach

Biological communities respond to any number of environmental stressors, including physical impacts and changes in water and sediment chemistry. TMDL development for biologically impaired streams was based on the stressors (pollutants) identified through the SI process. The primary sources of data used in SI were water quality, biomonitoring, habitat, and other information contained in the WVDEP Watershed Assessment Branch (WAB) database; TMDL and source tracking data; WVDEP mining activities data; National Land Cover Dataset (NLCD 2001) landuse information; National Resource Conservation Service State Soil Geographic

Database (NRCS STATSGO; NRCS, 1994) soils data; National Pollutant Discharge Elimination System (NPDES) point source data; literature sources; and past TMDL studies.

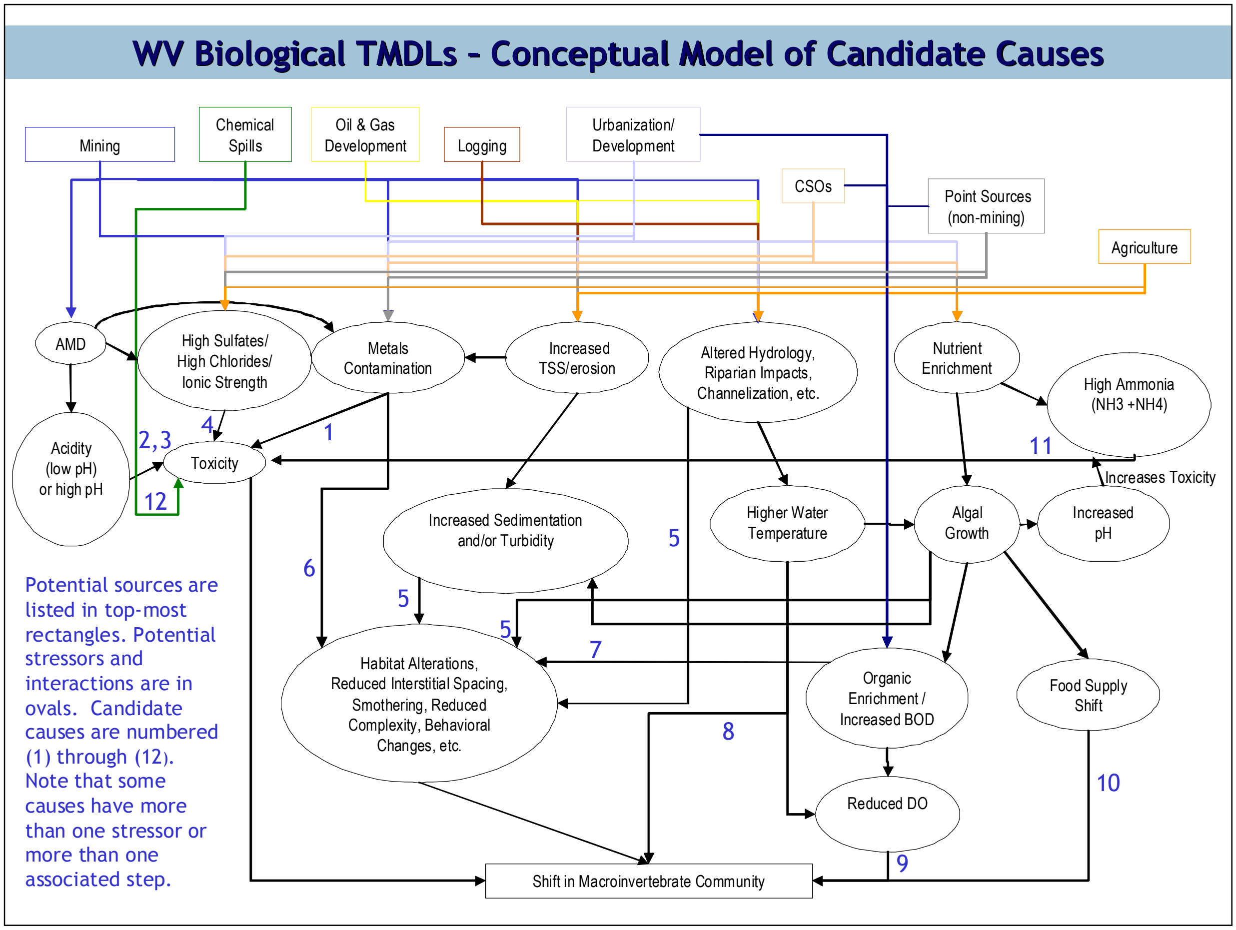
WVDEP collects and interprets water quality and biological information within the state's 32 watersheds on a five-year rotation. Within the context of the WAB, streams in the Group B TMDL watersheds were sampled in 2002 and 2007. WVDEP collected additional water quality and biological data within the past few years to support TMDL development for impaired streams in the watersheds. WVDEP staff also conducted site visits to all impaired streams in recent months to identify pollutant sources in these watersheds not previously known and to collect additional data needed for SI and TMDL model setup. The water quality and biological data analyses presented in this document are based on all of the data collected by WVDEP in the impaired watersheds to date.

2.1.3. Biologically Impaired Streams

The biologically impaired streams and the pollutants for which they are listed are presented in **Appendix A**.

2.1.4. Development of the Conceptual Model

The first step in the SI process was to develop the list of candidate causes, or stressors. Potential causes were evaluated based on an assessment of watershed characteristics and the likely causes and sources of biological impairment. To analyze the relationship between candidate causes of impairment and potential biological effects, a conceptual model was developed. The conceptual model (**Figure 2-2**) graphically presents the process by which each candidate cause affects the biological community, including any pertinent intermediate steps. This model was based on discussions with WVDEP staff, initial data analyses, knowledge of these watersheds, and experience in defining impairment causes in similar watersheds. Sources, impairment causes, and the resulting effects on the biological community depend on the stream or watershed in question. In some cases, biological impairment can be linked to a single stressor; in other situations, multiple stressors might be responsible for the listed impairment. This conceptual model presents all potential causes that might be present in the watershed and their sources.



Potential sources are listed in top-most rectangles. Potential stressors and interactions are in ovals. Candidate causes are numbered (1) through (12). Note that some causes have more than one stressor or more than one associated step.

Figure 2-2. Overall conceptual model of candidate causes

The candidate causes depicted in the conceptual model (**Figure 2-2**) are summarized below:

1. Metals contamination (including metals contributed through soil erosion) causes toxicity
    - Dissolved Aluminum
    - Total Iron
2. Acidity (low pH) causes toxicity
3. High pH (pH>9) causes toxicity
4. High sulfates, high chlorides, and increased ionic strength causes toxicity
5. Increased total suspended solids (TSS)/erosion, altered hydrology (etc.), and algal growth causes sedimentation and other habitat alterations
6. Increased metals flocculation (aluminum and iron) and deposition causes habitat alterations (e.g., embeddedness)
7. Organic enrichment (e.g. sewage discharges, agricultural runoff) causes habitat alterations
8. Altered hydrology (etc.) causes higher water temperature resulting in direct impacts

9. Altered hydrology, nutrient enrichment, and increased biological oxygen demand (BOD) cause reduced dissolved oxygen (DO)
10. Algal growth causes food supply shift
11. High ammonia causes toxicity (including increased toxicity due to algal growth)
12. Chemical spills cause toxicity

2.1.5. Data Analysis

The second step in the SI process was to evaluate the information related to each of the candidate causes. Water quality parameters, habitat data, source tracking data, and other quantitative and qualitative data were grouped under each respective candidate cause for analysis. In some cases, a variety of information was used to evaluate a particular candidate cause (e.g., sedimentation). The evidence presented was used to determine support or non-support of the listed candidate cause. At the conclusion of this process, one or more stressors (pollutants) were identified as the likely cause(s) of impairment for each of the biologically impaired streams.

Water quality data, habitat information, and other non-biological data were evaluated using established water quality standards and threshold values that had been developed on the basis of a statistical analysis of stressor-response patterns using reference stream data. Stressor-response relationships were evaluated using statewide data from impaired and reference streams. These data were then partitioned by ecoregion to determine whether regional patterns varied from the results of the statewide analysis. West Virginia's water quality criteria for metals were also evaluated using this statistical framework to determine whether these criteria were protective of aquatic life uses.

SI involved comparing all of the data collected for each impaired stream and upstream tributaries with the threshold levels specified in **Table 2-1**. Two sets of threshold values: elimination and strength of evidence were designated for most parameters. Elimination threshold values represent "not to exceed" levels for water quality and habitat variables. Stream data were first compared with the elimination thresholds to determine whether additional analyses were necessary to evaluate a particular candidate cause (stressor). Each potential stressor was further evaluated using a strength-of-evidence approach if the elimination threshold was exceeded, related parameters or other information showed conflicting results, or there were limited data available.

Biological data were also used to determine water quality and habitat-related stressor thresholds. Abundance of indicator taxa, typically ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies) [EPT] organisms, were plotted against potentially influential variables to macroinvertebrate communities. This water quality and physiochemical data, collected concurrently, was used to interpolate relationships, or thresholds, to the benthic assemblage. Five linear, best-fit lines were applied to each plot, corresponding to the strength categories of potential stressors. In certain instances, other biological information was examined for relationships with stressors. For example, dipterans (true flies) were used to elucidate benthic relationships in waters heavily enriched by nutrients. Many pollutants have a direct and negative impact on macroinvertebrate presence/abundance; however, some stressors act by more complex means on the biota. Subsidy of abundance in specific invertebrate populations is typical of certain stressors; consequently, both the population's abundance and corresponding information regarding the potential stressor were closely considered. Finally, threshold values for some potential stressors were determined via abundance scatter plots versus more qualitative information. Evaluations of pre-TMDL monitoring information on algal density are one such example.

Table 2-1. Stressor identification analysis thresholds

Candidate Cause	Parameter	Elimination (Rule out stressors at these thresholds)	Strength of Evidence (Evidence for each Candidate Cause as stressor)
		Elimination Threshold	Candidate Stressor Thresholds
1. Metals toxicity	Al (dissolved)	<0.089 mg/L	>0.442 mg/L Definite Stressor 0.307 - 0.4419 Likely stressor 0.227 - 0.3069 Possible stressor 0.182 - 0.2269 Weak stressor 0.09 - 0.1819 Equivocal or No Trend
	Fe (total)		Fe toxicity to benthic invertebrates is not well established.
	Mn (total)		Mn toxicity to benthic invertebrates is not well established.
2. Acidity	pH	>6.3	<4.29 Definite Stressor 4.99-4.3 Likely stressor 5.29-5.0 Possible stressor 5.59-5.3 Weak stressor 6.29-6.0 Equivocal or No Trend
3. High pH	pH	< 8.39	>9.1 Definite Stressor 8.9-9.09 Likely stressor 8.8-8.89 Possible stressor 8.7-8.79 Weak stressor 8.4-8.69 Equivocal or No Trend
4. Ionic strength	Conductivity	< 326.9 umhos	Consider as independent stressor in non-acidic, non-AMD streams, when conductivity values met threshold ranges and sulfates and chloride violate conditions listed as follows. >1533 Definite Stressor 1075-1532.9 Likely stressor 767-1074.9 Possible stressor 517-766.9 Weak stressor 327-516.9 Equivocal or No Trend
	Sulfates	< 56.9 mg/l	>417 Definite Stressor 290-416.9 Likely stressor 202-289.9 Possible stressor 120-201.9 Weak stressor 57-119.9 Equivocal or No Trend
	Chloride	< 60 mg/l	>230.0 Definite Stressor 160.1-229.9 Likely stressor 125.1-160 Possible stressor 80.1-125.0 Weak stressor 60.1-80.0 Equivocal or No Trend
5. Sedimentation	TSS	Max < 10 mg/l	Not included as a stressor parameter at this time
	Fe (total) Iron Flocculation or precipitate	<0.49 mg/l	>1.867 Definite Stressor 1.367 - 1.8669 Likely stressor 1.017 - 1.3669 Possible stressor 0.767 - 1.0169 Weak stressor 0.5 - 0.7669 Equivocal or No Trend

Candidate Cause	Parameter	Elimination (Rule out stressors at these thresholds)	Strength of Evidence (Evidence for each Candidate Cause as stressor)
		Elimination Threshold	Candidate Stressor Thresholds
	% Fines (sand + silt + clay)	≤ 9.99%	>50 Definite Stressor 40-49.9 Likely stressor 30-39.9 Possible stressor 20-29.9 Weak stressor 10-19.9 Equivocal or No Trend
	RBP: Embeddedness RBP: Sediment Deposition	16.0 - 20.0 (optimal)	Evaluate based on RBP qualitative categories: 0-2.9 (poor) Definite Stressor 3.0-5.9 (poor) Likely stressor 6.0-8.9 (marginal) Possible stressor 9.0-10.9 (marginal) Weak stressor 11.0-15.9 (sub-optimal) Equivocal or No Trend
	RBP: Total (adjusted to post-1998 RBP)	≥110.1	Max <120 and n>2, or Median <120. <65 Definite Stressor 65.1-75 Likely stressor 75.1-85 Possible stressor 85.1-100 Weak stressor 100.1-110 Equivocal or No Trend
	Sediment Profile Index	90-100 SQ points = not limiting	<49.9 SQ points = severely limiting 50-59.9 SQ points = limiting 60-69.9 SQ points = likely limiting 70-79.9 SQ points = possibly limiting 80-89.9 SQ points = not likely limiting
	Sedimentation evaluation:		Professional judgment applied to combination of TSS, %Fines, and RBP embeddedness, sediment deposition, and total scores; supplemented with information from sources listed below this table (field notes and source tracking observations).
Other habitat	RBP: Cover RBP: Riparian Vegetation	16.0 - 20.0 (optimal)	No stressor-response detectable. Evaluate based on RBP qualitative categories: 0-2.9 (poor) Definite Stressor 3.0-5.9 (poor) Likely stressor 6.0-8.9 (marginal) Possible stressor 9.0-10.9 (marginal) Weak stressor 11.0-15.9 (sub-optimal) Equivocal or No Trend
6. Metals flocculation (habitat alteration)	Metal flocculation	No observations noted	Qualitative supplemental evidence (field notes and observations).
	Embeddedness due to metals flocculation	16.0 - 20.0 (optimal)	Evaluate based on RBP qualitative categories: 0-2.9 (poor) Definite Stressor 3.0-5.9 (poor) Likely stressor 6.0-8.9 (marginal) Possible stressor 9.0-10.9 (marginal) Weak stressor 11.0-15.9 (sub-optimal) Equivocal or No Trend
7. Organic enrichment	DO	>7.0 mg/L	<3.19 Definite Stressor 4.39-3.2 Likely stressor 5.39-4.4 Possible stressor 6.29-5.4 Weak stressor 6.99-6.3 Equivocal or No Trend
	Periphyton, Filamentous Algae	0.0-0.99	Qualitative ranking evaluations of indicator parameters (at left), supplemented by field notes and observations. 3.5-4.0 Definite Stressor 3.0-3.49 Likely stressor 2.5-2.99 Possible stressor 2.0-2.49 Weak stressor 1.0-1.99 Equivocal or No Trend

Candidate Cause	**Parameter**	**Elimination (Rule out stressors at these thresholds)**	**Strength of Evidence (Evidence for each Candidate Cause as stressor)**
		Elimination Threshold	**Candidate Stressor Thresholds**
	Fecal coliform	<150 counts/100 mL	>2300.1 Definite Stressor 1900.1-2300 Likely stressor 1400.1-1900 Possible stressor 400.1-1400 Weak stressor 150.1-400 Equivocal or No Trend
8. Temperature (direct)	Temperature	<25.69 C	Max >30.6 C May through November; or Max >22.8 C December through April. >30.6 Definite Stressor 28.9-30.59 Likely stressor 27.7-28.89 Possible stressor 26.7-27.69 Weak stressor 25.7-26.69 Equivocal or No Trend
9. Reduced DO/ high BOD/ nutrient enrichment	DO	≥ 7.0 mg/l	<3.19 Definite Stressor 4.39-3.2 Likely stressor 5.39-4.4 Possible stressor 6.29-5.4 Weak stressor 6.99-6.3 Equivocal or No Trend
	NO_3		Little data available; apply professional judgment to available nutrient data; supplement with indirect evidence from algae and/or fecal observations.
	NO_2 NO_3	<0.6829	>2.65 Definite Stressor 2.083-2.649 Likely stressor 1.55-2.0829 Possible stressor 0.983-1.549 Weak stressor 0.683-0.9829 Equivocal or No Trend
	Total Nitrogen	<2.1169 mg/L	>5.0 Definite Stressor 4.033-4.9 Likely stressor 3.367-4.0329 Possible stressor 2.733-3.3669 Weak stressor 2.117-2.7329 Equivocal or No Trend
	Total Phosphorus	<0.1319 mg/l	>0.51 Definite Stressor 0.37-0.509 Likely stressor 0.283-0.369 Possible stressor 0.193-0.2829 Weak stressor 0.132-0.1929 Equivocal or No Trend
10. Algae/ Food Supply Shift	Periphyton, Filamentous Algae	0.0-0.99	Little data available; based on field indicator notes such as “moderate” or “high” qualitative algae and periphyton observations. 3.5-4.0 Definite Stressor 3.0-3.49 Likely stressor 2.5-2.99 Possible stressor 2.0-2.49 Weak stressor 1.0-1.99 Equivocal or No Trend
11. Ammonia	NH_3	<0.99	Little data available; apply professional judgment to available ammonia data, indirect evidence from algae and/or pH observations, and/or point source monitoring data. >1.65 Definite Stressor 1.35-1.649 Likely stressor 1.2-1.349 Possible stressor 1.1-1.19 Weak stressor 1.0-1.09 Equivocal or No Trend
12. Chemical spills	Various chemical parameters		Qualitative supplemental information (field notes and other sources listed below this table).

Candidate Cause	Parameter	Elimination (Rule out stressors at these thresholds)	Strength of Evidence (Evidence for each Candidate Cause as stressor)
		Elimination Threshold	**Candidate Stressor Thresholds**

Notes:
1. Elimination: Screening step to rule out particular stressors, based on unambiguous criteria.
2. Strength of evidence: Data that provide evidence for identification of each particular candidate cause as a biological stressor. To be supplemented with evidence from additional information sources listed below the table.
3. (d) = dissolved; (+) = total; RBP = Rapid Bioassessment Protocol.

[a] Supplemental evidence to evaluate each candidate stressor:
Biological stressor-response gradients (Tetra Tech, Inc., analyses developed through statewide data set correlation analysis of metric responses in site classes and in subwatersheds)
Source tracking reports
Database summary Text/Note/Comment fields
Point source monitoring data (e.g., anhydrous ammonia, BOD, nutrients)
Benthic sampling taxa review

Water quality and other quantitative data were plotted and analyzed spatially using a "geo-order" scheme of assigning relative positions to sampling locations from downstream to upstream for each impaired stream and its tributaries within a watershed. An example of the "geo-order" station numbering convention is presented in **Figure 2-3**. Scatterplots of the data can then be produced for each numeric parameter to spatially represent all data collected in the watershed.

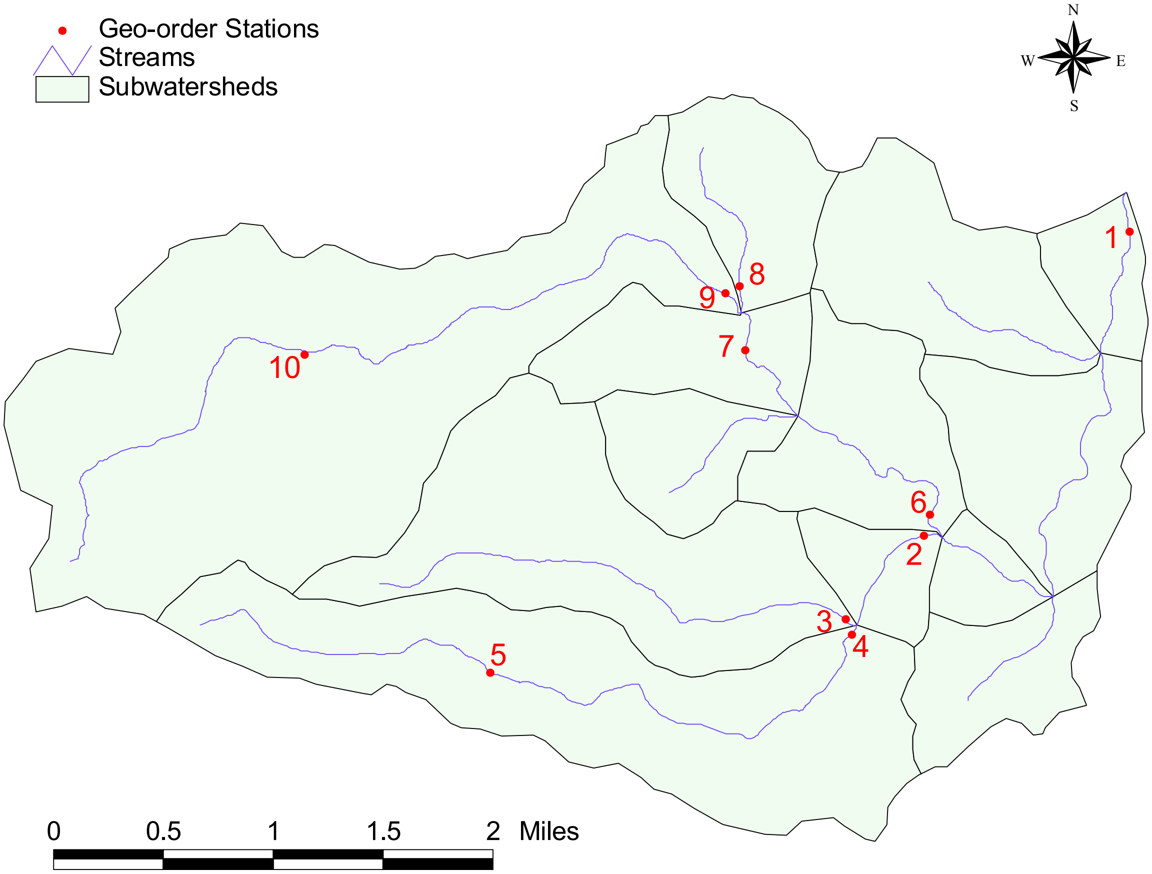


Figure 2-3. Example geo-order stations and naming convention

A summary of the data available for use in evaluating each candidate cause is presented in **Table 2-2**. All available data related to each candidate cause (including field notes from pre-TMDL monitoring and source tracking) were organized and compiled into summary tables to determine the primary stressor(s) responsible for each biological impairment. In some cases, several stressors were identified in the analysis.

Table 2-2. Available data for the evaluation of candidate causes

Candidate Cause	Summary of Available Evidence and Results
1. Metals toxicity 2. Acidity 3. High pH 4. Ionic strength 5. Sedimentation and habitat 6. Metals flocculation 7. Organic enrichment	Available evidence: water quality sampling data, source tracking reports and field observation notes, invertebrate community data. Results variable by stream; summaries to be presented by stream; evaluations based on strength of evidence.
8. Temperature 9. Oxygen deficit	No violations of standards in most streams: eliminate as cause (exceptions to be presented).
10. Algae/food supply shift 11. Ammonia toxicity 12. Chemical spills	Little data available; professional judgment applied to indirect evidence; not identified as stressors in most streams.

The SI process identified metals toxicity and pH toxicity as biological stressors in waters that also demonstrated violations of the iron, aluminum, and pH water quality criteria for protection of aquatic life. WVDEP determined that implementation of those pollutant-specific TMDLs would address the biological impairment.

There are 67 streams that were identified as impaired by sedimentation. Each of those streams is also impaired pursuant to the total iron criterion for aquatic life protection and WVDEP determined that implementation of the iron TMDLs would require sediment reductions sufficient to resolve the biological impairment. Additional information regarding the iron surrogate approach is provided in **Section 6.0**. Also, the analytical results and statistical information regarding the correlation of iron and TSS are displayed in **Appendix B**.

Where organic enrichment was identified as the biological stressor, the waters also demonstrated violations of the numeric criteria for fecal coliform bacteria. Detailed evaluation of field notes indicated that the predominant source of fecal coliform bacteria in the watershed was inadequately treated sewage. Key taxa groups known to thrive in organic sediments, such as those from untreated sewage, were also identified at biomonitoring sites on these streams. Furthermore, pasture areas were considered sources of organic enrichment in biologically impaired watersheds. This assumption was verified by using site-specific source tracking information. Based on the information presented above, WVDEP determined that implementation of fecal coliform TMDLs requiring reductions to pasture lands and the elimination of sources that discharge untreated sewage would remove untreated sewage and thereby reduce the organic and nutrient loading causing the biological impairment. Therefore, fecal coliform TMDLs serve as a surrogate where organic enrichment was identified as a stressor.

In certain waters, the SI process determined ionic toxicity to be a significant stressor (**Table 2-3**). A strong presence of sulfates and other dissolved solids exists in those waters and in all other streams where ionic toxicity has been determined to be a significant biological stressor. During the TMDL development period, there was insufficient information available regarding the causative pollutants and their associated impairment thresholds for biological TMDL development for ionic toxicity. WVDEP is deferring biological TMDL development for ionic toxicity stressed streams and retaining those waters on the Section 303(d) list. WVDEP and USEPA Region III have agreed upon a plan to develop these biological impairment TMDLs by 2014.

Table 2-3. Biologically impaired streams for which ionic toxicity was identified as a stressor

Watershed	TMDL Watershed	Stream Name	24K-Code
Elk	Leatherwood Creek	Leatherwood Creek	WV-KE-83
Elk	Leatherwood Creek	Right Fork/ Leatherwood Creek	WV-KE-83-H
Elk	Leatherwood Creek	Road Fork	WV-KE-83-N
Elk	Buffalo Creek	Big Branch	WV-KE-89-C-8
Elk	Birch River	Birch River	WV-KE-131
Elk	Birch River	Jacks Run	WV-KE-131-BH
Lower Kanawha	Joplin Branch	Joplin Branch	WV-KL-77

2.1.6. Empirical Model Development to Identify Multiple Stressors

Diagnosing the causes of impairment is essential to the development of environmental regulations and the ability of water resource managers to restore aquatic ecosystems. Ideally, based on the biological information found in a stream and the relationships between organisms and environmental variables, aquatic ecologists can predict environmental variables, as well as diagnose stressors that impair water quality (Cairns & Pratt, 1993). Diagnostic tools can be developed using two approaches: bottom-up, which is based on individual taxa responses, and top-down, which evaluates a biological community’s response to specific stressors.

To help identify nonpoint sources of pollution and diagnose environmental stressors, thousands of biological and chemical samples were collected and analyzed by WVDEP throughout West Virginia. Because of the large sample size of the dataset, data partitioning was implemented to examine the macroinvertebrate community response to single stressors. Four types of environmental stressors that have been shown to negatively impact species composition were identified: conductivity/sulfate, habitat/sediment, acidic/nonacidic metals, and organic/nutrient enrichment.

The bottom-up approach used weighted averaging (WA) regression models to develop indicators of environmental stressors based on the taxonomic response to each stressor. WA regression is a statistical procedure used to estimate the optimal environmental conditions of occurrence for an individual taxon (ter Braak & Barendregt, 1986; ter Braak & Looman, 1986). Tolerance values and breadth of disturbance (indicator values) were determined for individual taxa groups based on available literature and professional judgment. WA models were then calibrated and used to predict the environmental variables for each site based on the indicator values and abundance of taxa at each site. The predictive power of WA inference models was measured by calculating coefficients of determination (R^2) between invertebrate taxa-inferred and observed values for environmental variables of interest. Eight WA models were developed and tested using four groups of candidate stressors based on generic macroinvertebrate abundance. The strongest predictive models were for acidic metals (dissolved Al) (R^2=0.76) and conductivity (R^2=0.54). Benthic macroinvertebrates also responded to environmental variables: habitat, sediment, sulfate, and fecal coliform with good predictive power (R^2 ranged from 0.38-0.41). Macroinvertebrate taxa had weaker responses and predictive power to total phosphorus (R^2=0.25) and non-acidic Al models (R^2=0.29).

The top-down approach was based on the hypothesis that exposure to various stressors leads to specific changes in macroinvertebrate assemblages and taxonomic composition. A “dirty reference” approach was used to define groups of sites affected by a single stressor. Four “dirty” reference groups were identified and consisted of sites that are primarily affected by one of the following single stressor categories: dissolved metals (Al and Fe); excessive sedimentation; high nutrients and organic enrichment; or increased ionic strength (using sulfate concentration as a surrogate). In addition, a “clean” reference group of sites with low levels of stress was identified. Nonmetric multi-dimensional scaling (NMDS) and multiple responses of permutation procedures (MRPP) were used to examine the separation of the “dirty” reference groups from each other and from the “clean” reference group. The results indicated that the centroids of the “dirty” reference groups were significantly different from the “clean” reference group (p=0.000). Of the “dirty” reference groups, the dissolved metals group was significantly different from the other three “dirty” reference groups (p=0.000). The other three “dirty” reference groups, though overlapping in ordination space to some extent, were also different from each other ($p<0.05$). Overall, each of the five “dirty reference” models was significantly different from one another (p=0.000), indicating that differences among stressors may have led to different macroinvertebrate assemblages. Thus, independent biological samples known to be impaired by a single stressor were used to test the effectiveness of these diagnostic models. The Bray-Curtis similarity index was used to measure the similarity of test sites to each of the reference groups, and multiple stressors were then ranked according to the measured similarity to each reference group. The relative similarity and the variation explained by each model were taken into account in the final ranking of the predicted stressors for each impaired site. The majority of the test results indicated that the model results agreed with the stressor conclusions based on the physical and chemical data collected at each site. Most of the “clean” test samples (80%) were correctly identified as unimpaired, with 10% considered as unclassified. None of the “dirty” test samples were classified as “clean” samples. In addition, all of the metal test samples were either correctly classified as metals impaired (87.5%) or were not classified. The majority of the sulfate test samples (75%) were correctly identified as sulfate impaired. The “dirty” reference models also identified most of the fecal test samples (78%) as fecal impaired, although 22% of the fecal test samples were misclassified as sediment-impaired. Some of the sediment test samples (37.5%) were also misclassified.

The weighted averaging indicator approach (based on taxa tolerance values) and the dirty reference approach provide valid tools for identifying environmental stressors in multiple stressor environments. The application of these biologically-based diagnostic models helped facilitate SI. Model predictions for each sample were incorporated into the strength-of-evidence analysis for final stressor determinations.

3.0 MINING DATA ANALYSIS SYSTEM OVERVIEW

The MDAS was developed specifically for TMDL application in West Virginia to facilitate large scale, data intensive watershed modeling applications. The MDAS is particularly applicable to support TMDL development for areas affected by acid mine drainage (AMD) and other point and nonpoint pollution sources. A key advantage of the MDAS' development framework is that unlike Hydrologic Simulation Program–FORTRAN (HSPF), upon which it is based, it has no inherent limitations in terms of modeling size or upper limit of model operations and can be customized to fit West Virginia's individual TMDL development needs. The system integrates the following:

- Graphical interface
- Data storage and management system
- Dynamic watershed model
- Data analysis/post-processing system

The graphical interface supports basic GIS (geographic information system) functions, including electronic geographic data importation and manipulation. Key geographic datasets include stream networks, landuse, flow and water quality monitoring station locations, weather station locations, and permitted facility locations. The data storage and management system functions as a database and supports storage of all data pertinent to TMDL development, including water quality observations, flow observations, and permitted facilities' discharge monitoring reports (DMRs), as well as stream and watershed characteristics used for modeling. The dynamic watershed model, also referred to as the Loading Simulation Program–C++ (LSPC) (Shen, et al., 2002), simulates nonpoint source flow and pollutant loading as well as instream flow and pollutant transport, and is capable of representing time-variable point source contributions. The data analysis/post-processing system conducts correlation and statistical analyses and enables the user to plot model results and observation data.

The LSPC model is the MDAS component that is most critical to TMDL development because it provides the linkage between source contributions and instream response. LSPC is a comprehensive watershed model used to simulate watershed hydrology and pollutant transport, as well as stream hydraulics and instream water quality. It is capable of simulating flow; the behavior of sediment, metals, nutrients, pesticides, and other conventional pollutants; temperature; and pH for pervious and impervious lands and for waterbodies. LSPC is essentially a recoded C++ version of selected HSPF modules. LSPC's algorithms are identical to HSPF's. **Table 3-1** lists the modules from HSPF that are used in LSPC. Refer to the *Hydrologic Simulation Program–FORTRAN User's Manual for Release 11* (Bicknell, Imhoff, Kittle, Donigian, & Johansen, 1996) for a more detailed discussion of simulated processes and model parameters.

Table 3-1. Modules from HSPF converted to LSPC

RCHRES Modules	HYDR	Simulates hydraulic behavior
	CONS	Simulates conservative constituents
	HTRCH	Simulates heat exchange and water
	SEDTRN	Simulates behavior of inorganic sediment
	GQUAL	Simulates behavior of a generalized quality constituent
	PHCARB	Simulates pH, carbon dioxide, total inorganic carbon, and alkalinity
PQUAL and IQUAL Modules	PWATER	Simulates water budget for a pervious land segment
	SEDMNT	Simulates production and removal of sediment

	PWTGAS	Estimates water temperature and dissolved gas concentrations
	IQUAL	Uses simple relationships with solids and water yield
	PQUAL	Simple relationships with sediment and water yield

Source: Bicknell et al., 1996.

3.1 Mining Data Analysis System (MDAS) Model Configuration

The MDAS was configured for all watersheds, and LSPC was used to simulate each of the watersheds as a series of hydrologically connected subwatersheds. Configuration of the model involved subdividing each large watershed into modeling units and performing continuous simulation of flow and water quality for these units using meteorological, landuse, point source loading, and stream data. The specific pollutants simulated were total aluminum, total iron, pH, sediment, and fecal coliform bacteria. This section describes the configuration process and key components of the model in greater detail.

3.1.1. Watershed Subdivision

To represent watershed loadings and the resulting concentrations of pollutants of concern, each watershed was divided into hydrologically connected subwatersheds. These subwatersheds represent hydrologic boundaries. The division was based on elevation data (7.5-minute Digital Elevation Model [DEM] from the U.S. Geological Survey [USGS]), stream connectivity (from USGS's National Hydrography Dataset [NHD] stream coverage), the impairment status of tributaries, and the locations of monitoring stations. This delineation enabled the evaluation of water quality and flow at impaired water quality stations, and it allowed management and load reduction alternatives to be varied by subwatershed. An example subwatershed delineation is shown in **Figure 3-1**.

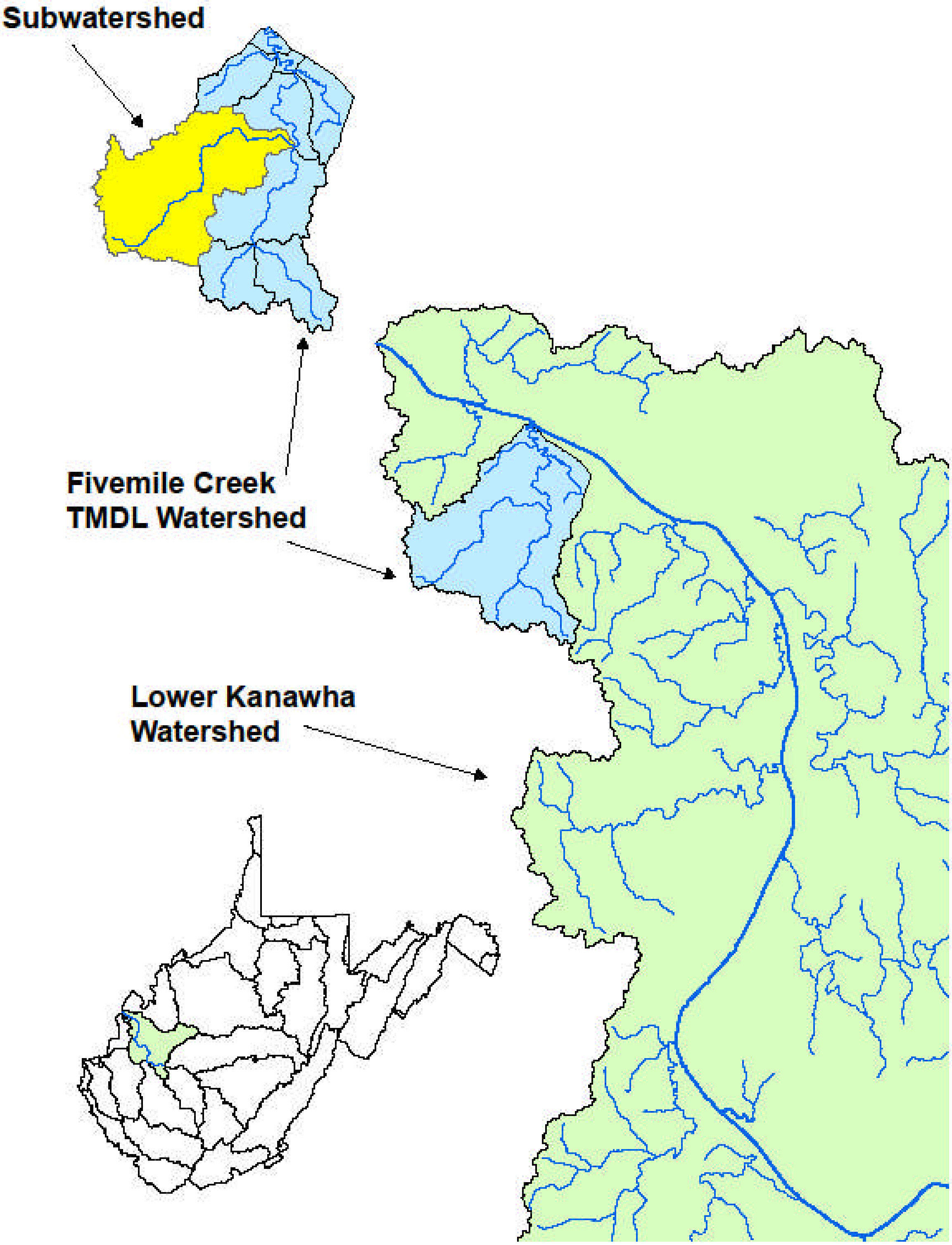


Figure 3-1. Example subwatershed delineation

3.1.2. Meteorological Data

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dewpoint is required to develop a valid model. Meteorological data were obtained from a number of weather stations in an effort to develop the most representative dataset for each watershed.

In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly recorded data were considered in developing a representative dataset. Long-term hourly precipitation data available from the National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA-NCDC) weather stations Moorefield (WV6163) and Charleston (WV1570) were used.

The remaining required meteorological data (wind speed, potential evapotranspiration, cloud cover, temperature, and dewpoint) were available from the Martinsburg Regional Airport (WBAN 13734) and the Charleston Yeager Airport (WBAN 13866) station. The data were applied to each subwatershed according to proximity.

3.1.3. Stream Representation

Modeling subwatersheds and calibrating hydrologic and water quality model components require routing flow and pollutants through streams and then comparing the modeled flows and concentrations with available data. In the MDAS model, each subwatershed was represented by a single stream segment, which was identified using the USGS NHD stream coverage.

To route flow and pollutants, rating curves were developed for each stream using Manning's equation and representative stream data. Required stream data include slope, Manning's roughness coefficient, and stream dimensions, including mean depths and channel widths. Manning's roughness coefficient was assumed to be 0.02 (representative of natural streams) for all streams. Slopes were calculated based on DEM data and stream lengths measured from the NHD stream coverage. Stream dimensions were estimated using regression curves that related upstream drainage area to stream dimensions (Rosgen, 1996).

3.1.4. Hydrologic Representation

Hydrologic processes were represented in the MDAS using algorithms from two HSPF modules: PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) (Bicknell et al., 1996). Parameters associated with infiltration, groundwater flow, and overland flow were designated during model calibration.

3.1.5. Pollutant Representation

In addition to flow, five pollutants were modeled with the MDAS:

- Total aluminum
- Total iron
- pH

- Sediment (using total iron as a surrogate)
- Fecal coliform bacteria

The loading contributions of these pollutants from different nonpoint sources were represented in MDAS using the PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules of HSPF (Bicknell et al., 1996). Pollutant transport was represented in the streams using the GQUAL (simulation of behavior of a generalized quality constituent) module.

3.1.6. Streambank Erosion Representation

Streambank erosion was modeled as a unique sediment source independent of other upland-associated erosion sources. The MDAS bank erosion model takes into account stream flow and bank stability. The relevant parameters in the bank erosion algorithms are the threshold flow at which bank erosion starts to occur, and a coefficient for scour of the bank matrix soil for the reach. The threshold flow at which bank erosion starts to occur was estimated as the flow that occurs at bankfull depth. This flow threshold was user specified for each reach. The bank scouring process is a power function dependent on high-flow events (those exceeding the flow threshold). The coefficient of scour for the bank soil was related to the bank erosion hazard index (BEHI).

The bank erosion rate per unit area was defined as a function of bank flow volume above a specified threshold and the bank erodible area. The wetted perimeter and reach length represent ground area covered by water (**Figure 3-2**). The erodible wetted perimeter is equal to the difference between the actual wetted perimeter and wetted perimeter during threshold flow conditions. The bank erosion rate per unit area was multiplied by the erodible perimeter and the reach length to obtain the estimate of sediment mass eroded corresponding to the stream segment.

Figure 3-2. Conceptual diagram of stream channel components of bank erosion model

During the sediment calibration process, the suspended sediment time series were compared with available data. Adjustments were made to the initial parameterization, but the relative magnitude between the sources was kept constant.

3.1.7 Iron Sediment Correlation

Sediment-producing landuses and bank erosion are sources of iron because the relatively high iron content of the soils in the watersheds. Statistical analyses using pre-TMDL monitoring data collected throughout the subject watersheds were performed to establish the correlation between iron loads and sediment loads. Linear regression analysis was performed on in-stream TSS and total iron data collected at individual WAB monitoring stations. An example of instream iron sediment correlation is displayed in **Figure 3-3**.

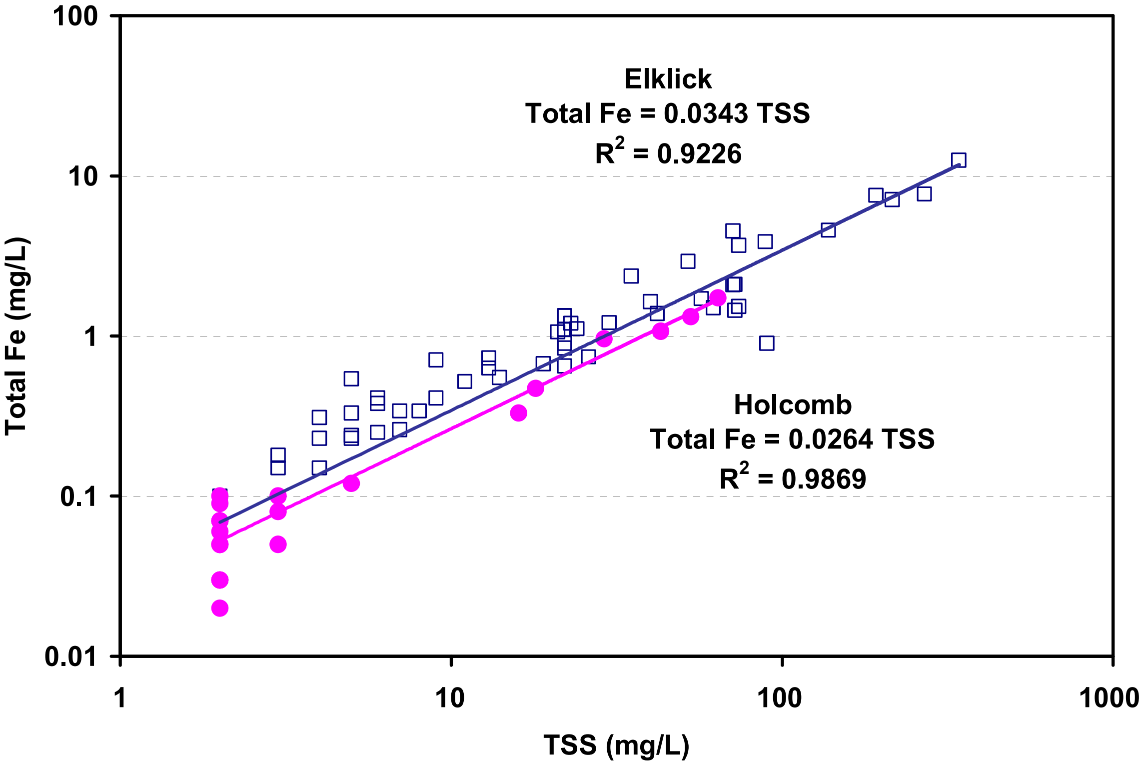


Figure 3-3. Example of instream iron-sediment correlation

The WAB stations with more than five effective observations and statistically significant Fe/TSS slopes were selected to evaluate spatial variability of iron sediment relationships. The iron sediment slopes calculated from linear regression analysis was grouped into slope groups to calculate potency factors used in the MDAS modeling. Potency factors indicating the iron loads relative to the sediment produced from soil and stream bank erosion was calculated from average Fe/TSS slope of each slope group. Average iron sediment slopes and associated sediment potency factors for the slope groups in the Elk River Watershed and Lower Kanawha River Watershed are given in **Table 3-2 and Table 3-3**, respectively. A slope group was assigned to each modeled subwatershed in the subject watersheds through spatial analysis using GIS. The results of iron sediment relationship analysis are provided in Appendix B and the relationship category applied to all modeled subwatershed is displayed graphically in the GIS project.

Table 3-2. Average iron sediment slope for slope groups in the Elk River watershed

Slope Group	Fe/TSS Slope	Potency Factor (lbs Fe/ton Sediment)
1	0.013	26
2	0.025	50
3	0.034	68
4	0.047	94

Table 3-3. Average iron sediment slope for slope groups in the Lower Kanawha River watershed

Slope Group	Fe/TSS slope	Potency Factor (lbs Fe/ton Sediment)
1	0.024	48
2	0.035	70
3	0.045	90

3.1.8. Chemical Species Transformation

MDAS includes a dynamic chemical species fate and transport model. Using results from the HSPF component, MDAS simulates soil subsurface and in-stream water quality taking into account chemical species interaction and transformation. The modules are composed of two major components:

- Subwatershed basis of pollutant simulation (HSPF algorithms)
- Simulation of selected chemical reactions using MINTEQ computational codes (USEPA (U.S. Environmental Protection Agency), 1991)

The total chemical concentration and flow time series generated by MDAS are used as inputs for the modules’ pollutant transformation and transport routines. The modules simulate soil subsurface and instream chemical reactions, assuming instant mixing and concentrations equally distributed throughout soil and stream segments. The model supports major chemical reactions, including acid/base, complexation, precipitation, and dissolution reactions and some kinetic reactions, if selected by the user.

3.2. MDAS Fecal Coliform Overview

Watersheds with varied landuses, dry- and wet-period loads, and numerous potential sources of pollutants typically require a model to ascertain the effect of source loadings on instream water quality. This relationship must be understood to develop a TMDL that addresses a water quality standard, as well as an effective implementation plan. In this section, the modeling techniques that were applied to simulate fecal coliform bacteria fate and transport are discussed.

3.2.1. Landuse

To explicitly model non-permitted (nonpoint) sources of fecal coliform bacteria, the existing NLCD 2001 landuse categories were consolidated to create model landuse groupings, as shown in **Table 3-4**. Modeled landuses contributing to bacteria loads include pasture, cropland, urban pervious lands, urban impervious lands, and forest (including barren land and wetlands). The modeled landuse coverage provided the basis for estimating and distributing fecal coliform bacteria loadings associated with conventional landuses. Subwatershed-specific details of the modeled landuses are shown in **Appendix C**.

Residential/urban lands contribute fecal coliform loads to the receiving streams through the wash-off of bacteria that build up in industrial areas, on paved roads, and in other residential/urban areas because of human activities. These contributions differ, based on the perviousness of the land. For example, the transport of the bacteria loads from impervious surfaces is faster and more efficient, whereas the accumulation of bacteria loads on pervious areas is expected to be higher (because pets spend more time on grass). Therefore, residential/urban lands were divided into two categories—residential/urban pervious and residential/urban impervious. Percent impervious estimates for the residential/urban landuse categories were used to calculate the total area of impervious residential/urban land in each subwatershed. The percent pervious/impervious assumptions for residential/urban land categories are shown in **Table 3-5.**

Table 3-4. Fecal coliform bacteria model landuse grouping

Model Category	NLCD 2001 Category
Barren	Barren Land (Rock/Sand/Clay)
Cropland	Cultivated Crops
Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Dwarf Scrub
	Shrub/Scrub
Pasture	Grassland/Herbaceous
	Pasture/Hay
Residential/Urban Impervious (See **Table 3-5**)	Developed, Open Space (15% impervious)
	Developed, Low Intensity (35% impervious)
	Developed, Medium Intensity (65% impervious)
	Developed, High Intensity (90% impervious)
Residential/Urban Pervious (See **Table 3-5**)	Developed, Open Space (85% pervious)
	Developed, Low Intensity (65% pervious)
	Developed, Medium Intensity (35% pervious)
	Developed, High Intensity (10% pervious)
Water	Open Water
Wetlands	Palustrine Forested Wetland
	Palustrine Scrub/Shrub Wetland
	Emergent Herbaceous Wetland

Table 3-5. Average percentage of pervious and impervious land for NLCD 2001 residential/urban landuse types

Landuse	Pervious (%)	Impervious (%)
Developed, Open Space (85% pervious)	85	15
Developed, Low Intensity (65% pervious)	65	35
Developed, Medium Intensity (35% pervious)	35	65
Developed, High Intensity (10% pervious)	10	90

3.2.2. Source Representation

Sources of fecal coliform bacteria were represented in the model differently, based on the type and behavior of the source. NPDES-permitted sewage treatment plant effluents were modeled with a constant flow and concentration based upon permit requirements. Most non-permitted sources were modeled as precipitation-driven sources, characterized by a build-up and wash-off process. However, there are also non-permitted sources, such as leaking septic systems, which are not primarily driven by precipitation and can be modeled with an estimated constant flow and concentration.

3.2.3. Fecal Coliform Point Sources

The most prevalent fecal coliform point sources are the permitted discharges from sewage treatment plants. All treatment plants are regulated by NPDES permits that require effluent disinfection and compliance with strict fecal coliform limitations (200 counts/100 milliliters [monthly geometric mean] and 400 counts/100 mL [maximum daily]). However, noncompliant discharges and collection system overflows can contribute loadings of fecal coliform bacteria to receiving streams. This section discusses how the specific types of fecal coliform permitted/point sources were represented in the model.

NPDES Permitted Outlets

For the Elk River TMDL watersheds, three individually permitted POTWs discharge treated effluent at three outlets. One additional privately owned sewage treatment plant operating under an individual NPDES permit discharges treated effluent at one outlet. In the areas draining to streams for which fecal coliform TMDLs have been developed, 26 facilities are registered under the “package plant” general permit and 108 are home aeration units registered under the “HAU” general permit.

For the Lower Kanawha TMDL watersheds, two individually permitted POTWs discharge treated effluent at two outlets. In addition, the City of Hurricane has two stormwater outlets associated with the POTW. No additional privately owned sewage treatment plants operating under an individual NPDES permit discharge treated effluent in subject watersheds. In the areas draining to streams for which fecal coliform TMDLs have been developed, 18 facilities are registered under the “package plant” general permit and 213 are registered under the “HAU” general permit.

The various sewage treatment plant effluents were represented in the model by their permitted design flows and the monthly geometric mean fecal coliform effluent limitation of 200 counts/100 mL.

3.2.4. Non-permitted (Nonpoint) Sources

In addition to permitted sources, non-permitted (nonpoint) sources contribute fecal coliform bacteria loads to the waters. The nonpoint fecal coliform sources are represented differently in the model depending on their type and behavior. The following nonpoint fecal coliform sources have been identified in the watersheds:

- Natural background (wildlife)
- Agriculture (pasture)
- Residential/urban runoff
- Failing septic systems

Natural Background (Wildlife) and Agriculture

Frequently, nonpoint sources are characterized by build-up and wash-off processes. On the land surface, fecal coliform bacteria accumulate over time and wash off during rain events. As the runoff transports the sediment over the land surface, more fecal coliform bacteria are collected and carried to the stream. While the concentrations of bacteria are increasing, some bacteria are also dying. The net loading into the stream is determined by the local watershed hydrology. Nonpoint sources are represented in the model as land-based runoff from the landuse categories described in **Section 3.2.1**. Fecal coliform accumulation rates (in number per acre per day) can be calculated for each landuse based on all sources contributing fecal coliform bacteria to the land surface. For example, grazing livestock and wildlife are specific sources that contribute to various landuses in the watershed. The landuses that experience bacteria accumulation due to livestock and wildlife include the following:

- Wetlands (wildlife)
- Forest (wildlife)
- Cropland (wildlife)
- Pasture/Grassland (livestock and wildlife)
- Barren (wildlife)

Accumulation rates for the above landuses can be derived using the distribution of animals by landuse and the typical fecal coliform production rates for different animal types. For example, the fecal coliform bacteria accumulation rate for pasture land is the sum of the individual fecal coliform accumulation rates due to contributions from grazing livestock and wildlife.

A compilation of storm sampling data, literature values and previous TMDL fecal coliform loading rates were used to develop initial estimates of rates of fecal coliform bacteria accumulation on the land surface (Miertschin, 2006). Estimates derived from these sources were used as inputs to the watershed loading model. However, these initial estimates did not apply uniformly to the greater watershed area being modeled. Therefore, the fecal coliform modeling parameters of build-up, wash-off, and storage limit were fine-tuned during the model testing (calibration) process to more closely match available monitoring data.

Agricultural runoff potential was assessed by WVDEP during source tracking efforts. Pastures were categorized into four general types of runoff potential: high, moderate, low or negligible. In general, pastures with steeper slopes and livestock with stream access or close proximity to the stream channel received a high runoff potential assessment. Pastures in areas with gentle slopes, without livestock stream access, with greater distance to a stream, or where streams contained well-established riparian buffers received a low or negligible runoff potential. Fecal coliform build-up, wash-off and storage limit parameters in areas rated as high or moderate with respect to runoff potential were assigned higher values; pastures with low or negligible runoff potential were assigned values slightly above natural background conditions. Each of the TMDL watersheds was assigned a unique set of loading parameters due to the differing characteristics of the watersheds.

A certain "natural background" contribution of fecal coliform bacteria can be attributed to deposition by wildlife in forested areas. Accumulation rates for fecal coliform bacteria in forested areas were developed using reference numbers from past TMDLs, incorporating wildlife estimates obtained from West Virginia's Division of Natural Resources (WVDNR). In addition, WVDEP conducted storm sampling on a 100 percent forested subwatershed (Shrewsbury Hollow) within the Kanawha State Forest, Kanawha County, West Virginia to determine wildlife contributions of fecal coliform. These results were used during the model calibration process. On the basis of the low fecal accumulation rates for forested areas, the stormwater sampling results, and model simulations, wildlife is not considered to be a significant nonpoint source of fecal coliform bacteria in any of the watersheds.

Residential/Urban Runoff

Sources of fecal coliform bacteria in residential/urban areas include wildlife and pets, particularly dogs. Much of the loading from urban areas is due to the greater amount of impervious area relative to other landuses, and the resulting increase in runoff. In estimating the potential loading of fecal coliform bacteria from residential/urban areas, accumulation rates are often used to represent the aggregate of available sources.

Residential/urban lands contribute nonpoint source fecal coliform bacteria loads to receiving streams through the wash-off of fecal coliform bacteria that build up on both pervious and impervious surfaces in industrial areas, on paved roads, and in residential areas (from failing septic systems, straight pipes contributing raw sewage, and wildlife). Residential/urban areas were consolidated into two landuse categories—residential/urban pervious and residential/urban impervious—as described in **Section 3.2.1**.

Failing Septic Systems and Straight Pipes

Failing septic systems represent non-permitted (nonpoint) sources that can contribute fecal coliform to receiving waterbodies through surface or subsurface flow. Fecal coliform loads from failing septic systems were modeled as point sources in the MDAS. To calculate point source loads, values for both wastewater flow and fecal coliform concentration are needed. Literature values for failing septic system flows and fecal concentrations vary over several orders of magnitude. Therefore it was necessary to perform original analysis using West Virginia pre-TMDL monitoring and source tracking data.

To calculate failing septic wastewater flows, TMDL watersheds were divided into four septic failure zones during the source tracking process. Septic failure zones were delineated by geology, and defined by rates of septic system failure. Two types of failure were considered: complete failure and periodic failure. For the purposes of this analysis, complete failure was defined as 50 gallons per house per day of untreated sewage escaping a septic system as overland flow to receiving waters. Periodic failure was defined as 25 gallons per house per day of untreated sewage escaping a septic system as overland flow to receiving waters. Both types of failure were modeled as daily, year-round flows to simplify calculations.

Table 3-6 shows the percentage of homes with septic systems in each of the four septic zones experiencing septic system failure.

Table 3-6. Septic failure rates in septic failure zones

	Zone			
Type	**Very Low**	**Low**	**Medium**	**High**
Percent Homes with Periodic Failure	3%	7%	13%	19%
Percent Homes with Complete Failure	5%	10%	24%	28%

GIS shapefiles identifying the location of public sewer systems were used to identify sewered areas in the watersheds. GIS shapefiles developed to track all addressable structures in West Virginia for 911 emergency purposes were used to determine the locations of structures with potentially failing septic systems in the fecal coliform TMDL watersheds. In the first step of the analysis, structures falling within known sewered areas were excluded from further consideration. The remaining structures were assigned to the TMDL modeled subwatersheds they fell within. These structures were further stratified by geographic zones of septic failure based on soil characteristics and geology. Frequently, subwatersheds had area straddling more than one failing septic zone. Using GIS techniques, each structure was identified both by subwatershed and failing septic zone.

Under WVDEP guidance, it was assumed that 54 percent of the non-sewered structures in each subwatershed were inhabited homes with septic systems. Septic failure rates were applied to the assumed homes with septic systems in each modeled subwatershed. Once those proportions of complete and seasonal failure were applied, failing septic wastewater flow was calculated by subwatershed using the periodic and seasonal flow rates of 50 gallons per house per day for complete failure, and 25 gallons per house per day for seasonal failure. For modeling purposes, failing septic system flows from multiple houses were totaled and incorporated into the model as a single constant point source for each subwatershed.

Once failing septic flows had been modeled, an appropriate a fecal coliform concentration was determined at the TMDL watershed scale. Based on past experience with other West Virginia TMDLs, a base concentration of 10,000 counts per 100 mL was used as a beginning concentration for failing septics. This concentration was further refined during model calibration at the subwatershed scale. A sensitivity analysis was performed by varying the modeled failing septic concentrations in multiple model runs, and then comparing model output to pre-TMDL monitoring data. The failing septic analyses are presented in **Appendix D**.

3.3. MDAS Metals and Sediment Overview

Watersheds with varied landuses, dry- and wet-period loads, and numerous potential sources of pollutants typically require a model to ascertain the effect of source loadings on instream water quality. This relationship must be understood in order to develop a TMDL that addresses a water quality standard, as well as an effective implementation plan. This section discusses the existing point and nonpoint sources of sediment and metals in the Elk and Lower Kanawha River watersheds and the process used to represent these sources in the MDAS model.

3.3.1. Landuse

To explicitly model nonpoint sources in the sediment and metals impaired watersheds, the existing NLCD 2001 landuse categories were consolidated to create the modeled landuse groupings shown in **Table 3-7**. Several additional landuse categories were created and added to the modeled landuse groupings. The additional categories are explained in the following sections. The updated landuse coverage provided the basis for estimating and distributing sediment, total aluminum and total iron loadings associated with land-based precipitation-driven sources.

Table 3-7. Consolidation of NLCD 2001 landuses for the sediment and metals MDAS model

Model Category	NLCD 2001 Category
Barren	Barren Land (Rock/Sand/Clay)
Cropland	Cultivated Crops
Mature Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Dwarf Scrub
	Shrub/Scrub
Pasture	Grassland/Herbaceous
	Pasture/Hay
Residential/Urban Impervious (See **Table 3-5**)	Developed, Open Space (15% impervious)
	Developed, Low Intensity (35% impervious)
	Developed, Medium Intensity (65% impervious)
	Developed, High Intensity (90% impervious)
Residential/Urban Pervious (See **Table 3-5**)	Developed, Open Space (85% pervious)
	Developed, Low Intensity (65% pervious)
	Developed, Medium Intensity (35% pervious)
	Developed, High Intensity (10% pervious)
Water	Open Water

Model Category	NLCD 2001 Category
Wetlands	Palustrine Forested Wetland
	Palustrine Scrub/Shrub Wetland
	Emergent Herbaceous Wetland

Additional landuse categories were created from various sources to produce a more detailed landuse set that represented specific land-based sources of metals and sediment. **Table 3-8** displays the additional landuse categories and the datasets from which they were created. The processes by which the landuses were created are described in the following sections.

Table 3-8. Additional modeled sediment/metals landuse categories

Model Category	Source
Burned Forest	Burned area details provided by Division of Forestry
Harvested Forest	Logging sites and areas provided by Division of Forestry
Skid Roads	Skid road areas provided by Division of Forestry
Roads_Paved	2000 TIGER/Line GIS and WV_Roads shapefiles
Roads_Unpaved	2000 TIGER/Line GIS shapefile and digitized from aerial photographs and topos
Oil and Gas	OOG shapefile provided by Office of Oil and Gas
Surface Mining	HPU shapefile and information gathered from SMCRA Article 3 permits by WVDEP personnel
Revoked	Bond Forfeiture information provided by WVDEP
AML	AML polygon shapefile provided by WVDEP
Highwall	AML highwall shapefile provided by WVDEP
Construction Stormwater	Construction Stormwater permits provided by WVDEP
Industrial Stormwater	Industrial Stormwater permits provided by WVDEP
Future Growth	A certain percentage of each subwatershed's area was set aside for future growth

Watershed-specific modeled landuse tables for each watershed are presented in **Appendix C**.

3.3.2. Additional Abandoned Mine Lands (AML)

The two abandoned mine lands (AML) landuse categories added to the landuse coverage were abandoned mine lands and highwalls. The AML landuses represent those areas that have been historically disturbed by mining activities and have not been reclaimed. The GIS coverages of AML and highwall sites provided by WVDEP were used to modify the NLCD 2001 landuse coverage because specific data regarding these sources was not available from the NLCD 2001 landuse coverage.

To appropriately account for runoff and loading characteristics related to AML sites, the NLCD 2001 landuse coverage was modified on a subwatershed basis. The AML GIS coverages were intersected with the subwatersheds, and the areas of abandoned mines and highwall were calculated. This area was then assigned to the respective AML landuse category and subtracted from the barren land landuse of NLCD 2001. If the barren landuse area for the particular subwatershed did not account for the entire area of AML, then the remaining area was subtracted from forest. This assured that the total area of the subwatershed remained the same.

For example, assume that data from WVDEP indicated no active mining, 80 acres of abandoned mines and 40 acres of highwalls in a particular subwatershed, while available NLCD 2001 data indicated 900 acres of forested land and 100 acres of barren land in the same watershed. The NLCD 2001 data would be modified such that the 100 acres of barren land would become 120 acres of AML landuse distributed according to the WVDEP data (i.e., 80 acres of abandoned mines and 40 acres of highwalls). Because the size of the new AML landuse coverage exceeds the original barren land area by 20 acres, the forested landuse coverage would be reduced by 20 acres such that the total size of the watershed would remain constant. In no case was the total size of any subwatershed modified as a result of including more accurate data regarding AML landuses.

3.3.3. Additional Sediment Source Landuse Categories

Additional landuse categories were required to represent differences in the sediment loading and transport characteristics from various landuse activities. Separate landuse categories were designated for forest harvest areas (recent timber removal), oil and gas operations, paved roads, and unpaved roads.

Forestry

The West Virginia Bureau of Commerce’s Division of Forestry provided information on registered logging operations in the watersheds. This information included the location, the area of land harvested, and the subset of land disturbed by haul roads and landings over the past three years. Registered forest harvest sites are presented in **Appendix E**.

West Virginia recognizes the water quality issues posed by sediment from logging sites. In 1992 the West Virginia Legislature passed the Logging Sediment Control Act. This act requires that best management practices (BMPs) be used to reduce sediment loads to nearby waterbodies. Without properly installed BMPs, logging and the land disturbance associated with the creation and use of haul roads to serve logging sites can increase sediment loading to streams.

Forest harvest areas were calculated by subwatershed, assigned to the corresponding landuse category (harvested forest or skid roads), and then subtracted from the mature forest landuse category of NLCD 2001. The harvested forest landuse category represents the total timber harvested in each subwatershed.

According to the Division of Forestry, illicit logging operations account for approximately an additional 2.5 percent of the total registered harvested forest area throughout West Virginia. The illicit logging acreage was calculated for each watershed and the resulting area was subtracted from forest and added to the barren landuse category. These illicit operations do not have properly installed BMPs and can contribute significant sediment loading to streams.

Agriculture

Agricultural land can be a significant source of sediment. Agricultural runoff can contribute excess sediment loads when farming practices allow soils to be washed into the stream. The erosion potential of cropland and overgrazed pasture is particularly high because of the lack of year round vegetative cover. Livestock traffic, especially along streambanks, disturbs the riparian buffer and reduces vegetative cover, causing an increase in erosion from these areas.

Based on modified modeled landuse data, approximately 1.2 percent of the Elk River watershed, and 4.1 percent of the Lower Kanawha River watershed are used for livestock pasture and crop production. Although agriculture is not widespread in the impaired portions of the watershed, source tracking efforts identified isolated instances of pastures and feedlots in the subwatersheds of biologically impaired waters for which sediment has been identified as a significant stressor.

Oil and Gas

WVDEP's Office of Oil and Gas (OOG) provided information regarding the location and status of oil and gas operation sites in the subject watersheds. Each active oil and gas operation was assumed to have a well site and access road area totaling approximately 64,000 square feet. This assumption was supported by results from a random well survey conducted by WVDEP OOG in the Elk River watershed during summer 2001 that showed similar average well site and access road areas. The cumulative area for oil and gas operations in each subwatershed was subtracted from the barren and mature forest categories as described for AML in **Section 3.3.2**.

Roads

Runoff from paved and unpaved roadways can contribute significant sediment loads to nearby streams. Heightened stormwater runoff from paved roads (impervious surface) can increase erosion potential. Unpaved roads can contribute significant sediment loads through precipitation-driven runoff, as they are a source of and easy pathway for sediment transport. Roads that traverse stream paths elevate the potential for direct deposition of sediment. Road construction and repair can further increase sediment loads if BMPs are not properly employed.

Information on roads was obtained from various sources, including the 2000 TIGER/Line GIS shapefiles from the US Census Bureau, the WV Roads GIS coverage prepared by West Virginia University (WVU), and manually delineated roads from the 2003 aerial photography.

Initial data on paved and unpaved roads in the watershed was obtained from the Census 2000 TIGER/Line Files. These GIS files provide the location and length of roads for the entire country. Each road is also assigned a code based on its attributes. The codes start with an A and are followed by a number. The codes are shown in **Table 3-9** and described in further detail in **Appendix F**. The lengths of roads by subwatershed were calculated by intersecting the TIGER/Line shapefile with the subwatershed delineation. Following this, an estimated width was assigned to each category of road to obtain an area. Based on the description for the appropriate category, the roads were designated as paved, unpaved, or, in the case of A4, 60 percent paved and 40 percent unpaved.

Table 3-9. Assigned perviousness and estimated width for each type of road

Code	Description	Percent Pervious	Estimated Width (ft)
A1	Primary Highway With Limited Access	0	35
A2	Primary Road Without Limited Access	0	35
A3	Secondary and Connecting Road	0	26
A4	Local, Neighborhood, and Rural Road	40	16
A5	Vehicular Trail	100	12
A6	Road with Special Characteristics	0	12
A7	Road as Other Thoroughfare	0	12

Source: Census 2000 TIGER/Line technical documentation.

The *WV Roads* GIS coverage prepared by WVU, topographic maps, and aerial photos were used to identify additional unpaved roads not included in the TIGER/Line Files. Unpaved road areas were subtracted from barren and mature forest lands. Paved road areas were subtracted from the residential/urban impervious landuse category and then from forest lands, if necessary.

3.3.4. Additional Residential/Urban Pervious and Impervious Landuse Categories

Impervious residential/urban lands contribute metals loads from nonpoint sources to the receiving streams through the wash-off of metals that build up in industrial areas and in other residential/urban areas because of human activities. Percent impervious estimates for residential/urban landuse categories were used to calculate the total area of impervious residential/urban land in each subwatershed. Pervious and impervious residential/urban land areas were estimated using typical percent pervious/impervious assumptions for residential/urban land categories, as shown in **Table 3-10**.

Table 3-10. Average percentage of pervious and impervious area for different residential/urban landuse types

NLCD 2001 Landuse Category	Pervious (%)	Impervious (%)
Developed, Open Space	85	15
Developed, Low Intensity	65	35
Developed, Medium Intensity	35	65
Developed, High Intensity	10	90

3.3.5. Other Nonpoint sources

In addition to land based sources, metals and sediment contributions from groundwater and streambank erosion were also considered in the modeling process.

Groundwater Sources

Contributions of relevant parameters from groundwater sources were also considered in metals/sediment TMDL development. In the case of naturally occurring parameters, such as aluminum and iron, it is important to consider and incorporate groundwater contributions for a more accurate representation of actual conditions. The MDAS model calculates the components of the water budget and simulates the delivery of water to the stream in three ways: overland runoff, interflow, and groundwater flow. The water that is infiltrated or percolated and does not go to lower zone storage becomes inflow to the groundwater storage. The outflow from the groundwater storage is based on simple algorithms that relate to the cross-sectional area and to the energy gradient of the flow. This process is modeled individually for every landuse in every subwatershed, and the resulting groundwater outflow essentially relates to the individual characteristics of the land and its corresponding area.

Streambank Erosion

Streambank erosion is another sediment source throughout the watershed. Information regarding the stability of streambanks was provided by WVDEP. WVDEP assessed bank erosion potential at each sampling station using a bank erosion hazard index (BEHI). BEHI variables included bankfull height, bankfull angle, vegetation and root density, bank stratification, and particle size of bank materials (ADEQ, 2004). The sample reach is assigned a qualitative value between 1 and 3 for each BEHI variable, with higher scores representing less stable streambanks and higher sediment bank erosion rates. Groves Creek (WV-KE-118) was selected as the reference watershed for the Elk River watershed and Higby Run (WV-KL-57-BH-3) was selected as the reference watershed for the Lower Kanawha River watershed. For model purposes, the BEHI variables are multiplied together for an overall bank stability score to compute bank erosion rate. If there were no WAB stations in a subwatershed, the BEHI scores were interpolated from the two closest stations upstream and downstream.

3.3.6. Sediment and Metals Point Sources

Point sources of sediment and metals include permitted loadings from traditional NPDES permits and the precipitation-induced loadings associated with mining and stormwater NPDES permits. Point sources were represented in the model differently, based on the type and behavior of the source.

Permitted Mining Point Sources

There are 51 mining-related NPDES permits, with 317 associated outlets in the metals impaired watersheds of the Elk River watersheds. There are three mining-related NPDES permits, with eight associated outlets in the metals impaired watersheds of the Lower Kanawha River watershed. Among these, one permit (two outlets) is for a quarry. WVDEP's Division of Mining and Reclamation (WVDMR) provided a spatial coverage of the mining-related NPDES permit outlets. The discharge characteristics, related permit limits, and discharge data for these NPDES outlets were acquired from West Virginia's Environmental Resources Information System (*ERIS)* database system. The spatial coverage was used to determine the location of the permit outlets. However, additional information was needed to determine the areas of the mining activities.

WVDEP Division of Water and Waste Management (DWWM) personnel used the information contained in the Surface Mining Control and Reclamation Act (SMCRA) Article 3 and NPDES permits to further characterize the mining point sources. Information gathered included type of discharge, pump capacities, and drainage areas (including total and disturbed areas), by outlet. Using this information, the permitted mining point sources (open NPDES outlets) were grouped into landuse categories based on the type and status of mining activity and effluent discharge characteristics. Phase II and Completely Released permitted facilities were not modeled because reclamation of these mines is completed or nearly complete and they are assumed to have little potential for water quality impact (WVDEP, 2000a). **Table 3-11** shows the landuses representing current active mines that were modeled. Details for both non-mining and mining point sources are provided in **Appendix G**.

Table 3-11. Model nonpoint source representation of different permitted mines

Type and Status of Active Mine	Landuse Representation
Surface mines	M_S
Deep mines (gravity fed discharge)	M_DG
Deep mines (pumped discharge)	M_DP
Co-mingled surface and deep mines (deep portion gravity fed)	M_CSDG
Co-mingled surface and deep mines (deep portion pumped)	M_CSDP
Quarry	Quarry

Note: M_S = surface mine; M_DG = deep mine gravity fed; M_DP = deep mine pumped discharge; M_CSDG = co-mingled discharge from surface and deep mine (gravity fed discharge from deep mine portion); M_CSDP = co-mingled discharge from surface and deep mine (pumped discharge from deep mine portion).

Surface mines, and co-mingled surface mines were treated as land-based precipitation-induced sources. The deep mine portions of co-mingled mines were characterized as continuous flow point sources. Deep mines were also characterized as continuous flow point sources.

To account for the additional surface mine areas, which were not categorized in the NLCD 2001 landuse coverage, the areas of each permitted surface mine (determined by aggregating the total drainage areas for each outlet) were subtracted from the existing NLCD 2001 barren and mature forest landuse areas as described for AML areas in **Section 3.3.2** and were assigned to the mining landuse categories.

Co-mingled discharges contain effluent discharges from both surface and deep mining activities. Co-mingled discharges where the deep mine portion is gravity fed (M_CSDG) were represented as described above by aggregating the total drainage areas from the surface and deep mines. For co-mingled discharges where the deep mine portion is pumped (M_CSDP), the pumped discharge was represented as a continuous flow point source (at maximum pump capacity) and areas associated with the surface mine were represented as described above. Any other pumped deep mine discharges were represented as continuous flow point sources at their maximum pumping capacities.

Point sources were represented differently during model calibration than they were during allocations. To match model results to historical water quality data for calibration, it was necessary to represent the existing point sources using available historical data. During allocations, permitted sources were represented at their allowable permit limits.

SMCRA Bond Forfeiture Sites

Information and data associated with bond forfeiture sites were made available by the Office of Special Reclamation (OSR) in WVDEP's Division of Land Restoration. The OSR classified the status of land disturbance and the water quality of the bond forfeiture sites into various categories. These status categories were used to characterize the bond forfeiture sites in the watersheds. The sites were then incorporated into the bond-forfeitures modeled landuse as described for AML above.

Facilities that were subject to SMCRA during active operations are required to post a performance bond to ensure the completion of reclamation requirements. When a bond is forfeited, WVDEP assumes the responsibility for the reclamation requirements. The Office of Special Reclamation in WVDEP's Division of Land Restoration provided bond forfeiture site locations and information regarding the status of land reclamation and water treatment activities. There are 12 unreclaimed bond forfeiture sites located in or contributing to the metals impaired TMDL watersheds. In past TMDLs, bond forfeiture sites were classified as nonpoint sources. A recent judicial decision (West Virginia Highlands Conservancy, Inc., and West Virginia Rivers Coalition, Inc. v. Randy Huffman, Secretary, West Virginia Department of Environmental Protection. [1:07CV87]. 2009) requires WVDEP to obtain an NPDES permit for discharges from forfeited sites. As such, this TMDL project classifies bond forfeiture sites as point sources and provides wasteload allocations.

Construction Stormwater General Permit

WVDEP issues a General NPDES Permit (Permit WV0115924) to regulate stormwater discharges associated with construction activities. Registration under the permit is required for construction activities with a land disturbance greater than one acre. Construction activities that disturb less than one acre are not subject to construction stormwater permitting and are uncontrolled sources of sediment. Both the land disturbance and the permitting process associated with construction activities are transient; that is, the water quality impacts are minimal after construction is completed and the sites are stabilized. Individual registrations under the General Permit are usually limited to less than one year. These permits require that the site have properly installed BMPs, such as silt fences, sediment traps, seeding and mulching, and riprap, to prevent or reduce erosion and sediment runoff. At the time the TMDLs were developed, there were 62 active construction sites registered under the Construction Stormwater General Permit in the watersheds of metals or sediment impaired waters (**Appendix G)**. Although specific wasteload allocations are not prescribed for these sites, the associated disturbed areas conform to the subwatershed based allocations for registrations under the permit.

Other Individual and General NPDES Permits

Individual and General NPDES Permits for sewage treatment facilities, industrial process wastewater, and stormwater associated with industrial activity generally contain technology-based TSS and metals effluent limitations. Facilities that are compliant with such limitations are not considered to be significant sediment or metals sources. All such facilities are recognized in the modeling process and are assigned WLAs that allow for continued discharge under existing permit conditions.

3.4. MDAS Overview for Dissolved Aluminum and pH

As stated previously, to appropriately address dissolved aluminum and pH TMDLs for the Elk and Lower Kanawha River watersheds, it was necessary to include additional MDAS modules capable of representing instream chemical reactions of several water quality components. With the atmospheric deposition module, MDAS is able to model acidity loading from dry and wet deposition. The Moisture Storage and Transport in Soil Layers (MSTLAY) module uses the fluxes that are computed from surface water, converts them into soil moisture and interlayer fluxes, and makes them usable for adsorption/desorption in solute transport calculations. MSTLAY estimates moisture storages in the four soil layers, in addition to the fluxes of moisture between the storages. To address water chemical and biogeochemical reactions affecting pH and dissolved aluminum, six modules were developed and added to the MDAS to better simulate pH levels: (1) the nitrogen soil (subsurface) transformation module, (2) the nitrogen stream (instream transformation) module, (3) the sulfate (subsurface) adsorption/desorption module, (4) the sulfate stream (aqueous chemical reaction) module, (5) the soil (subsurface) chemical reaction module, and (6) the stream (instream) chemical reaction module.

3.4.1. Atmospheric Deposition

Acid rain is produced when atmospheric moisture reacts with gases to form sulfuric acid, nitric acid, and carbonic acid. These gases are primarily formed from nitrogen dioxides and sulfur dioxide, which enter the atmosphere through exhaust and smoke from burning fossil fuels such as gas, oil, and coal. Two-thirds of sulfur dioxides and one-forth of nitrogen oxides present in the atmosphere are attributed to fossil fuel burning electric power generating plants (USEPA, 2005a). Acid rain crosses watershed boundaries and may originate in the Ohio valley or the midwest.

The majority of acid deposition occurs in the eastern United States. In March 2005 USEPA issued the Clean Air Interstate Rule (CAIR), which places caps on emissions for sulfur dioxide and nitrogen dioxides for the eastern United States. It is expected that CAIR will reduce sulfur dioxide emissions by more than 70 percent and nitrogen oxides emissions by more than 60 percent from 2003 emission levels (USEPA, 2005b). Because the pollution is highly mobile in the atmosphere, reductions based on CAIR in West Virginia, Ohio, and Pennsylvania will likely improve the quality of precipitation in the watersheds.

Atmospheric deposition occurs by two main methods: wet and dry. Wet deposition occurs through rain, fog, and snow. Dry deposition occurs from gases and particles. Dry deposition accounts for approximately half of the atmospheric deposition of acidity (USEPA, 2005a).

Particles and gases from dry deposition can be washed from trees, roofs, and other surfaces by precipitation after it is deposited and washed into streams. Winds blow the particles and gases contributing to acid deposition over large distances, including political boundaries such as state lines. The primary pollutants from atmospheric deposition are sulfur dioxide (SO2) and nitrogen oxides (NOx). The majority of sulfur dioxides (two-thirds) and one-fourth of nitrogen oxides are from fossil fuel burning electric power generating plants (USEPA, 2005a).

Atmospheric deposition data were obtained from the USEPA Office of Air Quality Planning and Standards at Research Triangle Park, North Carolina. The data are a result of air quality modeling in support of the CAIR. The data include concentrations of sulfate and nitrogen oxides in wet and dry deposition. For the technical information on these data, see the Technical Support Document for the Final Clean Air Interstate Rule—Air Quality Modeling (USEPA, 2005c). For the technical information on these data, please see the Technical Support Document for the Final Clean Air Intestate Rule – Air Quality Modeling (USEPA, 2005c). National Atmospheric Deposition Program (NADP) monitoring data collected at Babcock State Park, Fayette County, WV and the USDA Forest Service Northeastern Research Station, Tucker County, WV were also used to characterize the extent of atmospheric deposition in the watershed.

The atmospheric deposition module was added to the MDAS from HSPF. With this addition, the model is able to model dry and wet deposition. Users have the option to enter fluxes (mass per area per time) for dry deposition and concentrations for wet deposition, which the program automatically combines with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a constant value or alternatively, as a set of monthly values that is used for each year of the simulation. The MSTLAY module, which was copied from HSPF, uses the fluxes that are computed from surface water, converts them into soil moisture and interlayer fluxes, and makes them usable for adsorption/desorption in solute transport calculations. MSTLAY estimates moisture storages in the four soil layers (surface, upper, lower, groundwater), in addition to the fluxes of moisture between the storages.

Six modules were created to better simulate pH in the subsurface and in stream reaches by modeling sulfate and nitrogen species. These modules include routines to calculate the transfer and transformation of the different constituents in surface water and subsurface soils:

- Sulfate and nitrate from atmospheric deposition carry hydrogen, which is the source of acidity, and play a role in water quality in the eastern United States.
- Acidity from atmospheric deposition might intensify or buffer pH levels in the subsurface environment.
- Minerals in the subsurface buffer pH.
- Seasonal biological activity generates carbon dioxide, which can influence pH. Carbon dioxide-saturated interflow/groundwater can increase pH when the transport water is subjected to air and the carbon dioxide is released from the water.
- Biological nitrogen transformation, which changes concentrations of nitrate and ammonium, influences pH.
- Increased pH levels could again decrease pH because of dissolved aluminum entering surface water from interflow/groundwater flow.

All of these processes are important in the pH modeling process, and each was added to the MDAS model to better predict pH in the watersheds. A generalized diagram of how the model flows is shown in **Figure 3-4**.

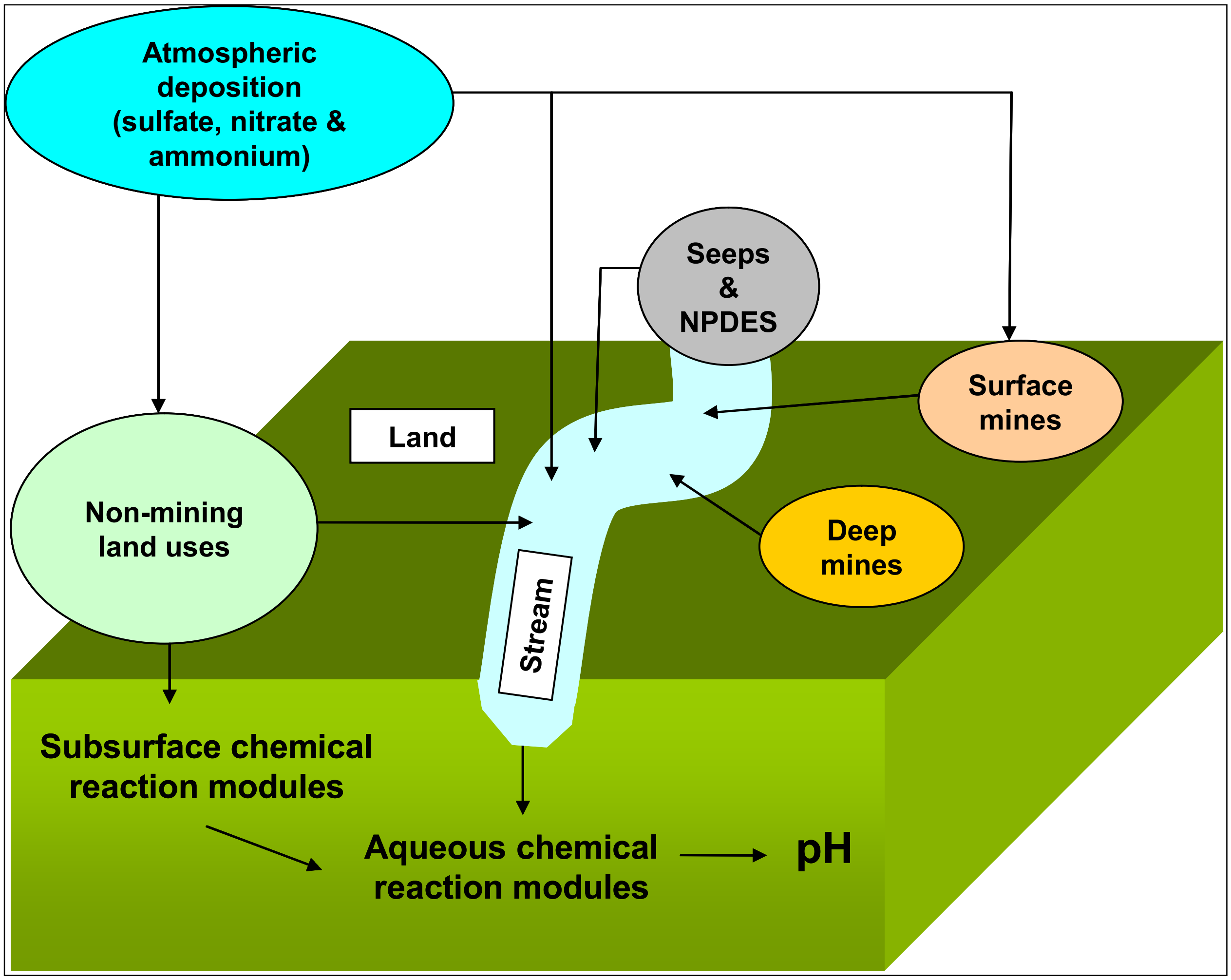


Figure 3-4. Generalized diagram of pollutant flow in the modeling process

3.4.2. Acid Mine Drainage

Historical mining activities are an important consideration in the development of dissolved aluminum and pH TMDLs. AMD is drainage that flows from open or deep mines and coal refuse piles. It tends to be highly acidic and to contain high dissolved metals concentrations. The formation of AMD is a function of geology, hydrology, and mining technologies used at the site. When water is exposed to pyrite in coal, refuse, or the overburden of mining operations, complex reactions occur that result in water with high acidity and dissolved metal content. These metals remain dissolved until the pH of the water increases to the level at which the metals precipitate out.

With respect to AMD, pH is not a good indicator of the acidity in a waterbody and can be a misleading characteristic. Water with near-neutral pH (~ 7) but containing elevated concentrations of dissolved ferrous (Fe^{2+}) ions can become acidic after oxidation and precipitation of the iron (PADEP, 2000). Therefore, a more practical approach to meeting the water quality criteria for pH is to use the concentration of metal ions as a surrogate for pH. It was assumed that reducing instream concentrations of dissolved metals (iron and aluminum) to meet water quality criteria (or TMDL endpoints) would result in meeting the water quality standard for pH. This assumption was verified by applying the MDAS. By executing the model under TMDL conditions (conditions in which TMDL endpoints for metals were met), the equilibrium pH could be predicted. The following sections describe the approaches used to derive pH TMDLs.

Streams affected by acid mine drainage often exhibit high dissolved metal concentrations, specifically for iron (Fe) and aluminum (Al), along with low pH. The relationship between these metals and pH provides justification for using metals TMDLs as a surrogate for a separate pH TMDL calculation. **Figure 3-5** shows three representative physical components that are critical to establishing this relationship.

Figure 3-5. Three physical components of the relationship between high metals and pH

Note: Several major ions compose the water chemistry of a stream. The cations are usually Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and H^{+}, and the anions consist of HCO_3^{-}, CO_3^{2-}, NO_3^{-}, Cl^{-}, SO_4^{2-}, and OH^{-} (Stumm and Morgan, 1996).

Component 1 in the figure describes the beginning of the pyrite (FeS_2) oxidation process that results from the exposure of pyrite to water (H_2O) and oxygen (O_2). This process is common in mining areas. The kinetics of pyrite oxidation processes are also affected by bacteria (*Thiobacillus ferrooxidans*), pH, pyrite surface area, crystallinity, and temperature (PADEP, 2000). The overall stoichiometric reaction of the pyrite oxidation process is as follows:

$$FeS_2(s) + 3.75O_2 + 3.5H_2O \qquad\qquad Fe(OH)_3\,(s) + 2SO_4^{2-} + 4H^{+}$$

Component 2 presents an example chemical reaction occurring within a mining treatment system. Examples of treatment systems are wetlands, successive alkalinity-producing systems, and open limestone channels. Carbonate and other bases (e.g., hydroxide) created in treatment systems consume hydrogen ions produced by pyrite oxidation and hydrolysis of metals, thereby increasing pH. The increased pH of the solution precipitates metals as metal hydroxides. Treatment systems might not necessarily work properly, however, because the removal rate of metals, and therefore the attenuation of pH, depends on the chemical constituents of the inflow;

the age of the systems; and the physical characteristics of the systems such as flow rate and detention rate (West Virginia University Extension Service, 2000).

It is assumed that implementing TMDLs for dissolved aluminum and total iron will result in instream dissolved metals concentrations that meet the water quality criteria. This assumption is based on the assumption that treatment systems will be implemented properly and will effectively increase pH to precipitate metals and thus lower their instream concentrations.

After treatment, the focus shifts to Component 3 and the relationship between metals concentrations and pH in the stream. The chemical process that needs to be considered is the hydrolysis reaction of metals in the stream. Component 3 presents an example of this reaction. The MDAS was used to estimate the pH resulting from chemical reactions occurring in the stream.

3.4.3. Chemical Transformation Parameters

pH changes in streams and waterbodies result from water chemical and biogeochemical reactions in their different environments—air, soil, and water. These reactions are important to consider in modeling pH levels in streams. This section discusses how each chemical was represented in the MDAS model and how the predictions were generated. Model assumptions and the calibration process are also discussed. Models are configured to the pollutant sources in the watersheds by selection of acid deposition and/or acid drainage components.

The total chemical concentration and flows time series generated by MDAS are used as inputs for the aqueous chemical reaction modules' pollutant transformation and transport routines. The modules simulate soil subsurface and in-stream chemical reactions, assuming instant mixing and concentrations equally distributed throughout soil and stream segments. The model supports major chemical reactions, including acid/base, complexation, precipitation, and dissolution reactions and some kinetic reactions.

To address water chemical and biogeochemical reactions affecting pH, six modules were developed and added to the MDAS to better simulate pH levels: (1) the nitrogen soil (subsurface) transformation module, (2) the nitrogen stream (instream transformation) module, (3) the sulfate (subsurface) adsorption/desorption module, (4) the sulfate stream (aqueous chemical reaction) module, (5) the soil (subsurface) chemical reaction module, and (6) the stream (instream) chemical reaction module.

Figure 3-6 through **Figure 3-8** present generalized representations of how the modules interact with each other, the flow of chemical species through the model layers, and the interactions of the species within the modules. With these modules, additional variables (**Table 3-12**) were added to the model.

Chemical species generated in the surface storage layer of the modeling environment by the nitrogen, sulfate, and soil chemical reaction modules are either transported to stream segments as surface runoff loadings or percolate into the upper subsurface and enter the subsurface module. Nitrogen, sulfate, and soil chemical reaction modules are applied to the chemical species in the subsurface storage. Once the chemical species are generated in the upper zone, they are transported to the lower subsurface (groundwater storage) level to undergo nitrogen reactions.

The species eventually enter into the corresponding stream segment as interflow and groundwater loadings.

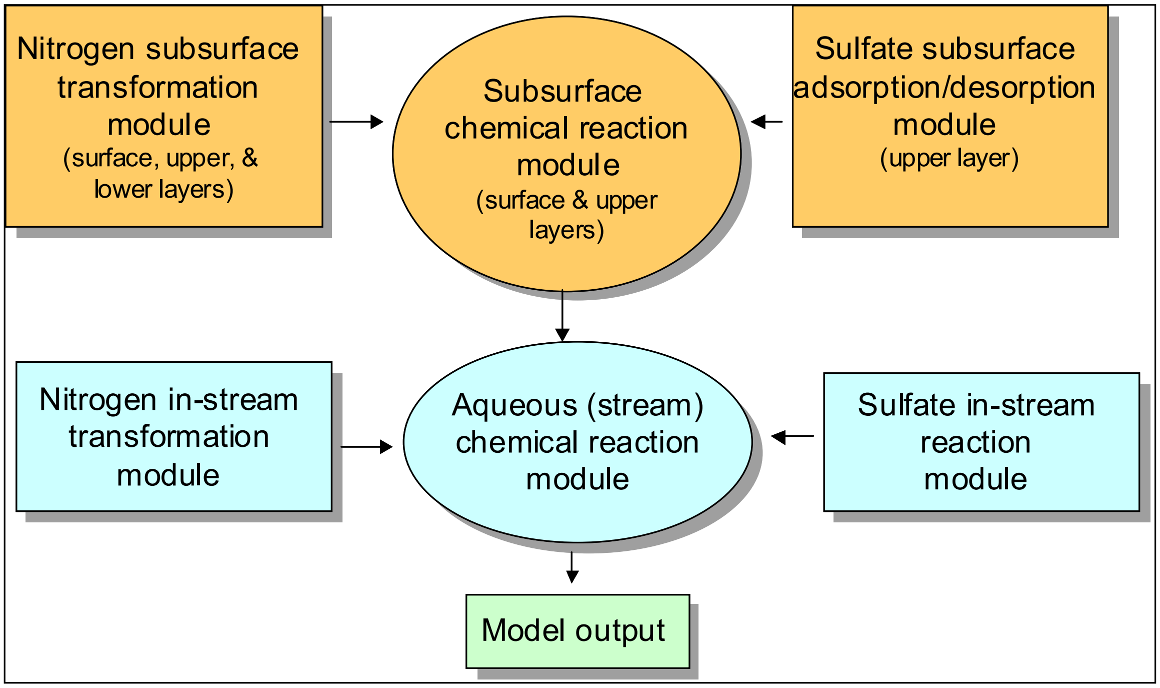


Figure 3-6. MDAS module overview

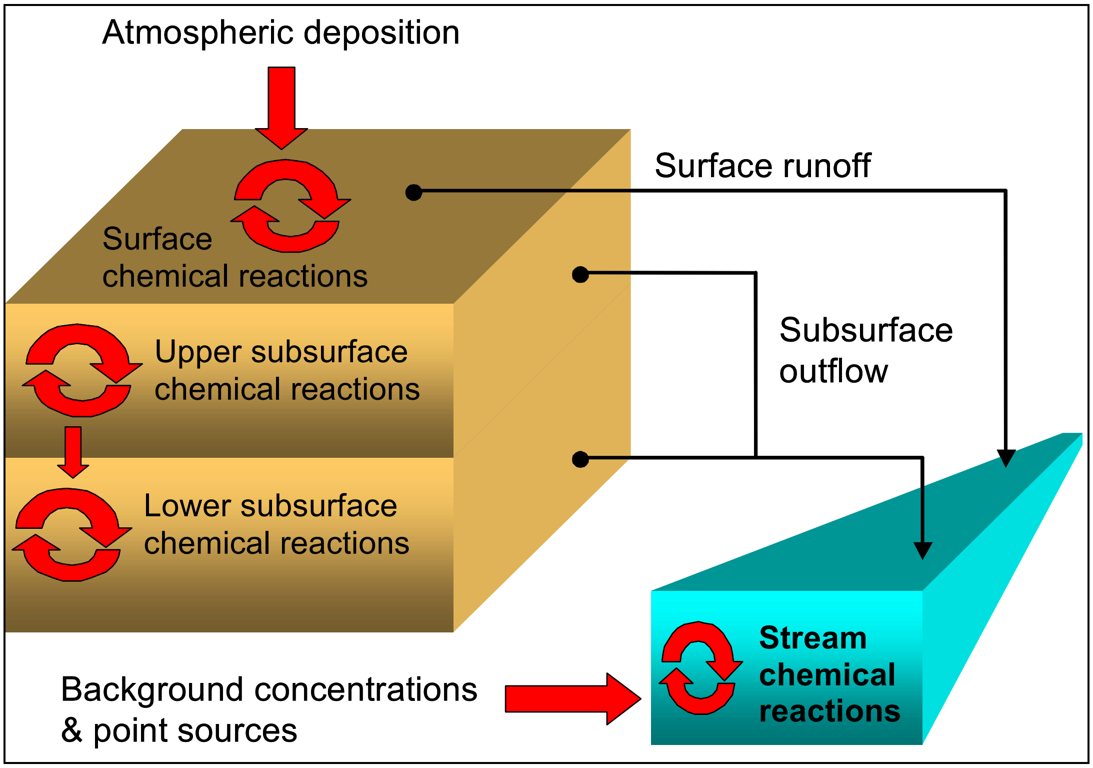


Figure 3-7. Chemical reaction flow in the MDAS

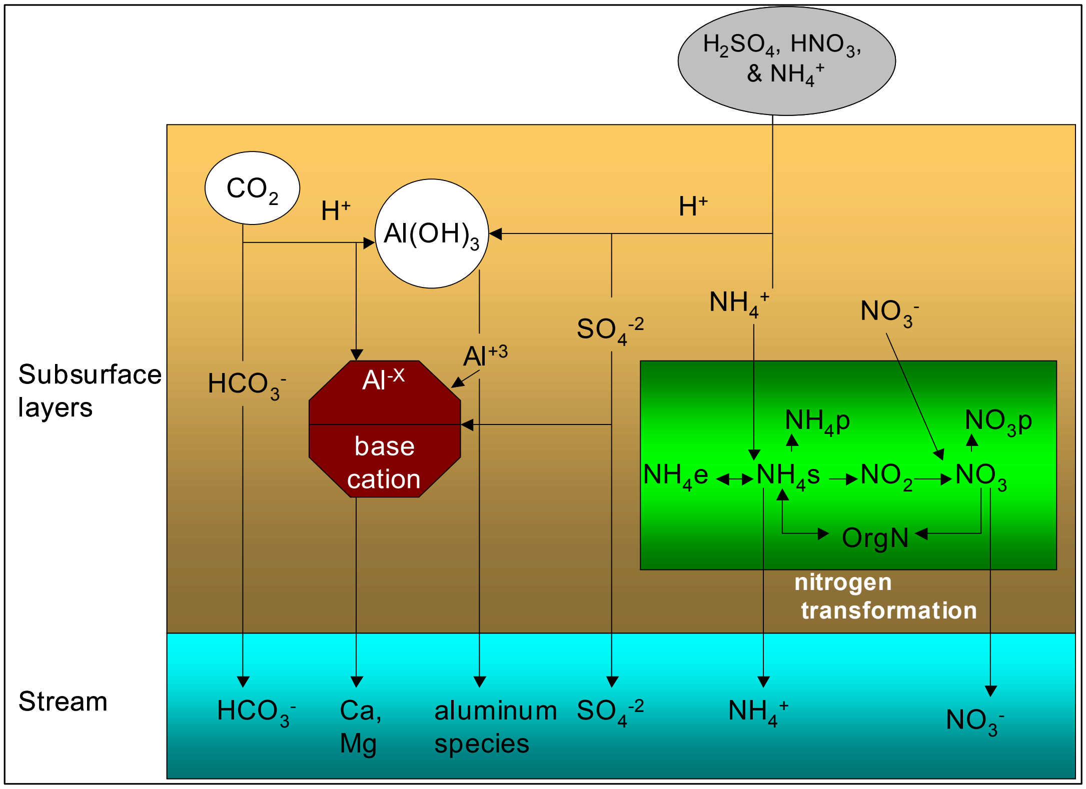


Figure 3-8. Chemical species flow in the MDAS

Table 3-12. MDAS model variables

Variable	Description	Variable	Description
AlK	metal (aluminum) dissolution constants	k_3	nitrogen transformation (plant uptake of NO_3) rate (per day)
CaX	base saturation percentage (fraction)	k_4	nitrogen transformation (plant uptake of NH_4S) rate (per day)
DESORP	ratio of dissolved and adsorbed sulfate	k_6	nitrogen transformation (OrgN to NH_4S) rate (per day)
FEK	iron dissolution constants	k_{es}	nitrogen transformation (NH_4E to NH_4S) rate (per day)
FR_3	precipitation rate for Ca^{+2} (per day)	kk_1	sulfate transformation rate (per day)
FR_4	precipitation rate for CO_3^{-2} (per day)	kk_6	nitrogen transformation (NH_4S to OrgN) rate (per day)
FR_5	precipitation rate for dissolved iron (per day)	kk_8	nitrogen transformation (NO_3 to OrgN) rate (per day)
FR_8	precipitation rate for dissolved aluminum (per day)	Log Ks	log of selectivity coefficient
FR_9	precipitation rate for organic nitrogen (OrgN) (per day)	k_{se}	nitrogen transformation (NH_4S to NH_4E) rate (per day)
FRP_5	precipitation rate for particulate iron (per day)	P_{CO}	CO_2 value (per day)
FRP_8	precipitation rate for particulate aluminum (per day)	PeakMon	growing season peak month
k_1	nitrogen transformation (NH_4S to NO_2) rate (per day)	Theta	temperature correction coefficient for nitrogen transformation

Variable	Description	Variable	Description
k_2	nitrogen transformation (NO_2 to NO_3) rate (per day)		

Nitrogen

Nitrogen compounds, such as nitrate and ammonium from atmospheric deposition, accumulate and undergo chemical reactions on land surfaces until they infiltrate into soils or run off. The hydrogen ions that are carried with nitrate are a significant contributor to the acidity often observed in rain (Sullivan, 2000; Stumm and Morgan, 1996) and thus have an impact on pH levels.

Nitrate and ammonium enter the model as atmospheric deposition (wet and dry). These nitrate and ammonium loadings are added directly to land surfaces and stream channels. Loadings from dry deposition are added directly to the stream or to the different landuses and accumulate until they are washed off by precipitation. Loadings due to wet weather are calculated using precipitation data and deposited to different landuses or the stream.

For land surface contributions, the MSTLAY module transports moisture and chemical species from surface soils through the subsurface soil zones. The MDAS processes water quality in the subsurface soils and surface water through the nitrogen soil transformation and nitrogen stream modules, which are described below. In the model, nitrogen assimilation and mineralization reactions are considered first-order reactions.

Nitrate and ammonium from atmospheric deposition on the land surface percolate through soils, where they are subject to biological transformation. The nitrogen subsurface transformation module performs nitrogen transformations through first-order kinetics and includes uptake of nutrients by plants. Nitrogen species considered in the module are exchangeable ammonium on clays (NH_4E), ammonium (NH_4S), nitrite (NO_2), nitrate (NO_3), and organic nitrogen (OrgN) in solution. **Figure 3-8** (above), shows the interaction of these different species.

The nitrogen soil transformation module applies to different soil layers: surface, upper layer, and lower layer. Equations in the module are included in **Equation Set 1** with rate constants (/day) and nitrogen species (mg/L). This module is based on the concept presented by Mehran and Tanji (1974).

Equation Set 1. Nitrogen soil transformation module

1-1: $$\frac{\Delta OrgN}{\Delta t} = (-K_6 \times OrgN^n) + (KK_6 \times NH_4S^n) + (KK_8 \times NO_3^{\,n})$$

1-2: $$\frac{\Delta NH_4S}{\Delta t} = (-(K_1 + K_{se} + KK_6 + K_4) \times NH_4S^n) + (K_{es} \times NH_4E^n) + (K_6 \times OrgN^n)$$

1-3: $$\frac{\Delta NO_3}{\Delta t} = (-(K_3 + KK_8) \times NO_3^{\,n}) + (K_2 \times NO_2^{\,n})$$

1-4: $\frac{\Delta NO_2}{\Delta t} = (-K_2 \times NO_2^{\ n}) + (K_1 \times NH_4S^n)$

1-5: $\frac{\Delta NH_4E}{\Delta t} = (-K_{es} \times NH_4E^n) + (K_{se} \times NH_4S^n)$

In the nitrogen stream module, the transformation from ammonium to nitrite to nitrate is considered in the stream using processes similar to those in the subsurface module. The nitrate uptake by aquatic plants is implicitly expressed through first-order kinetic rates. Nitrate and ammonium from background concentrations, atmospheric deposition, and point sources are added to the nitrogen cycle and transformed by this module. Equations in this module are included in **Equation Set 2** with rate constants (/day) and nitrogen species (mg/L).

Equation Set 2. Nitrogen stream module

2-1: $\frac{\Delta NO_3}{\Delta t} = (-K_3 \times NO_3^{\ n}) + (K_2 \times NO_2^{\ n})$

2-2: $\frac{\Delta NO_2}{\Delta t} = (-K_2 \times NO_2^{\ n}) + (K_1 \times NH_4S^n)$

2-3:
$\frac{\Delta NH_4S}{\Delta t} = (-K_1 \times NH_4S^n) + (K_6 \times OrgN^n)$

2-4: $\frac{\Delta OrgN}{\Delta t} = -K_6 \times OrgN^{\ n}$

Very little and in most cases no instream nitrate and ammonium data exists for the pH impaired streams in the watersheds. Therefore, the model was validated using representative background observed stream concentrations from throughout the watersheds. Calibration parameters included the nitrogen transformation rates in the different model layers (surface layer, upper subsurface layer, lower subsurface layer, and streams) and precipitation of organic nitrogen in streams. In addition, a temperature correction for nitrogen transformation rates could be calibrated.

Sulfate

Sulfate is the most significant acid-carrying chemical with potential to decrease the pH of waterbodies in the United States (Sullivan, 2000). Sulfate contributions from a variety of sources are represented in the model including background contributions and atmospheric deposition. Some contributions are direct to the streams while others accumulate on the land surface and undergo chemical reactions until they ultimately infiltrate into the subsurface or wash off during rainfall events.

Sulfate loading from wet and dry atmospheric deposition is added directly to land surfaces and stream channels in the model. Loadings from dry deposition are added to the different landuses and accumulate until they are washed off by precipitation. Loadings due to wet weather are calculated using precipitation data. Wet and dry deposition are also added directly to the streams. Point source contributions of sulfate are represented as direct stream contributions in the model.

The MSTLAY module transports moisture and chemicals from surface soils through the subsurface soil zones. Water quality in the subsurface soils (upper zone only) and surface water are processed through the sulfate adsorption/desorption module and sulfate stream modules, which are described below.

The sulfate adsorption/desorption module simulates the amount of sulfate in solution by using the desorption rate (DESORP). The module simulates adsorption/desorption mechanisms of sulfate onto and from soil particles. The model assumes that adsorption and desorption reactions can be explained linearly using DESORP to estimate the sulfate existing in the soil solution.

The sulfate stream module simulates sulfate loading from the land surface that travels to the stream goes through a first-order reaction in the stream. Equations in this module are included in **Equation Set 3** with rate constants (/day) and sulfate (mg/L).

Equation Set 3. Sulfate stream module

$$\boxed{\text{3-1: } \frac{\Delta SO_4}{\Delta t} = (-KK_1 \times SO_4{}^{n})}$$

The sulfate subsurface module runs in conjunction with the sulfate module in the stream. The modules were calibrated using observed instream sulfate concentrations for the pH impaired streams in the watersheds. In most cases, instream sulfate concentrations indicated background levels (<10 mg/L). The calibration was conducted by adjusting the stream and subsurface variables. Calibration parameters included the desorption rate (DESORP), sulfate transformation rate (kk_1), and background concentrations.

Subsurface Chemical Reaction Module

The outputs from the nitrogen and sulfate modules are used as inputs to the chemical reaction modules. These inputs, along with inputs of iron and aluminum, are used to predict pH and acidity levels in the stream segments.

This module calculates total aluminum, total hydrogen, total calcium, total nitrate, total sulfate, and total carbonate levels and determines loadings that are applied to the aqueous (stream) chemical reaction module. In the subsurface environment, hydrogen generated by acid inputs tends to dissolve aluminosilicate (aluminum hydroxide) if there are insufficient basic cations to counteract the acidic effect. Subsurface processes associated with this effect are the core part of the module and are based on the model presented by Reuss and Johnson (1986).

This module uses the charge balance principle—any increase of negative charges should be accompanied by an equivalent increase in positive charge—to estimate pH levels and aluminum species. The module uses sulfate, nitrate, ammonium, and CO_2 gas as chemical inputs. It is run for pervious landuses in the surface layer and upper subsurface layer. The convergence of the numerical calculation was assured by the bisection method, which was used only if the Newton-Raphson method (Schnoor 1996; Morel and Morgan 1972) failed to converge.

The method for estimating available subsurface CO_2 gas was based on methods found in Appelo and Postma (2005). The method uses the mean annual actual evapotranspiration to estimate the mean growing season soil CO_2. The estimated mean annual actual evapotranspiration was estimated for West Virginia based on soil CO2 pressure and evapotranspiration (Appelo and Postma, 2005). The CO_2 daily values in the model were estimated using sine curves to assign the peak CO_2 month and peak CO_2 value because CO_2 levels in soils tend to rise due to microbial and plant activities during warmer months (Brady and Weil, 1999). The model allows for a user-defined peak growing season month, and, thus, the peak month of CO_2 usage. The module uses a fixed atmospheric CO_2 gas level of 0.00035 atmospheres (atm) for the surface soil layer. For the upper subsurface soil layer, the CO_2 gas level is derived from equations 4-1 through 4-4 in **Equation Set 4**.

Equation Set 4. CO_2 peak sine curve calculations

4-1: $\max = 10^{-3.47 + 2.09 \times (1^{-0.00172 \times AET})}$

4-2: $amp = 0.5 \times (max - min)$

4-3: $up = amp + min$

4-4: $CO_2 = up + (amp \times \sin(\frac{Pi \times 360 \times JDay}{180 \times DaysInYear} + \frac{90 \times Pi}{180} - \frac{Pi \times 360 \times PeakJDay}{180 \times DaysInYear}))$

Where AET = annual actual mean evapotranspiration (AET = 800 mm)

max = maximum height of the sine curve

min = minimum height of the sine curve (min = 0.00035)

amp = amplification of the sine curve

up = vertical movement of the sine curve

Pi = 3.14159265358979323

$JDay$ = Julian day

The model also requires an aluminum solubility constant (K_Al), exchange selectivity coefficient (K_s), and base cation saturation ratio (CaX) for basic cations. The selectivity coefficient describes the tendency of soil particles to exchange aluminum with base cations such as calcium, magnesium, and sodium or vice versa, while the base saturation ratio indicates how much base cation is available for the exchanges.

The output from the subsurface chemical reaction module (total aluminum, total hydrogen, total calcium, total nitrate, total sulfate, and total carbonate) is input into the aqueous chemical reaction module. **Equation Set 5** describes the main equations used for the soil chemical reaction module. Details and the model concepts can be found in Reuss and Johnson (1986).

Equation Set 5. Chemical reaction module main equations

5-1: $3[Al^{+3}]+2[Ca^{+2}]+2[Al(OH)^{+2}]+[Al(OH)_2^{+}]+[H^{+}]+[NH_4^{+}]=$

$[HCO_3^{-}]+2[SO_4^{-2}]+[NO_3^{-}]+[OH^{-}]+2[CO_3^{-2}]$

5-2: $[Al^{+3}] = K\_Al \times [H^{+}]^3$

5-3: $[Al(OH)^{+2}] = K\_Al \times 10^{-5.02} \times [H^{+}]^2$

5-4: $[Al(OH)^{+2}] = K\_Al \times 10^{-9.3} \times [H^{+}]$

5-5: $[Ca^{+2}] = \dfrac{K_s (CaX^3)^{2/3} \times K\_Al^{1/3} \times [H^{+}]^2}{(1-CaX)^2}$

5-6: $[HCO_3^{-}] = \dfrac{P_{CO_2} \times 10^{-7.81}}{[H^{+}]}$

Aqueous (Stream) Chemical Reaction Module

The chemical concentrations estimated from the subsurface chemical reaction module are used as input for the aqueous chemical reaction module. Main inputs include total aluminum, total hydrogen, total iron, total calcium, total nitrate, total sulfate, total ammonium and total carbonate. The model simulates the concentrations for different chemical species and pH, and if metals become supersaturated, the model precipitates the metals out of solution. The aqueous chemical reaction module is based on a chemical speciation model, MINEQL (Westall et al., 1974). MINEQL uses the same numerical solution method used for USEPA's MINTEQA4 (Allison et al., 1991). **Table 3-13** shows chemical species considered in the aqueous model.

Table 3-13. Stoichiometric matrix

Name	H^+	Ca^{+2}	CO_3^{-2}	Fe^{+3}	NO_3^-	NH_4^+	Al^{+3}	SO_4^{-2}	K (reaction constants)
H^+	1	0	0	0	0	0	0	0	0
Ca^{+2}	0	1	0	0	0	0	0	0	0
CO_3^{-2}	0	0	1	0	0	0	0	0	0
Fe^{+3}	0	0	0	1	0	0	0	0	0
NO_3^-	0	0	0	0	1	0	0	0	0

Name	H^+	Ca^{+2}	CO_3^{-2}	Fe^{+3}	NO_3^-	NH_4^+	Al^{+3}	SO_4^{-2}	K (reaction constants)
NH_4^+	0	0	0	0	0	1	0	0	0
Al^{+3}	0	0	0	0	0	0	1	0	0
SO_4^{-2}	0	0	0	0	0	0	0	1	0
OH^-	-1	0	0	0	0	0	0	0	-13.998
NH_3	-1	0	0	0	0	1	0	0	-9.25
$Al(OH)_2^+$	-2	0	0	0	0	0	1	0	-10.1
$Al(OH)_3$	-3	0	0	0	0	0	1	0	-16
$Al(OH)_4^-$	-4	0	0	0	0	0	1	0	-23
$AlOH^{+2}$	-1	0	0	0	0	0	1	0	-4.9
$Al(SO_4)^+$	0	0	0	0	0	0	1	1	3.89
$CaCO_3$	0	1	1	0	0	0	0	0	3.15
$CaHCO_3^+$	1	1	1	0	0	0	0	0	11.33
$CaOH^+$	-1	1	0	0	0	0	0	0	-12.598
$CaSO_4$	0	1	0	0	0	0	0	1	2.309
H_2CO_3	2	0	1	0	0	0	0	0	16.681
HCO_3-	1	0	1	0	0	0	0	0	10.33
$FeOH^{+2}$	-1	0	0	1	0	0	0	0	-2.19
$Fe(OH)_2^+$	-2	0	0	1	0	0	0	0	-5.67
$Fe_2(OH)_2^{+4}$	-2	0	0	2	0	0	0	0	-2.95
$Fe(OH)_3$	-3	0	0	1	0	0	0	0	-13.6
$FeOH_4^-$	-4	0	0	1	0	0	0	0	-21.6
$Fe_3(OH)_4^{+5}$	-4	0	0	3	0	0	0	0	-6.3
$FeSO_4^+$	0	0	0	1	0	0	0	1	3.92
CO_2	2	0	1	0	0	0	0	0	18.16
H_2O	0	0	0	0	0	0	0	0	0
$Fe(OH)_3$ (solid)	-3	0	0	1	0	0	0	0	-4.891
$Al(OH)_3$ (solid)	-3	0	0	0	0	0	1	0	-8.7

4.0 MDAS MODEL CALIBRATION

After the various models were configured, calibration was performed at multiple locations in each watershed. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. Model calibration focused on three main areas: hydrology, sediment and water quality. Upon completion of the calibration at selected locations, the calibrated dataset containing parameter values for modeled sources and pollutants was complete. This dataset was applied to areas for which calibration data were not available.

4.1. Hydrology Calibration

This section describes the modeling and calibration of the snow and hydrology components of the watershed model. Simulation of hydrologic processes is an integral part of the development of an effective watershed model. The goal of the calibration was to obtain physically realistic model prediction by selecting parameter values that reflect the unique characteristics of the watershed. Spatial and temporal aspects were evaluated through the calibration process.

Hydrologic calibration was performed after configuring the model. For the MDAS, calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest. It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Hydrology calibration was based on several years of simulation to evaluate parameters under a variety of climatic conditions. The calibration procedure resulted in parameter values that produce the best overall agreement between simulated and observed stream flow values throughout the calibration period. Calibration included a time series comparison of daily, monthly, seasonal, and annual values, and individual storm events. Composite comparisons (e.g., average monthly stream flow values over the period of record) were also made. All of these comparisons must be evaluated for a proper calibration of hydrologic parameters.

The MDAS hydrology algorithm follows a strict conservation of mass, with various compartments available to represent different aspects of the hydrologic cycle. Sources of water are direct rainfall or snowmelt. Potential sinks from a land segment are total evapotranspiration, flow to deep groundwater aquifers, and outflow to a reach. From the reach perspective, sources include land outflow (runoff and baseflow), direct discharges, precipitation, or flow routed from upstream reaches. Sinks include surface evaporation, mechanical withdrawals, or reach outflow.

Snow

The method used to simulate snow behavior was the energy balance approach. The MDAS SNOW module uses the meteorological forcing information to determine whether precipitation falls as rain or snow, how long the snowpack remains, and when snowpack melting occurs. Heat is transferred into or out of the snowpack through net radiation heat, convection of sensible heat from the air, latent heat transfer by moist air condensation on the snowpack, from rain, and through conduction from the ground beneath the snowpack. Melting occurs when the liquid portion of the snowpack exceeds its holding capacity; melted snow is added to the hydrologic cycle.

Surface Hydrology

As mentioned earlier, the MDAS hydrology algorithms follow a strict conservation of mass. The source of water to the land is either direct precipitation or snowmelt. Some of this water is intercepted by vegetation or by other means. The interception is represented in the model by a "bucket" that must be filled before any excess water is allowed to reach the land surface. The size, in terms of inches per unit of area, of this "bucket" can be varied monthly to represent the level of each compartment (both above and below the land surface).

Water that is not intercepted is placed in surface detention storage. If the land segment is impervious, no subsurface processes are modeled, and the only pathway to the stream reach is through surface runoff. If the land segment is pervious, the water in the surface detention storage can infiltrate, be categorized as potential direct runoff, or be divided between the two depending on a function of the soil moisture and infiltration rate. The water that is categorized as potential direct runoff is partitioned into surface storage/runoff, interflow, or kept in the upper zone storage. Surface runoff that flows out of the land segment depends on the land slope and roughness, and the distance it has to travel to a stream. Interflow outflow recedes based on a user-defined parameter.

Water that does not become runoff, interflow, or lost to evaporation from the upper zone storage will infiltrate. This water will become part of the lower zone storage, active groundwater storage or be lost to the deep/inactive groundwater. The lower zone storage acts like a "container" of the subsurface. This "container" needs to be full in order for water to reach the groundwater storage. Groundwater is stored and released based on the specified groundwater recession, which can be made to vary non-linearly.

The model attempts to meet the evapotranspiration demand by evaporation of water from baseflow (groundwater seepage into the stream channel), interception storage, upper zone storage, active groundwater, and lower zone storage. How much of the evapotranspiration demand is allowed to be met from the lower zone storage is determined by a monthly variable parameter. Finally, water can exit the system in three ways: evapotranspiration, deep/inactive groundwater, or entering the stream channel. The water that enters the stream channel can come from direct overland runoff, interflow outflow, and groundwater outflow.

Some of the hydrologic parameters can be estimated from measured properties of the watersheds while others must be estimated by calibration. Model parameters adjusted during calibration are associated with evapotranspiration, infiltration, upper and lower zone storages, recession rates of baseflow and interflow, and losses to the deep groundwater system. During hydrology calibration, land segment hydrology parameters were adjusted to achieve agreement between daily average simulated and observed USGS stream flow at selected locations throughout the basin. The Elk and North Branch Potomac watersheds each had one USGS flow gauging station with adequate data records for hydrology calibration, USGS gauging stations:

- 01604500 Patterson Creek near Headsville,
- WV 03197000 Elk River at Queen Shoals, WV

The average of the 24 hourly model predictions was compared to daily mean flow values measured at these two USGS streamflow gages. The calibration period was from January 1, 2003 to October 31, 2006.

There were no USGS flow gauging stations with adequate data records for hydrology calibration on tributaries to the Lower Kanawha River. USGS gages on the Lower Kanawha mainstem were not appropriate for this effort because the mainstem was not modeled. Instead, a reference approach was used to define hydrologic parameters used in the model. Model parameters developed concurrently for the nearby and hydrologically similar Elk River were transferred to the Lower Kanawha model.

As a starting point, many of the hydrology calibration parameters originated from the USGS Scientific Investigations Report 2005-5099 (Atkins et al., 2005). During calibration, agreement between observed and simulated stream flow data was evaluated on an annual, seasonal, and daily basis using quantitative as well as qualitative measures. Specifically, annual water balance, groundwater volumes and recession rates, surface runoff and interflow volumes and timing were evaluated. Calibration of the hydrologic model was accomplished by first adjusting model parameters until the simulated and observed annual and seasonal water budgets matched. Then, the intensity and arrival time of individual events was calibrated. This iterative process was repeated until the simulated results closely represented the system and reproduced observed flow patterns and magnitudes. The model calibration was performed using the guidance of error statistics criteria specified in HSPEXP (Lumb et al., 1994). Output comparisons included: mean runoff volume for simulation period, monthly runoff volumes, daily flow time series, and flow frequency curves, among others. The flow-frequency curves and temporal analyses are presented in **Appendix H**. The hydrology calibration statistics for the flow gage at Elk River at Queen Shoals, WV are shown in **Table 4-1**. A graphical representation of hydrology calibration results is presented in **Figure 4-1**. Refer to **Appendix H** for additional calibration results.

Table 4-1. Comparison of simulated and observed flow from January 1, 1998 to December 31, 2007 (USGS station ID number 03197000 Elk River at Queen Shoals)

Simulated versus Observed Flow	Percent Error	Recommended Criterion[a]
Error in total volume:	5.25	10
Error in 50% lowest flows:	8.37	10
Error in 10% highest flows:	4.58	15
Seasonal volume error - summer:	9.91	30
Seasonal volume error - fall:	7.87	30
Seasonal volume error - winter:	4.40	30
Seasonal volume error - spring:	2.68	30
Error in storm volumes:	4.94	20
Error in summer storm volumes:	11.00	50

[a] Recommended criterion: HSPExp.

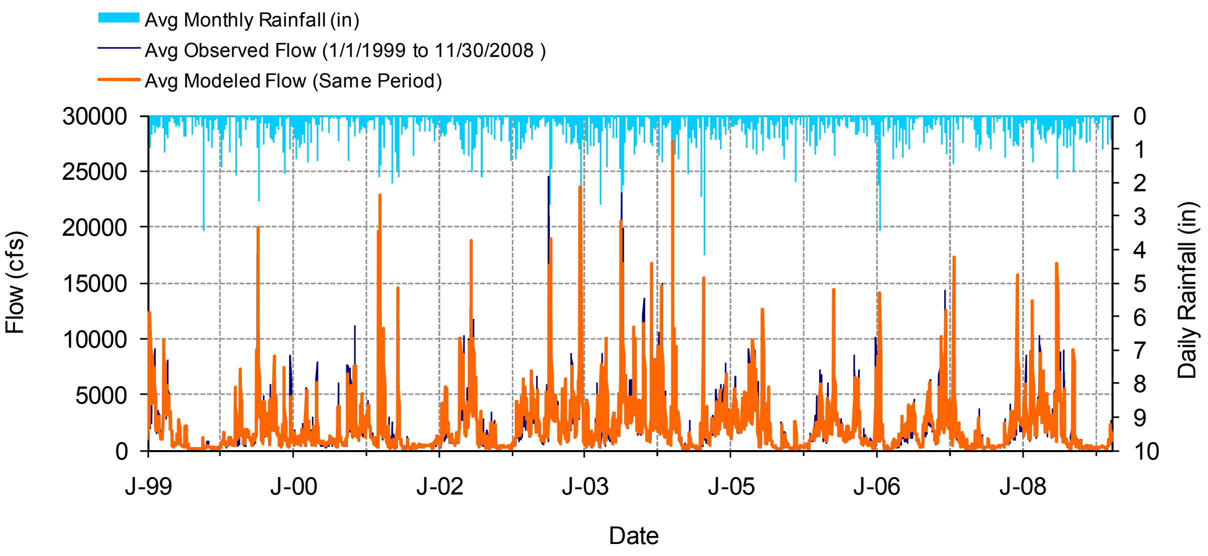


Figure 4-1. Comparison of simulated and observed flow for the calibration period (USGS station ID number 03197000 Elk River at Queen Shoals)

4.2. Sediment and Water Quality Calibration

A significant amount of time-varying monitoring data was necessary to calibrate the sediment and water quality portions of the model. Available monitoring data in the watershed were identified and assessed for application to calibration (**Appendix I**). Only monitoring stations with data that represented a range of hydrologic conditions, source types, and pollutants were selected. The WAB database provided very good spatial and temporal coverage of water quality data and was used extensively during calibration.

In addition, a detailed stormwater monitoring evaluation was performed by WVDEP on two small watersheds (Coalburg Branch and Shrewsbury Hollow), each draining only one landuse source. These were a surface mine and a forested area, respectively. Analysis of the data gathered provided the necessary information to inform the model parameterization and calibration for these two very significant landuse categories. The MDAS was set up to simulate the two small watersheds sampled during storm events. These two separate models were composed of one subwatershed, one stream reach, and one landuse each. The models were calibrated on an hourly time step, and the resulting parameters were used as initial values in the watershed models. **Appendix H** presents the results for the calibration of these sampling events.

The period selected for water quality calibration, June 1, 2007, through June 30, 2008 was the period for which pre-TMDL monitoring data were available. Permitted discharges that were issued permits after the calibration period were not considered during the calibration process.

Sediment

The MDAS water quality is a function of the hydrology. Sediment production is directly related to the intensity of surface runoff. Sediment yield varies by landuse and the characteristics of the land segment. Sediment is delivered to the streams through surface runoff erosion, direct point sources, and instream bank erosion. Once sediment reaches the stream channel, it can be transported, deposited and scoured, depending on the sediment size and flow energy. **Figure 4-2** shows a schematic of the sediment pathways.

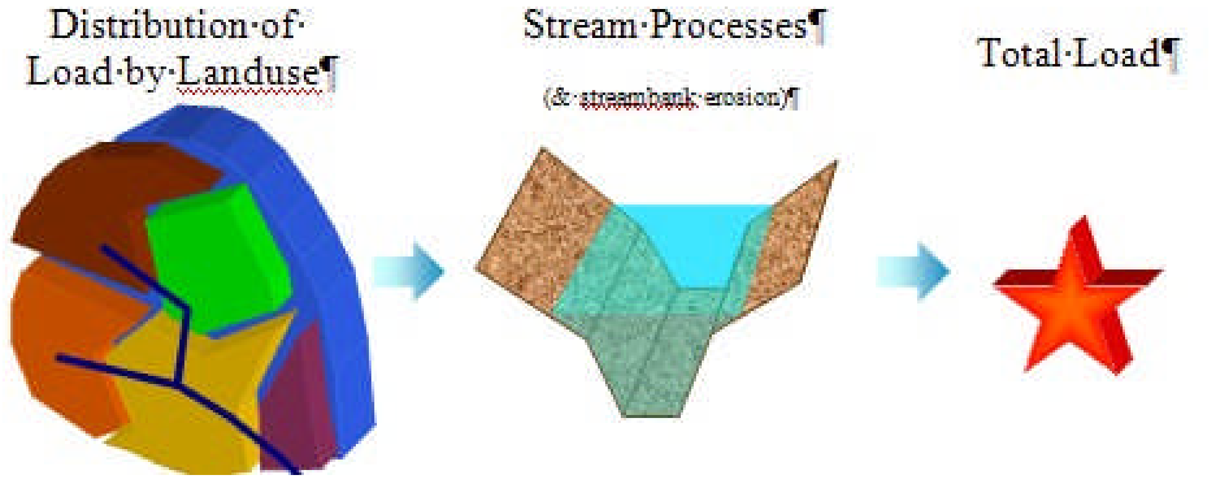


Figure 4-2. Schematic of sediment sources and transport pathways

MDAS model parameters were adjusted to obtain a calibrated model for sediment load. The erosion on pervious landuses was simulated as the result of soil detachment driven by rainfall precipitation and sediment transport with overland flow. The coefficient in the soil detachment equation (KRER) was estimated from the RUSLE erodibility values of specific soil types in the STATSGO soil database. The primary sediment parameter adjusted by landuses was the sediment washoff coefficient (KSER). Other relevant parameters for the land based sediment calibration such as daily reduction in detached sediment (AFFIX) and fraction land surface protected from rainfall (COVER) were estimated for each modeled landuse. Initial parameter values for the sediment parameters were based on available landuse specific storm sampling monitoring data and landuse specific unit area loading values from literature. Values were refined during the calibration process by comparing the simulated sediment concentration with the water quality data in the WAB database. Land based sediment calibration consisted of adjusting the KSER for each landuse according to their sediment producing capacities. Background landuses were assigned sediment loading similar to the forested areas of Shrewsbury Hollow. Most sediment producing landuses were assigned sediment loading similar to the ones derived from the surface mine sites of Coalburg Branch. Oil and gas, harvested forest, and burned forest landuses were assigned sediment parameters assuming a split of 1/2 barren and 1/2 forested.

Water Quality Calibration

Iron and aluminum loads are delivered to the tributaries with surface runoff, subsurface flows, and direct point sources. Sediment-producing landuses and bank erosion are also sources of total iron, since iron contents are relatively high in the soils in those watersheds. The MDAS provides mechanisms for representing all of these various pathways of pollutant delivery.

A detailed water quality analysis was performed using statistically based load estimates with observed flow and instream monitoring data. The confidence in the calibration process increases with the quantity and quality of the monitoring data. The WAB database provides very good spatial and temporal coverage of water quality data.

Statistical analyses using pre-TMDL monitoring data collected throughout the subject watersheds were performed to establish the correlation between iron loads and sediment loads and to evaluate spatial variability. The results were then applied to the sediment-producing landuses during the water quality calibration phase of the MDAS. The results of the correlation analysis are shown in **Appendix B**.

In addition, non-sediment-related iron and aluminum land-based sources were modeled using average concentrations for the surface, interflow and groundwater portions of the water budget. For these situations, discharges were represented in the model by adjusting parameters affecting pollutant concentrations in the PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules of the MDAS.

For the permitted mining land-based sources, parameters developed from the Coalburg Branch model set-up were initially used. Concentrations from these mines were adjusted to make them consistent with typical discharge characteristics from similar mining activities or to match site-specific instream monitoring data.

For AML areas, parameters to simulate iron and aluminum loads were developed by calibrating subwatersheds where the only significant source of metals were the AML lands.

To validate the sediment/metals model, daily average instream concentrations from the model were compared directly with observed data at several locations throughout the watershed. The goal was to confirm that low flow, mean flow, and storm peaks at water quality monitoring stations draining mixed landuse areas were being represented. The representative stations were selected based on location (distributed throughout the TMDL watersheds) and loading source type. Results of the water quality calibration and validation are presented in **Appendix H**.

For fecal coliform model water quality calibration, fecal coliform build-up and limit parameters specific to modeled landuses were adjusted to calibrate the model. Modeled fecal coliform concentrations from failing septic systems were adjusted to best represent fecal loading in impaired streams. Results from fecal coliform water quality calibration are also presented in **Appendix H**.

5.0 TMDL ALLOCATION ANALYSIS FOR FECAL COLIFORM BACTERIA, METALS, AND PH

A TMDL is the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. In addition, the TMDL must include a margin of safety (MOS), implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. TMDLs can be expressed in terms of mass per time or other appropriate measures. Conceptually, this definition is denoted by the equation

TMDL = sum of WLAs + sum of LAs + MOS

To develop aluminum, iron, pH, and fecal coliform bacteria TMDLs for each of the waterbodies, the following approach was taken:

- Define TMDL endpoints.
- Simulate baseline conditions.
- Assess source loading alternatives.
- Determine the TMDL and source allocations.

5.1. TMDL Endpoints

TMDL endpoints represent the water quality targets used to quantify TMDLs and their individual components. In general, West Virginia's numeric water quality criteria for the subject pollutants and an explicit five percent MOS were used to identify endpoints for TMDL development.

The five percent explicit MOS was used to counter uncertainty in the modeling process. Long-term water quality monitoring data were used for model calibration. Although these data represented actual conditions, they were not of a continuous time series and might not have captured the full range of instream conditions that occurred during the simulation period. The explicit five percent MOS also accounts for those cases where monitoring might not have captured the full range of instream conditions.

The TMDL endpoints for the various criteria are displayed in **Table 5-1**.

Table 5-1. TMDL endpoints

Water Quality Criterion	Designated Use	Criterion Value	TMDL Endpoint
Total Iron	Aquatic life, warmwater fisheries	1.5 mg/L (4-day average)	1.425 mg/L (4-day average)
Total Iron	Aquatic life, troutwaters	1.0 mg/L (4-day average)	0.95 mg/L (4-day average)
Dissolved Aluminum	Aquatic life, warmwater fisheries	0.75 mg/L (1-hour average)	0.7125 mg/L (1-hour average)
Dissolved Aluminum	Aquatic life, troutwaters	0.087 mg/L (4-day average)	0.0827 mg/L (4-day average)
Total Selenium	Aquatic life, warmwater fisheries	0.005 mg/L (4-day average)	0.005 mg/L (4-day average)
Fecal Coliform	Water Contact Recreation and Public Water Supply	200 counts / 100 mL (Monthly Geometric Mean)	190 counts / 100 mL (Monthly Geometric Mean)
Fecal Coliform	Water Contact Recreation and Public Water Supply	400 counts / 100 mL (Daily, 10% exceedance)	380 counts / 100 mL (Daily, 10% exceedance)

Water Quality Criterion	Designated Use	Criterion Value	TMDL Endpoint
pH	Aquatic Life	6.00 Standard Units (Minimum)	6.02 Standard Units (Minimum)

With the exception of selenium, TMDLs are presented as average annual loads that were developed to meet TMDL endpoints under a range of conditions observed throughout the year. Equivalent, daily average TMDLs are also presented. For most pollutants, analysis of available data indicated that critical conditions occur during both high- and low-flow events. To appropriately address the low- and high-flow critical conditions, the TMDLs were developed using continuous simulation (modeling over a period of several years that captured precipitation extremes), which inherently considers seasonal hydrologic and source loading variability. Because the selenium impairments have been attributed to point source discharges and low-flow critical conditions, the TMDLs are presented as an equation for the maximum daily load that is variable with receiving stream flow.

5.2. Baseline Conditions and Source Loading Alternatives

The calibrated model provided the basis for performing the allocation analysis. The first step in this analysis involved the simulation of baseline conditions. Baseline conditions represent existing nonpoint source loadings and point sources loadings at permit limits. Baseline conditions allow for an evaluation of instream water quality under the highest expected loading conditions.

The MDAS model was run for baseline conditions using hourly precipitation data for a representative six-year time period (1998 to 2003). The precipitation experienced over this period was applied to the landuses and pollutant sources as they existed at the time of TMDL development. Predicted instream concentrations were compared directly with the TMDL endpoints. Using the model linkage described in **Section 3.4**, the MDAS model was used to compare predicted dissolved aluminum concentrations and pH value with the TMDL endpoint. This comparison allowed for the evaluation of the magnitude and frequency of exceedances under a range of hydrologic and environmental conditions, including dry periods, wet periods, and average periods.

Figure 5-1 and Figure 5-2 presents examples of the annual rainfall totals for the years 1990 through 2008 at the Charleston and Moorefield weather stations in West Virginia. Charleston precipitation information was used in the Elk River model and Moorefield data was used in the North Branch Potomac River watershed model. The years 1998 to 2003 are highlighted to indicate that a range of precipitation conditions used for TMDL development.

Permitted conditions for mining facilities were represented during baseline conditions using precipitation-driven flow estimations and the metals concentrations presented in **Table 5-1** (above). Permitted conditions for fecal coliform bacteria point sources were represented during baseline conditions using the design flow for each facility and the monthly geometric mean effluent limitation of 200 counts/100 mL.

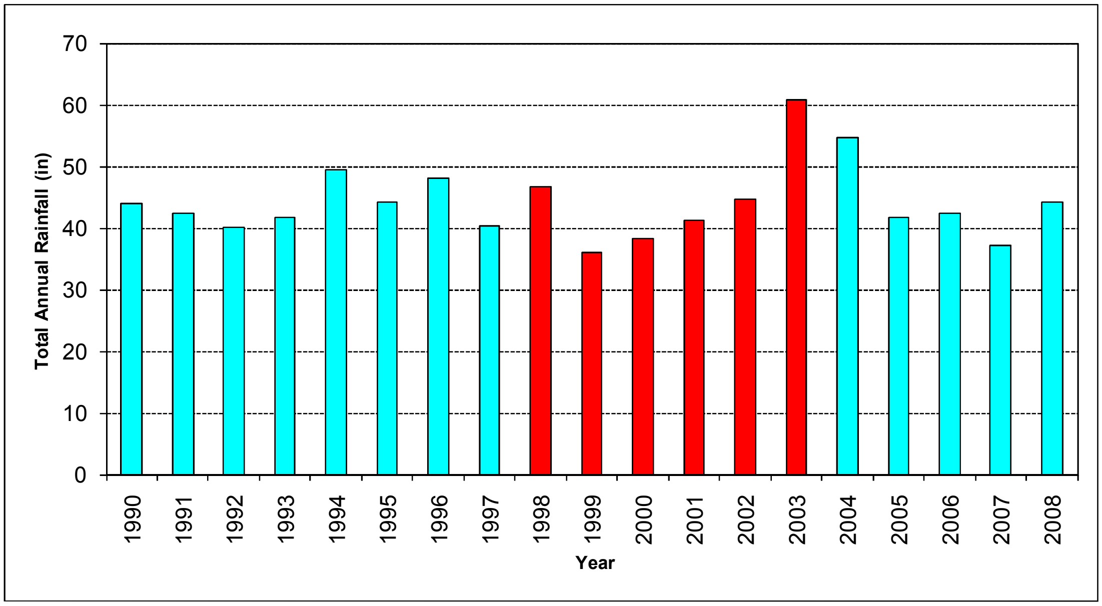


Figure 5-1. Annual precipitation totals for the Charleston (WV1570) weather station in West Virginia

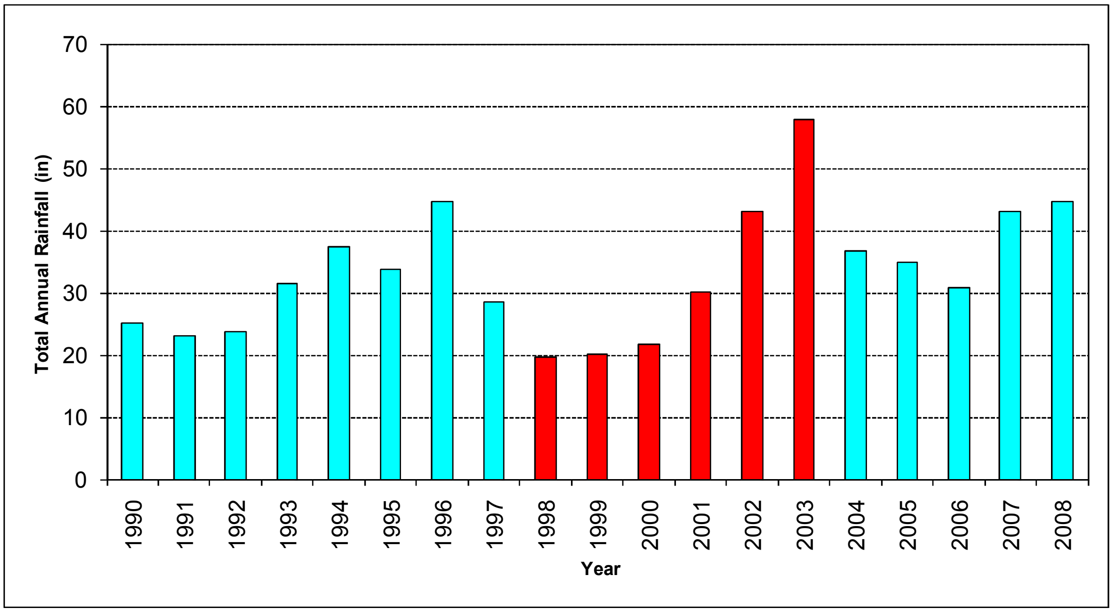


Figure 5-2. Annual precipitation totals for the Moorefield (WV6163) weather station in West Virginia

Multiple allocation scenarios were run for the impaired waterbodies. Successful scenarios were those which achieved the TMDL endpoints under all flow conditions throughout the modeling period. The averaging period and allowable exceedance frequency associated with West Virginia water quality criteria were considered in these assessments. In general, loads contributed by sources that had the greatest impact on instream concentrations were reduced first. If additional load reductions were required to meet the TMDL endpoints, subsequent reductions were made to less significant source contributions.

Modeling for allocation conditions required running a number of scenarios, including a baseline scenario and multiple allocation scenarios. The period of 1998 to 2003, which represents a range of precipitation conditions, was applied to the sources that are present today for the allocation scenario. For the allocation conditions, all surface mining operations were represented using precipitation-driven nonpoint source processes in the model. Under nonpoint source representation, flow was estimated in a manner similar to other nonpoint sources in the watershed (i.e., based on precipitation and hydrologic properties). This approach is consistent with WVDMR's estimation that discharges from most surface mines are precipitation-driven (WVDEP, 2000b). Discharges from deep mines are typically continuous-flow and were represented as continuous flow point sources at their maximum pumping capacities. Under baseline conditions, the concentration of metals from point source discharges, including NPDES mining permits, was consistent with permit limits; i.e., the WLA is based on permit limits. During the allocation scenario, reductions were applied to AML, sediment-producing lands, and active mines to achieve instream TMDL endpoints.

Mining discharge permits have either technology-based or water quality-based limits. Monthly average and maximum daily permit concentrations for technology-based limits are 3.0 mg/L and 6.0 mg/L, respectively, for total iron. Permitted discharges with water quality-based limits must meet instream water quality criteria at end-of-pipe. In regard to aluminum, some permits contain specific limitations whereas others require only self-monitoring. Under baseline conditions, mining point sources were grouped into two categories (technology-based and water quality-based) and assigned concentrations based on their existing effluent limits, as shown in **Table 5-2**. For technology-based permits, the wasteload concentration for aluminum was assumed to be the 95th percentile value of the available discharge monitoring report data for mining discharges in the Elk River watershed (0.94 mg/L). Permits with existing permit limits less than water-quality based effluent limitations were assigned water quality-based concentrations.

Table 5-2. Metals concentrations used in representing permitted conditions for mines

Pollutant	Technology-based Permits	Water Quality-based Permits
Aluminum, total	0.94 mg/L (95th percentile discharge monitoring report values)	0.75 mg/L
Iron, total	3.2 mg/L	1.5 mg/L

An example of model output for a baseline condition and a successful TMDL scenario is displayed in **Figure 5-3**.

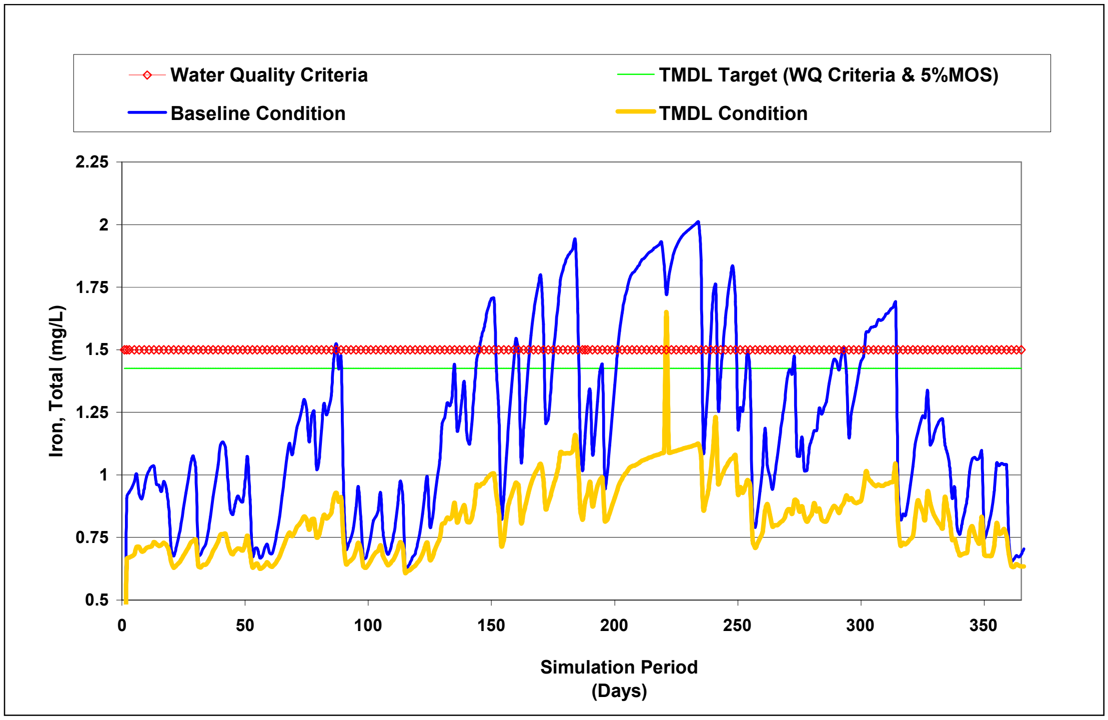


Figure 5-3. Example of baseline and TMDL conditions for iron

5.3. Allocation Methodology

TMDLs and source allocations were developed on a subwatershed basis for each of the three watersheds. A top-down methodology was followed to develop these TMDLs and allocate loads to sources. Headwaters were analyzed first because their loading affects downstream water quality. Loading contributions were reduced from applicable sources in impaired headwaters until criteria were attained at the outlet of the subwatershed. The loading contributions of unimpaired headwaters and the reduced loadings for impaired headwaters were then routed through downstream waterbodies. Using this method, contributions from all sources were weighted equitably. Reductions in sources affecting impaired headwaters ultimately led to improvements downstream and effectively decreased necessary loading reductions from downstream sources. Nonpoint source reductions did not result in loadings less than natural conditions, and point source allocations were not more stringent than numeric water quality criteria. Watershed-specific allocations spreadsheets are presented in the individual public reports.

5.3.1. Fecal Coliform Bacteria TMDLs

The following general methodology was used when allocating loads to sources for the fecal coliform bacteria TMDLs; all point sources in the watersheds were set at the permit limit (200 counts/100 mL monthly geometric mean). Because WV Bureau of Public Health (BPH) prohibits the discharge of raw sewage into surface waters, all illicit, non-disinfected discharges of human waste (from failing septic systems and straight pipes) were eliminated. If further reduction was necessary, combined sewer overflows (CSOs) and nonpoint source loadings from agricultural lands and residential areas were subsequently reduced until instream water quality criteria were met.

Wasteload Allocations (WLAs)

WLAs were developed for sewage treatment plant effluents, CSO discharges and municipal separate storm sewer system (MS4s), where applicable.

Load Allocations (LAs)

Fecal coliform bacteria LAs were assigned to the following source categories:

- Pasture and Cropland
- Background & Other Nonpoint Sources (loading associated with wildlife sources from forested land [contributions/loadings from wildlife sources were not reduced])
- Onsite Sewer Systems (loading from all illicit, non-disinfected discharges of human waste [including failing septic systems and straight pipes])
- Residential (loading associated with urban/residential runoff from non-MS4 areas)

5.3.2. Total Iron TMDLs

Source allocations were developed for all modeled subwatersheds contributing to the iron impaired streams. Nonpoint source reductions did not result in allocated loadings less than natural conditions. Allocations to continuous flow sources were no more stringent than water quality criteria.

Due to the highly erodible soils that are present in the watershed, land disturbing activities and stream bank erosion cause widespread nonattainment of the total iron criterion. In some subwatersheds, multiple source categories contribute problematic loadings during precipitation events and in others existing sources are limited to a particular category. The magnitude of predicted nonattainment is generally correlated to the amount of disturbed land within the subwatershed.

Although limited in this watershed, abandoned mine land (AML) influences and active mining discharges were shown to impact water quality in some watersheds where they were present. Non-mining discharges in compliance with existing permit limitations were not determined to be problematic.

The following methodology was used when allocating to iron sources.

- In watersheds influenced by AML, iron loadings were reduced until the water quality criterion was attained or until practical limits were reached.
- The loading from streambank erosion was reduced to the loading characteristics associated with the upper 5th percentile of observed bank conditions.
- For equity with permitted construction activities and among the various categories of sediment sources of iron, baseline loadings from harvested forest, oil and gas, barren,

unpaved roads, agriculture and pervious urban/residential landuses were reduced to the iron loadings associated with a 100 mg/l Total Suspended Solids discharge level.

- In watersheds influenced by active mining, discharges were reduced until instream water quality criterion was attained. The model predicted attainment for the majority of subwatersheds after this allocation step.
- If further reduction was necessary, an analysis of the relative existing areas of all land disturbing source categories was performed. If an individual source category comprised 75% or greater of the total disturbed area of a subwatershed, then additional reductions were prescribed only for that source category until the model predicted criterion attainment. If an individual source category was not prevalent (less than 75% of subwatershed disturbed area), then additional reductions were prescribed for all land disturbing sources until model predicted criterion attainment.

The flow chart presented in TMDLs and Source Allocations Section of the Public Reports displays the total iron allocation methodology.

Wasteload Allocations (WLAs)

WLAs were developed for all point sources permitted to discharge iron under a NPDES permit. Because of the established relationship between iron and TSS, iron WLAs are also provided for facilities with stormwater discharges that are regulated under NPDES permits that contain TSS and/or iron effluent limitations or benchmarks values, MS4 facilities, and facilities registered under the General NPDES permit for construction stormwater.

Active Mining Operations

WLAs are provided for all existing outlets of NPDES permits for mining activities, except those where reclamation has progressed to the point where existing limitations are based upon the Post-Mining Area provisions of Subpart E of 40 CFR 434. The WLAs for active mining operations consider the functional characteristics of the permitted outlets (i.e. precipitation driven, pumped continuous flow, gravity continuous flow, commingled) and their respective impacts at high and low flow conditions.

The federal effluent guidelines for the coal mining point source category (40 CFR 434) provide various alternative limitations for discharges caused by precipitation. Under those technology-based guidelines, effluent limitations for total iron and TSS may be replaced with an alternative limitation for “settleable solids” during certain magnitude precipitation events that vary by mining subcategory. The water quality-based WLAs and future growth provisions of the iron TMDLs preclude the applicability of the “alternative precipitation” iron provisions of 40 CFR 434. Also, the established relationship between iron and TSS requires continuous control of TSS concentration in permitted discharges to achieve iron WLAs. As such, the “alternative precipitation” TSS provisions of 40 CFR 434 should not be applied to point source discharges associated with the iron TMDLs.

In certain instances, prescribed WLAs may be less stringent than existing effluent limitations. However, the TMDLs are not intended to relax effluent limitations that were developed under the alternative basis of WVDEP’s implementation of the antidegradation provisions of the Water Quality Standards, which may result in more stringent allocations than those resulting from the TMDL process. Whereas TMDLs prescribe allocations that minimally achieve water quality criteria (i.e. 100 percent use of a stream’s assimilative capacity), the antidegradation provisions of the standards are designed to maintain the existing quality of high-quality waters. Antidegradation provisions may result in more stringent allocations that limit the use of remaining assimilative capacity. Also, water quality-based effluent limitations developed in the NPDES permitting process may dictate more stringent effluent limitations for discharge locations that are upstream of those considered in the TMDLs. TMDL allocations reflect pollutant loadings that are necessary to achieve water quality criteria at distinct locations (i.e., the pour points of delineated subwatersheds). In contrast, effluent limitation development in the permitting process is based on the achievement/maintenance of water quality criteria at the point of discharge.

Specific WLAs are not provided for “post-mining” outlets because programmatic reclamation was assumed to have returned disturbed areas to conditions that approach background. Barring unforeseen circumstances that alter their current status, such outlets are authorized to continue to discharge under the existing terms and conditions of their NPDES permit.

Discharges regulated by the Multi Sector Stormwater Permit

Certain registrations under the general permit for stormwater associated with industrial activity implement TSS and/or iron benchmark values. Facilities that are compliant with such limitations are not considered to be significant sources of sediment or iron. Facilities that are present in the watersheds of iron-impaired streams are assigned WLAs that allow for continued discharge under existing permit conditions.

Municipal Separate Storm Sewer System (MS4)

USEPA’s stormwater permitting regulations require municipalities to obtain permit coverage for stormwater discharges from MS4s. In the TMDL watersheds of the Elk and Lower Kanawha River there are five designated MS4 entities. Each entity will be registered under, and subject to, the requirements of General Permit Number WV0110625. The stormwater discharges from MS4s are point sources for which the TMDLs prescribe wasteload allocations. Individual registration numbers for the MS4 entities are as follows:

• City of Charleston	WVR030006
• City of Hurricane/Storm Water Board	WVR030010
• City of Nitro	WVR030027
• City of South Charleston	WVR030001
• WV Department of Transportation	WVR030004

In the majority of the subwatersheds where MS4 entities have areas of responsibility, the urban, residential and road landuses strongly influence bank erosion. As such, portions of the baseline and allocated loads associated with bank erosion are included in the MS4 wasteload allocations. The subdivision of the bank erosion component between point and nonpoint sources, and where applicable, between multiple MS4 entities, is proportional to their respective drainage areas within each subwatershed. Model representation of bank erosion is accomplished through consideration of a number of inputs including slope, soils, imperviousness, and the stability of existing streambanks. Bank erosion loadings are most strongly influenced by upland impervious area and bank stability. The decision to include bank erosion in the MS4 wasteload allocations results from the predominance of urban/residential/road landuses and impacts in MS4 areas. WVDEP's assumption is that management practices will be implemented under the MS4 permit to directly address impacts from bank erosion. However, even if the implementation of stormwater controls on uplands is maximized, and the volume and intensity of stormwater runoff are minimized, the existing degraded stability of streambanks may continue to accelerate erosion. The erosion of unstable streambanks is a nonpoint source of sediment that is included in the MS4 allocations. Natural attenuation of legacy impacts cannot be expected in the short term, but may be accelerated by bank stabilization projects. The inclusion of the bank erosion load component in the wasteload allocations of MS4 entities is not intended to prohibit or discourage cooperative bank stabilization projects between MS4 entities and WVDEP's Nonpoint Source Program, or to prohibit the use of Section 319 funding as a component of those projects.

Construction Stormwater

Specific WLAs for future activity under the Construction Stormwater General Permit are provided at the subwatershed. An allocation of 1.5 or 2.5 percent of subwatershed area was provided with loadings based upon precipitation and runoff and an assumption that proper installation and maintenance of required BMPs will achieve a TSS benchmark value of 100 mg/L. The existing level of activity under the Construction Stormwater General Permit conforms to the subwatershed allocations. As such, specific WLAs for existing registrations under the General Permit are not presented.

Load Allocations (LAs)

LAs are made for the dominant nonpoint source categories as follows:

- AML: loading from abandoned mine lands, including loads from disturbed land, highwalls, deep mine discharges and seeps
- Sediment sources: loading associated with sediment contributions from barren land, harvested forest, oil and gas well operations, agricultural landuses, and residential/urban/road landuses and streambank erosion in non-MS4 areas
- Background and other nonpoint sources: loading from undisturbed forest and grasslands (loadings associated with this category were represented but not reduced)

5.3.3. Dissolved Aluminum and pH TMDLs

Source allocations were developed for all modeled subwatersheds contributing to the dissolved aluminum and/or pH impaired streams of the Elk River watershed. Sources of total iron were reduced prior to total aluminum reduction because existing instream iron concentrations can significantly reduce pH and consequently increase dissolved aluminum concentrations. The dissolved aluminum and pH TMDL endpoints were not attained after source reductions to iron, therefore the total aluminum loading from AMLs was reduced in combination with acidity reduction (via alkalinity addition) to the extent necessary to attain the water quality criteria for both pH and dissolved aluminum. The following methodology was used when allocating aluminum loadings and/or prescribing acidity reductions:

- For subwatersheds with acidic atmospheric deposition sources and low watershed buffering capacity and no AML sources, acidity load reductions were prescribed (via alkalinity addition) to the extent necessary to attain pH criteria at the subwatershed outlet.
- For subwatersheds with historical mining sources present, the predicted acid loads from atmospheric deposition were first offset by alkalinity addition then the total aluminum loading from AMLs were reduced to the extent necessary to attain dissolved aluminum water quality criteria.

All sources were represented and provided allocations in terms of the total aluminum loadings that are necessary to attain the dissolved aluminum water quality criteria. The reductions of total aluminum loading from land-based sources, coupled with the mitigation of acid precipitation impacts by alkalinity addition, are predicted to result in attainment of both dissolved aluminum and pH water quality criteria at all evaluated locations in the pH and dissolved aluminum impaired streams.

Wasteload Allocations (WLAs)

WLAs were developed for all point sources permitted to discharge aluminum under a NPDES permit. Active Mining Operations WLAs are provided for all existing outlets of NPDES permits for mining activities, except those where reclamation has progressed to the point where existing limitations are based upon the Post-Mining Area provisions of Subpart E of 40 CFR 434. The WLAs for active mining operations consider the functional characteristics of the permitted outlets (i.e. precipitation driven, pumped continuous flow, gravity continuous flow, commingled) and their respective impacts at high- and low-flow conditions.

Load Allocations (LAs)

LAs of total aluminum are made for contributing nonpoint source categories as follows:

- AML: loading from abandoned mine lands, including loads from disturbed land, highwalls, deep mine discharges and seeps
- Other nonpoint sources: loading associated with sediment contributions from barren land, harvested forest, oil and gas well operations, agriculture, undisturbed forest and grasslands, and residential/urban/road landuses were represented but not reduced

Baseline and TMDL load allocations (LAs) include the natural background sources of alkalinity from carbonate geologic formations. The additional acidity reduction (alkalinity addition) required to meet pH water quality criterion are presented in the TMDL load allocations for the pH impaired streams.

5.3.4. Selenium TMDLs

The selenium TMDLs are based upon the assimilative capacity of the receiving streams at the predicted 7-day, 10-year (7Q10) low flow. The USGS south central equation was used to estimate 7Q10 flows absent any influence of deep mine discharges. Estimated low flows were partitioned between permitted and dilution flow by area weighting using permit bonded area. Deep mine flows were added and mass balancing produced wasteload allocations for permitted discharges under a “top down” allocation methodology. Headwaters were analyzed first because their loading affects downstream water quality. Loading contributions were reduced from applicable sources in impaired headwaters until criteria were attained at the subwatershed outlet. The loading contributions of unimpaired headwaters and the reduced loadings for impaired headwaters were then routed through downstream waterbodies. Using this method, contributions from all sources were weighted equitably and ensured cumulative load endpoints were met at the most downstream subwatershed for each impaired stream. Reductions in sources affecting impaired headwaters ultimately led to improvements downstream and effectively decreased necessary loading reductions from downstream sources.

The derived wasteload allocations ensure attainment of the chronic aquatic life criterion at all subwatershed pour points at critical low flow conditions. The level of control necessary to achieve criteria during low flow conditions is also protective during higher flow periods when increased dilution is available. A summary of the selenium assessments is provided as **Appendix J.**

The approach presents uniform wasteload allocations for all permitted mining discharges in each modeled subwatershed that are calculated to protect the criterion at the subwatershed pour point. But the approach does not necessarily protect the criterion at the immediate discharge location and any allocations greater than “criterion end-of-pipe” would be inconsistent with the applicable water quality-based effluent limitation development protocols for instream treatment structures and/or pumped or gravity flow deep mine discharges that are active during low flow conditions. For that reason, an additional set of allocations, equal to the chronic criterion value, are prescribed for all deep mine discharges and discharges from instream treatment operations. TMDL implementation for the instream/deep mine subset of discharges provides a substantive implicit margin of safety for the selenium TMDLs.

5.3.5. Dissolved Oxygen TMDLs

The dissolved oxygen impairment of Little Five Mile Creek (WV-KL-7-A) is directly related to an animal confinement/feeding operation located within 50 meters of a stream monitoring location (KL-00083-0.8). Significant accumulations of animal wastes were routinely observed on the stream banks and substrate in the vicinity of the monitoring station. Pre-TMDL monitoring also documented extreme nonattainment with fecal coliform water quality criteria at this location and source tracking activities clearly identify the causative source of both impairments.

A fecal coliform TMDL is presented for Little Five Mile Creek Successful implementation of the 98.5% fecal coliform reduction prescribed for agriculture in the watershed (model subwatershed 30139) would necessitate installation of BMPs to cease releases of animal wastes to the stream which, in turn, would result in attainment of the dissolved oxygen criterion. As such, the Little

Five Mile Creek fecal coliform TMDL is an appropriate surrogate for the dissolved oxygen impairment.

5.4. Seasonal Variation

Seasonal variation was considered in the formulation of the modeling analysis. Continuous simulation (modeling over a period of several years that captures precipitation extremes) inherently considers seasonal hydrologic and source loading variability**.** Pollutant concentrations simulated on a daily time step by the model were compared with TMDL endpoints. Allocations that met these endpoints throughout the modeling period were developed.

5.4. Critical Conditions

TMDL developers must select the environmental conditions that will be used for defining allowable loads. Many TMDLs are designed around the concept of a "critical condition." The critical condition is the set of environmental conditions, which, if met, will ensure the attainment of objectives for all other conditions. Analysis of water quality data for the impaired streams addressed in this effort shows high pollutant concentrations for certain pollutants during both high- and low-flow thereby precluding selection of a single critical condition. Both high-flow and low-flow periods were taken into account during TMDL development by using a long period of weather data that represented wet, dry, and average flow periods.

Nonpoint source loading is typically precipitation-driven. Instream impacts tend to occur during wet weather and storm events that cause surface runoff to carry pollutants to waterbodies. During dry periods, little or no land-based runoff occurs, and elevated instream pollutant levels may be due to point sources (Novotny and Olem, 1994). However, failing on-site sewage systems and AML seeps (both categorized as nonpoint sources but represented as continuous flow discharges) often have an associated low-flow critical condition, particularly where such sources are located on small receiving waters.

6.0 SEDIMENT REFERENCE WATERSHED APPROACH

SI results indicated a need to reduce the contribution of excess sediment to many biologically impaired streams. Excessive sedimentation was determined to be a primary cause of biological impairment in these streams through habitat degradation, substrate embeddedness, and other direct and indirect impacts on the stream biota. A reference watershed approach was used during the SI process to quantify an acceptable level of sediment loading for each impaired stream on a watershed-specific basis. This approach was based on selecting an unimpaired watershed that shares similar landuse, ecoregion, and geomorphological characteristics with the impaired watershed. Stream conditions in the reference watershed are assumed to be representative of the conditions needed for the impaired stream to attain its designated uses. Given these parameters and an unimpaired WVSCI score, the reference watersheds for the Elk River and Lower Kanawha River watersheds are Higby Run (WV-KL-57-BH-3) and Groves Creek (WV-KE-118), respectively. The locations of the reference subwatersheds are shown in **Figure 6-1 and Figure 6-2.**

Sediment loading rates were determined for impaired and reference watersheds through modeling studies. Both point and nonpoint sources were considered in the analysis of sediment sources and in watershed modeling. Numeric endpoints were based on the calculated reference watershed loading. Sediment load reductions necessary to meet these endpoints were then determined. TMDL allocation scenarios were developed based on an analysis of the degree to which contributing sources could be reasonably reduced.

Sediment models were developed using the MDAS. A variety of GIS tools, local watershed data, and site visit observations were used to develop the input data needed for modeling and TMDL development. Data were collected for impaired and reference streams in each watershed.

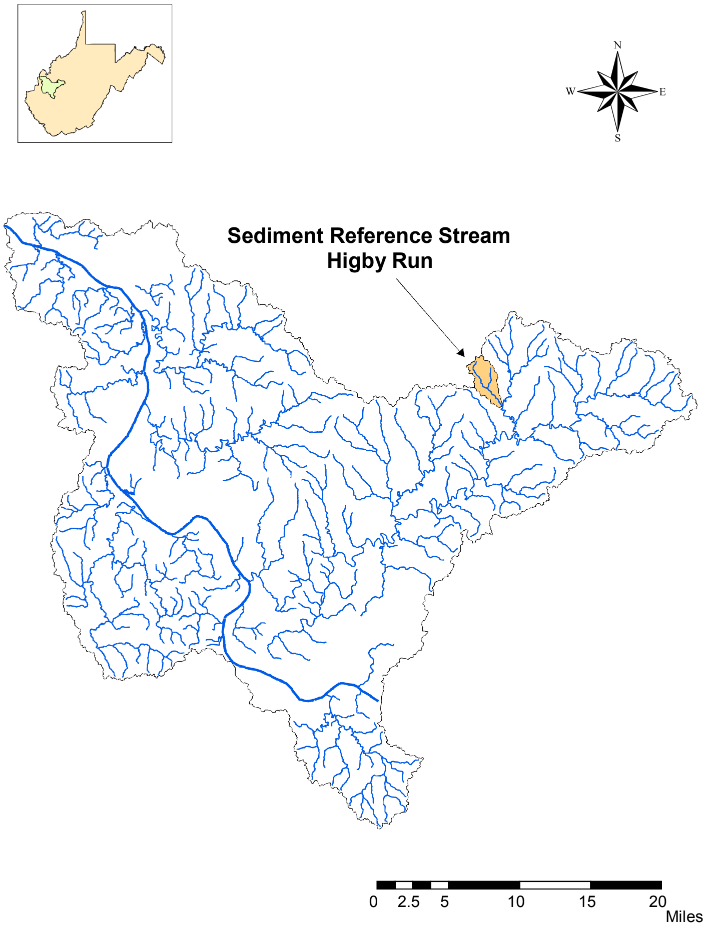


Figure 6-1. Location of the Higby Run (WV-KL-57-BH-3) sediment reference watershed

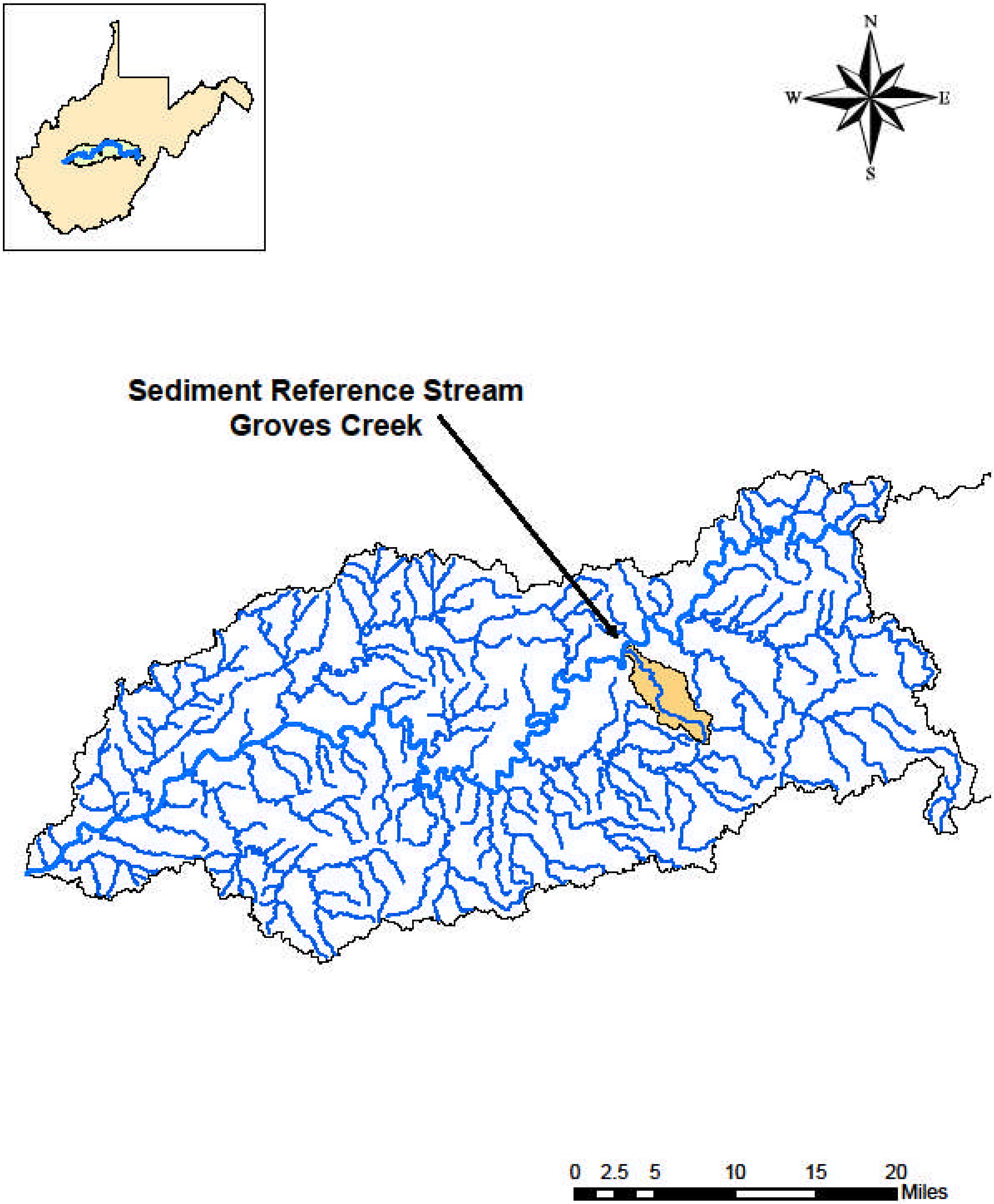


Figure 6-2. Location of the Groves Creek (WV-KE-118) sediment reference watershed

Upon finalization of modeling, it was determined that all of the sediment-impaired streams exhibited impairments pursuant to total iron water quality criteria, and that the sediment reductions that are necessary to ensure compliance with iron criteria exceed those necessary to resolve biological impairments. As such, the iron TMDLs presented for the subject waters are appropriate surrogates for necessary sediment TMDLs. For affected streams, **Table 6-1** contrasts the sediment reductions necessary to attain iron criteria with those needed to resolve biological impairment under the reference watershed approach.

Table 6-1. Sediment loadings using different modeling approaches in the Group B2 watersheds

Watershed	Stream Name	Stream Code	Allocated Sediment Load Iron TMDL (tons/yr)	Allocated Sediment Load Reference Approach (tons/yr)
Elk	Aarons Fork	WV-KE-13-G	127	213
Elk	Big Fork	WV-KE-13-F-2	18	27
Elk	Big Otter Creek	WV-KE-108	802	837
Elk	Big Sandy Creek	WV-KE-29	2676	4189
Elk	Blue Creek	WV-KE-18	1888	2501
Elk	Coonskin Branch	WV-KE-6	14	25
Elk	Granny Creek	WV-KE-159	171	223
Elk	Grassy Fork	WV-KE-70-M-2	21	62
Elk	Hurricane Creek	WV-KE-29-G-4	166	247
Elk	Indian Creek	WV-KE-12	174	255
Elk	Kaufman Branch	WV-KE-10-K	7	12
Elk	Leatherwood Creek	WV-KE-83	251	739
Elk	Leatherwood Creek (Clendenin)	WV-KE-27	173	279
Elk	Left Hand Creek	WV-KE-29-G	581	932
Elk	Little Otter Creek	WV-KE-151	242	386
Elk	Little Sandy Creek	WV-KE-13	1029	1586
Elk	Newhouse Branch	WV-KE-4	45	37
Elk	Old Woman Run	WV-KE-161	20	30
Elk	Poca Fork	WV-KE-13-O	117	168
Elk	Queen Shoals Creek	WV-KE-37	113	171
Elk	UNT/Porter Creek RM 5.49	WV-KE-44-M	13	25
Elk	Upper Mill Creek	WV-KE-138	102	175
Elk	Wills Creek	WV-KE-13-F	221	265
Lower Kanawha	Armour Creek	WV-KL-60	265	603
Lower Kanawha	Blakes Creek	WV-KL-60-C	104	266
Lower Kanawha	Bills Creek	WV-KL-56	64	229
Lower Kanawha	Coal Hollow	WV-KL-74-L	46	105
Lower Kanawha	Davis Creek	WV-KL-74	1439	4223
Lower Kanawha	Rays Branch	WV-KL-74-G	78	174
Lower Kanawha	Trace Fork	WV-KL-74-C	285	809
Lower Kanawha	Buckelew Hollow	WV-KL-27-AK	23	92

Watershed	Stream Name	Stream Code	Allocated Sediment Load Iron TMDL (tons/yr)	Allocated Sediment Load Reference Approach (tons/yr)
Lower Kanawha	Jakes Run	WV-KL-27-H	28	117
Lower Kanawha	Saltlick Creek	WV-KL-27-X-8	68	229
Lower Kanawha	UNT/Five and Twenty Mile Creek RM 7.41	WV-KL-35-H	32	127
Lower Kanawha	Gallatin Branch	WV-KL-64	42	121
Lower Kanawha	Cow Creek	WV-KL-42-I-4	65	337
Lower Kanawha	Hurricane Creek	WV-KL-42	1810	6868
Lower Kanawha	Long Branch	WV-KL-42-I-10	58	253
Lower Kanawha	Mill Creek	WV-KL-42-U	210	581
Lower Kanawha	Poplar Fork	WV-KL-42-I	562	2269
Lower Kanawha	Rider Creek	WV-KL-42-AO	25	118
Lower Kanawha	Sleepy Creek	WV-KL-42-N	210	1005
Lower Kanawha	UNT/Crooked Creek RM 0.72	WV-KL-42-I-16-B	16	62
Lower Kanawha	Joplin Branch	WV-KL-77	61	138
Lower Kanawha	UNT/Little Buffalo Creek RM 1.17	WV-KL-40-A	32	130
Lower Kanawha	Upper Ninemile Creek	WV-KL-12-B	81	369
Lower Kanawha	Boardtree Run	WV-KL-57-AA-4	10	69
Lower Kanawha	Camp Creek	WV-KL-57-AT	29	122
Lower Kanawha	Grapevine Creek	WV-KL-57-AA	162	804
Lower Kanawha	Harmond Creek	WV-KL-57-K	51	263
Lower Kanawha	Kelly Creek	WV-KL-57-Q	102	482
Lower Kanawha	Leatherwood Creek	WV-KL-57-AO	132	452
Lower Kanawha	Mckown Creek	WV-KL-57-BQ	117	441
Lower Kanawha	Middle Fork/Pocatalico Creek	WV-KL-57-AD-2	677	2640
Lower Kanawha	Pocatalico Creek	WV-KL-57-AD	1497	5814
Lower Kanawha	Pocatalico River	WV-KL-57	7679	31910
Lower Kanawha	Raccoon Creek	WV-KL-57-AL	48	204
Lower Kanawha	Rocky Fork	WV-KL-57-L	524	1702
Lower Kanawha	Straight Creek	WV-KL-57-AX	29	181
Lower Kanawha	Pond Branch	WV-KL-17	156	397
Lower Kanawha	Rockstep Run	WV-KL-63-C	55	182
Lower Kanawha	Scary Creek	WV-KL-63	252	841
Lower Kanawha	UNT/Scary Creek RM 0.14	WV-KL-63-A	8	41
Lower Kanawha	UNT/UNT RM 0.33/Scary Creek RM 2.13	WV-KL-63-E-1	24	104
Lower Kanawha	Poplar Fork	WV-KL-19-N	202	822
Lower Kanawha	Threemile Creek (South)	WV-KL-5	110	366

7.0 REFERENCES

ADEQ (Arkansas Department of Environmental Quality). 2004. West Fork White River Watershed -Data Inventory and Nonpoint Source Pollution Assessment. Arkansas Department of Environmental Quality, Little Rock, Arkansas

Allison, J.D., D. S. Brown, and K.J. Novo-Gradac. 1991. MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems: Version 3.0 User's Manual. EPA/600/3-91/021. U.S. Environmental Protection Agency, Washington, DC.

Appelo, C.A.J., and D. Postma. 2005. *Geochemistry, Groundwater and Pollution*. 2nd ed. Taylor & Francis.

Atkins, John T. Jr., Jeffery B. Wiley, Katherine S. Paybins. 2005. *Calibration Parameters Used to Simulate Streamflow from Application of the Hydrologic Simulation Program-FORTRAN Model (HSPF) to Mountainous Basins Containing Coal Mines in West Virginia.* Scientific Investigations Report 2005-5099. U.S. Department of the Interior, U.S. Geological Survey.

Bicknell, B.R., J.C. Imhoff, J. Kittle, A.S. Donigian, and R.C. Johansen. 1996. *Hydrological Simulation Program – FORTRAN: User's Manual for Release 11*. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Brady, N.C., and R.R. Weil. 1999. *Elements of the Nature and Property of Soils*. Prentice Hall, Upper Saddle River, NJ.

Cairns, J., Jr., and J.R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. In *Freshwater biomonitoring and benthic macroinvertebrates,* ed D.M. Rosenberg and V.H. Resh, pp. 10–27. Chapman and Hall, New York.

CCREM. 1987. Canadian water quality guidelines. Canadian Council of Ministers of Resources and Environment. Ottawa, Ontario.

Cormier, S., G. Sutter, and S.B. Norton. 2000. *Stressor Identification: Technical Guidance Document*. EPA-822B-00-25. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.

Dreher, G.B., and R. B. Finkelman. 1992. Selenium mobilization in a surface coal mine, Powder River basin, Wyoming, U.S.A. Enfiron. Geol. Water Sci. 19: 155-167.

Haygarth, P.M. 1994. Global importance and global cycling of selenium. Pages 1-28 in *Selenium in the environment*. Edited by W.T. Frankenberger, Jr. and S. Benson. Marcel Dekker, Inc. New York.

Lumb, Alan M.; Richard B. McCammon, and John L. Kittle, Jr. 1994. *User's Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program – FORTRAN.* Water Resources Investigations Report 94-4168, U.S. Geological Survey. Reston, VA.

McDonald, L.E., and M.M. Strosher. 1998. Selenium mobilization from surface coal mining in the Elk River basin, British Columbia: a survey of water, sediment and biota. Ministry of Environment, Lands and Parks. Cranbrook, British Columbia. 56 p.

Mehran. M., and K.K. Tanji. 1974. Computer Modeling of Nitrogen Transformation in Soils. *Journal of Environmental Quality*. 3(4):391–396.

Miertschin, James, 2006, Project Area 2 River Basin Groups D and E Bacteria Impairments TMDL, Texas Commission on Environmental Quality, James Miertschin & Associates, Inc.

Morel, F., and J. Morgan. 1972. A Numerical Method for Computing Equilibria in Aqueous Chemical Systems. *Environmental Science & Technology* 6(1):58–67.

NLCD (National Land Cover Database). 2001. Multi-Resolution Land Characteristics (MRLC) Consortium. Electronic source: www.mrlc.gov, accessed January 26, 2009.

Novotny, V., and H. Olem. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*. Van Nostrand Reinhold, New York, NY.

NRCS (Natural Resources Conservation Service). 1994. *State Soil Geographic (STATSGO) Data Base*. U.S. Department of Agriculture, Natural Resources Conservation Service, Fort Worth, TX.

PADEP (Pennsylvania Department of Environmental Protection). 2000. *Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania*. Pennsylvania Department of Environmental Protection, Harrisburg, PA.

Reuss, J.O., and D.W. Johnson. 1986. Acid Deposition and the Acidification of Soils and Waters. *Ecological Studies* 59, Springer-Verlag.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

Schnoor, J.L. 1996. Environmental Modeling: Fate and Transport of Pollutants in Water, Air, and Soil. Wiley-Interscience, New York, NY.

Scientific notation. Dictionary.com. *The American Heritage® Dictionary of the English Language, Fourth Edition*. Houghton Mifflin Company, 2004. http://dictionary.reference.com/browse/scientific notation (accessed: May 22, 2007).

Shen, Jian, M. Lahlou, L. Shoemaker, A. Parker, J. Ouyang, H.Yang, and Jon Ludwig. 2002. Mining Data Analysis System (MDAS). In *Water Environment Federation Watershed 2002 Proceedings*.

Stumm, W., and J.J. Morgan. 1996. *Aquatic Chemistry*. John Wiley, New York.

Sullivan, T.J. 2000. *Aquatic Effects of Acid Deposition 2000*. Lewis Publishers, Boca Raton, FL.

ter Braak, C. J. F. & Barendregt, L. G. 1986. Weighted averaging of species indicator values: its efficiency in environmental calibration. *Mathematical Biosciences* 78:57–72.

ter Braak, C. J. F. & Looman, C. W. N. 1986. Weighted averaging, logistic regression and the Gaussian response model. *Vegetation* 65:3–1.

USEPA (U.S. Environmental Protection Agency). 2005a. *EPA's Clean Air Market Programs—Acid Rain*. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/airmarkets/acidrain>. Accessed August 2011.

USEPA (U.S. Environmental Protection Agency). 2005b. *EPA: Clean Air Interstate Rule*. U.S. Environmental Protection Agency, Washington, DC. <>. (Accessed in August 2011.)

USEPA (U.S. Environmental Protection Agency). 2005c. *Technical Support Document for the Final Clean Air Interstate Rule – Air Quality Modeling*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. <http://www.epa.gov/cair/pdfs/finaltech02.pdf>. (Accessed in August 2011.)

USEPA. 1991. *MINTEQA2 PRODEFA2: A Geochemical Assessment Model for Environmental Systems: Version 3.0 User's Manual*. EPA/600/3-91/021. U.S. Environmental Protection Agency, Washington, DC.

West Virginia University Extension Service. 2000. *Overview of Passive Systems for Treating Acid Mine Drainage*. http://www.wvu/edu/~agexten/landrec/passtrt/passtrt.htm.

Westall, J.C., J.L. Zachary, and F.M.M. Morel. 1974. MINEQL, A computer Program for the Calculation of Chemical Equilibrium Composition of Aqueous Systems. MIT Technical Note No.18.

WVDEP (West Virginia Department of Environmental Protection). 2000a. Personal communication with Ken Politan, WVDEP Office of Mining and Reclamation. October 2000.

WVDEP. 2000b. Personal communication with Dave Vande Linde, WVDEP Office of Mining and Reclamation. October 2000.