Total Maximum Daily Loads for Selected Streams in the Monongahela River Watershed,

West Virginia

TECHNICAL REPORT

April 2014

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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
CSGP	Construction Stormwater General Permit
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 the Monongahela River Watershed for which total maximum daily loads (TMDLs) have been completed. 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 Monongahela River Watershed in West Virginia.

In 2002, EPA, with support from WVDEP, developed the metals and pH TMDLs for the Monongahela River Watershed (EPA, 2002). Significant aluminum and manganese water quality criterion revisions have been enacted since EPA approval of the 2002 TMDL project rendering the existing TMDLs obsolete. The form of the aluminum criteria was changed from total to dissolved and the chronic criterion value for warmwater fisheries was revised. The manganese water quality standard revision now limits applicability of the criterion to five mile stream segments upstream of existing public water supplies. The goal for this project is to produce TMDLs for the Monongahela River Watershed that are consistent with effective water quality criteria. All streams/impairments for which TMDLs were developed in 2002 have been re-evaluated.

Upon approval, the TMDLs presented herein shall supersede those developed previously. All total aluminum TMDLs developed for 36 streams in 2002 are no longer effective because of the criteria revisions. However, new dissolved aluminum TMDLs are presented for 19 of the 36 original streams. The remaining 17 streams for which total aluminum TMDLs were developed in 2002, attain the dissolved aluminum criterion. Additional dissolved aluminum impairments are also addressed. Previously developed total manganese TMDLs are no longer effective in 32 of the original 33 TMDL streams, because the manganese criterion is not applicable to those waters. A revised manganese TMDL is presented only for Brand Run (WV-M-20). Total iron TMDLs were previously presented for 35 streams. These streams were determined to be impaired and new TMDLs are presented. **Appendix A** lists the 2002 TMDLs for total iron, total aluminum, and total manganese, describes why the TMDLs are no longer effective, and indicates those streams for which new TMDLs are presented.

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 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
Manganese, total (mg/L)	--	--	--	--	1.0[c]
Chloride (mg/L)	860	230	860	230	250
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
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
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]Four-day 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.
[c] Not to exceed 1.0 mg/L within the five-mile zone upstream of known public or private water supply intakes used for human consumption.
Source: 47 CSR, Series 2, *Legislative Rules, Department of Environmental Protection: Requirements Governing Water Quality Standards*.

Numeric aquatic life water quality criteria for iron, dissolved aluminum, selenium, and chloride, 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. High dissolved aluminum concentration and low pH have been attributed to positive acidity including aluminum loading from legacy mining activity. Atmospheric acid deposition was additionally represented in the model as was the aluminum loading from permitted point sources. Atmospheric deposition was not found to be a causative source of impairment as effects are mitigated by available watershed buffering capacity. The TMDLs for pH and metal impairments were developed through simultaneous source metal loading reduction and pH increment of the source discharges.

Arnett Run (WV-M-49-G) was the only selenium impaired stream addressed in the Monongahela River Watershed TMDL project. The prevalence of reclaimed mining activity and the disposal of flyash from a coal burning power plant in proximity to observed exceedances of the selenium water quality criterion are likely causes of the selenium impairment.

There are dissolved oxygen impairments in Deckers Creek (WV-M-14) and Mod Run (WV-M-54-T). The Deckers Creek DO impairment limited to a 2-mile segment upstream of UNT/Deckers Creek RM 18.48 to pond outlet at RM 20.5. In general, point and non-point sources contributing to dissolved oxygen impairments are the same as those for fecal coliform Because of the effect of reducing organic loadings, the fecal coliform TMDLs developed by WVDEP are appropriate surrogates for the dissolved oxygen impairment for these streams.

The only total manganese impaired stream in the Monongahela River Watershed is Brand Run (WV M-20) and the impairment is solely attributed to discharges associated with legacy mining activities in the watershed.

The narrative water quality criterion of 47 CSR 2–3.2.i prohibits the presence of wastes in state waters that cause or contribute to significant adverse impact to the chemical, physical, hydrologic, and biological components of aquatic ecosystems. Historically, WVDEP based assessment of biological integrity on a rating of the stream's benthic macroinvertebrate community using the multimetric West Virginia Stream Condition Index (WVSCI). WVSCI-based "biological impairments" were included on West Virginia Section 303(d) lists from 2002 through 2010. The original scope of work for this project included approximately 20 biological impairments for which TMDLs were to be developed. A separate project addressing an additional 30 impacted streams was funded and initiated by the Environmental Protection

Agency Region III. The latter project focused on streams with elevated dissolved solids concentrations for which significant ionic stress to the benthic community was presumed.

Recent legislative action (Senate Bill 562) directed the agency to develop and secure legislative approval of new rules to interpret the narrative criterion for biological impairment found in 47 CSR 2-3.2.i. A copy of the legislation may be viewed at:

http://www.legis.state.wv.us/Bill_Text_HTML/2012_SESSIONS/RS/pdf_bills/SB562%20SUB1%20enr%20PRINTED.pdf

In response to the legislation, WVDEP is developing an alternative methodology for interpreting 47 CSR 2–3.2.i which will be used in the future once approved. WVDEP did not add new WVSCI-based biological impairments to the 2012 303(d) list that was submitted to EPA for approval on December 21, 2012. WVDEP has also suspended biological impairment TMDL development pending receipt of legislative approval of the new assessment methodology.

Although "biological impairment" TMDLs are not presented in this project, all of the streams for which available benthic information demonstrates biological impact (via WVSCI assessment) were subjected to a biological stressor identification (SI) process. The results of the SI process are displayed in **Appendix B**. **Section 2.0** discusses recent EPA oversight activities relative to Clean Water Act Section 303(d) and the relationship of the pollutant-specific TMDLs developed herein to WVSCI-based biological impacts.

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, 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. 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 metals, sediment, and fecal coliform bacteria modeling experience, the Mining Data Analysis System (MDAS) was chosen to represent the source-response linkage for pH, iron, sediment, dissolved aluminum, chloride, manganese, and fecal coliform bacteria, when applicable. 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. The details of MDAS model can be referred to in **Section 3.0**.

2.0 BIOLOGICAL STRESSOR IDENTIFICATION

On March 25, 2013, EPA partially approved and partially disapproved West Virginia's 2012 Section 303(d) list submittal. EPA disapproved West Virginia's failure to list multiple waters for which available biological information would have been deemed impairment pursuant to 47 CSR 2 §3.2.i if assessed using the WVSCI methodology as in past listing cycles. On April 8, 2013 EPA published a notice in the Federal Register of its proposal to add 255 waters to West Virginia's 2012 303(d) list and opened a 30-day public comment period regarding the same. Information regarding the public notice, the public comments received, and EPA's response to the same may be viewed in their entirety at: http://www.epa.gov/reg3wapd/tmdl/303list.html

On May 8, 2013, WVDEP submitted comments to EPA that expressed general disagreement with the proposed over-list action and provided technical considerations regarding proposed specific stream listings. EPA considered WVDEP's comments and altered their final action based on those comments, by removing eight streams that EPA initially proposed to add, adding one stream, and revising the segmentation of four streams. The final EPA action also delisted twelve streams that WVDEP included on its draft list. However, EPA declined to follow WVDEP's suggestion regarding waters for which WVDEP deemed the biological results uncertain based on the WVSCI methodology (i.e. WVSCI scores between 60.6 and 68). WVDEP did not historically assess such waters as biologically impaired, and EPA approved those assessments. However, in the instant Section 303(d) list, the EPA final action includes listing those streams as impaired. EPA contends that the previous uncertainty consideration is statistically unsupported. WVDEP disagrees with that contention and maintains that streams that are assessed to be in the "grey area" need not be listed on Section 303(d) lists as biologically impaired.

The above notwithstanding, all of the potentially impacted streams were subjected to the biological stressor identification process described in this Chapter. Independent of their fate on the 303(d) list, this process allowed stream-specific identification of the significant stressors associated with benthic macroinvertebrate community impact. If those stressors are resolved through the attainment of numeric water quality criteria, and TMDLs addressing such criteria are developed and approved, then additional “biological TMDL” development work is not needed. Although this project does not include “biological impairment” TMDLs, stressor identification results are presented so that they may be considered in listing/delisting decision-making in future 303(d) processes. The SI process demonstrated that biological stress would be resolved through the implementation of TMDLs developed in this project pursuant to effective numeric water quality criteria for the streams identified in Table 4-1. Table 4-2 identifies the potentially biologically impacted streams that are not affected by this TMDL development project. The SI process analyzes the existing quantitative and qualitative water quality data available for the watersheds to identify stressors, so that pollutants can be controlled. 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 impacted streams. The SI process is discussed in further detail in the sections that follow and final determinations are listed in **Appendix B**.

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 impact (Cormier et al., 2000). Elements of the SI process were used to evaluate and identify the primary stressors of the benthic community in the biologically impacted streams.

SI is a formal and rigorous method that identifies stressors and provides a structure for organizing the scientific evidence supporting the conclusions. The general SI process entails critically reviewing available information, forming possible stressor scenarios, analyzing those scenarios, and reaching conclusions about which stressor or stressors are impacting the biota. 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 impacted streams. As a result, the TMDL process establishes a link between the benthic community assessment and pollutant 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 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 stressors.

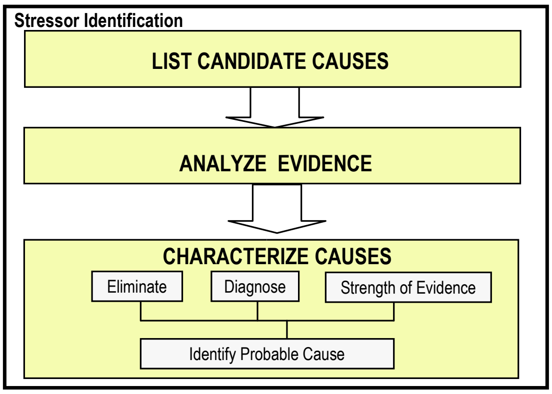


Figure 2-1. Stressor identification process

2.1.1 Technical Approach

Biological communities respond to any number of environmental stressors, including physical impacts and changes in water and sediment chemistry. 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 2006) 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 D TMDL watersheds were sampled in 2009 and 2010. WVDEP staff also conducted site visits to all impacted streams more recently 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 impacted watersheds to date.

2.1.2 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 impacts to analyze the relationship between candidate stressors 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 stressors in similar watersheds. In some cases, biological impacts can be linked to a single stressor; in other situations, multiple stressors might be responsible.. This conceptual model presents all potential causes that might be present in the watershed and their sources.

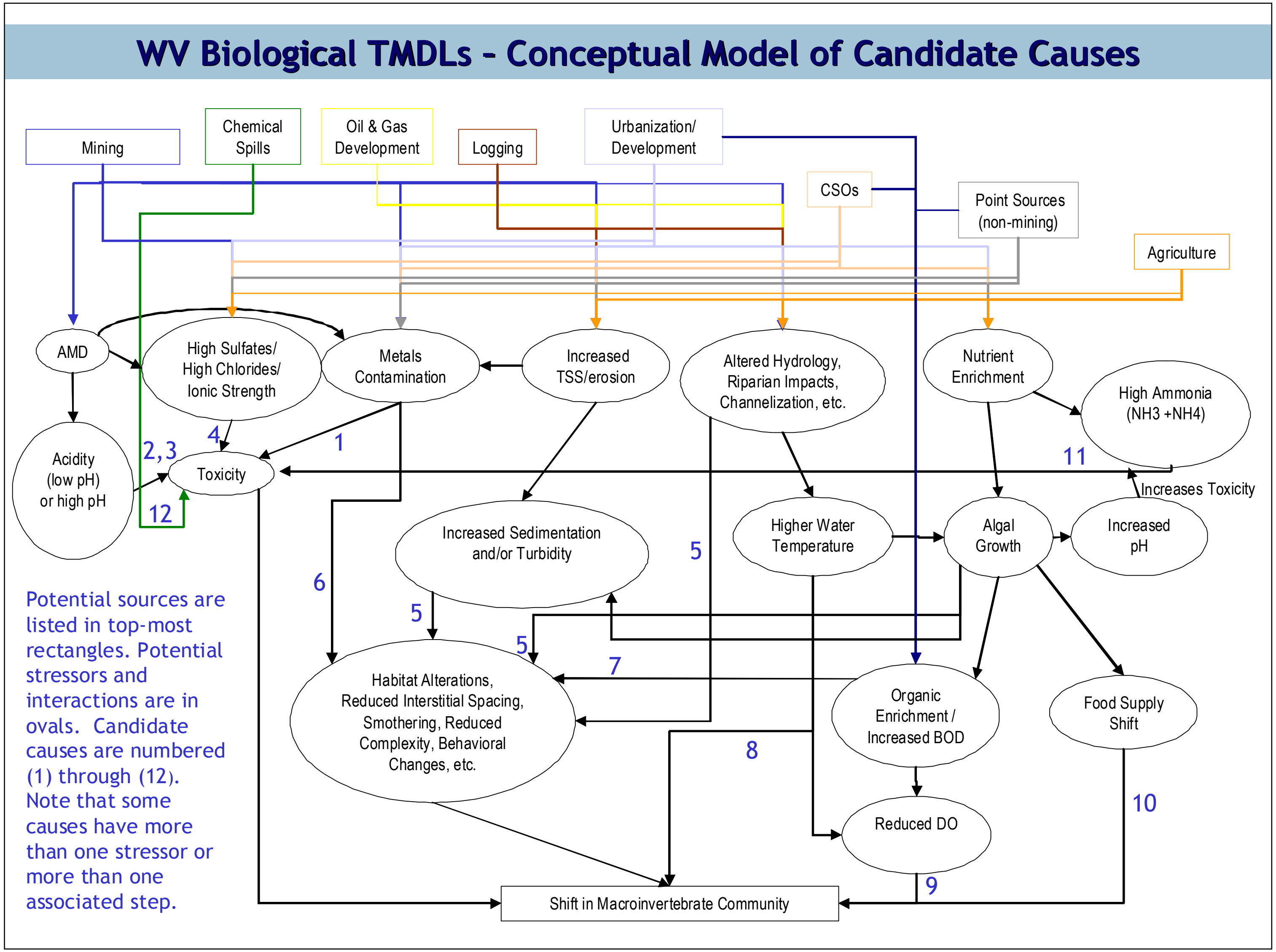


Figure 2-2. Overall conceptual model of candidate causes

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, <6) 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

2.1.3 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. 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. 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 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)	<0.09 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 0.0.091 - 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 5.99-5.3 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 or 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

Candidate Cause	Parameter	Elimination (Rule out stressors at these thresholds) Elimination Threshold	Strength of Evidence (Evidence for each Candidate Cause as stressor) Candidate Stressor Thresholds
	Sulfates	< 56.9 mg/l	>400 Definite Stressor 250-400 Likely stressor 175-250 Possible stressor 120-175 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
	% Fines (sand + silt + clay)	<10%	>40 Definite Stressor 30-40 Likely stressor 20-30 Possible stressor 10-20 Weak stressor <10 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

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
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
	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

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
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).

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 can be plotted and analyzed spatially using a "geo-ordering" scheme. In this process, "geo-orders" are assigned to relative positions of sampling locations from downstream to upstream for each 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.

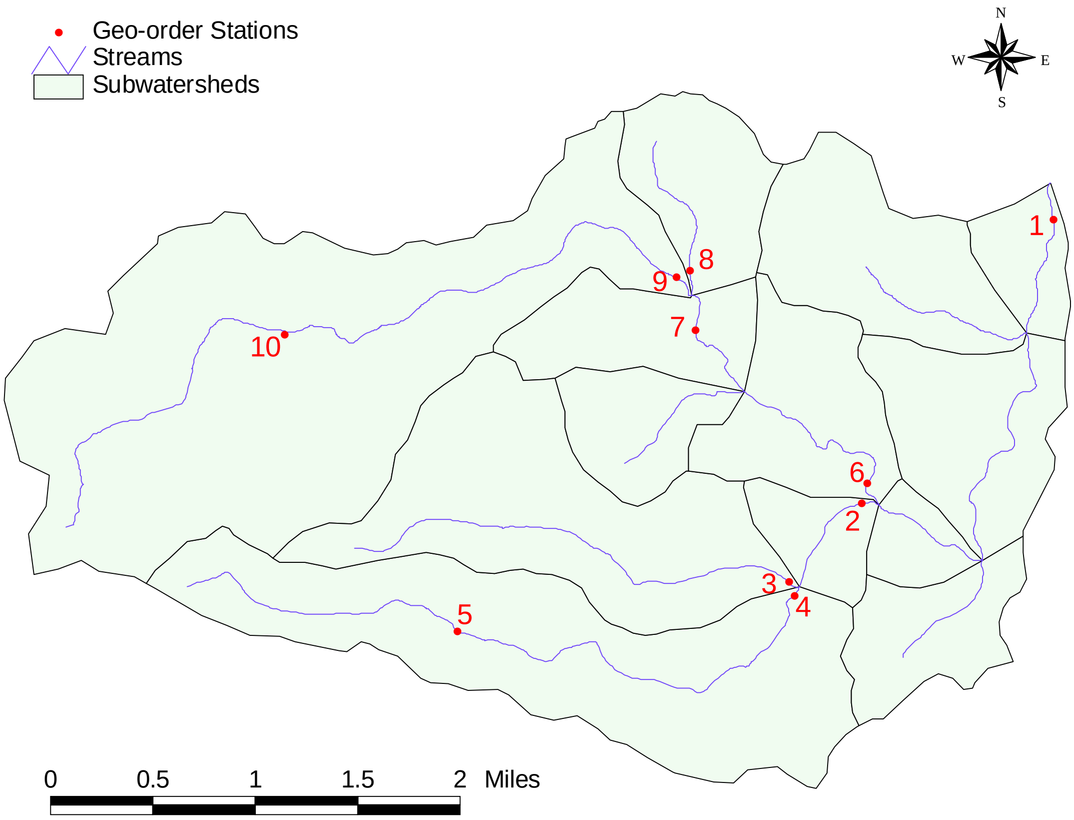


Figure 2-3. Example geo-order stations and naming convention

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). In some cases, several stressors were identified in the analysis. Refer to **Appendix B** for analysis results for specific streams and data supporting the SI process determinations.

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

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.

Based on the SI process, streams in the Monongahela River Watershed were found to be impacted by sedimentation, organic enrichment, pH toxicity, aluminum toxicity, iron toxicity, ionic stress, and metal hydroxides. Refer to **Appendix A** for a listing of stream with specific impairments related to numeric water quality criteria. Streams with sedimentation stress, in most cases, are 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 impacts. 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 C**.

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 or agricultural runoff. 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. 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 impacts. Therefore, fecal coliform TMDLs serve as a surrogate where organic enrichment was identified as a stressor.

2.1.4 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.

3.1 LSPC Water Quality Modeling Component

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 offers a number of key advantages over other modeling platforms, including:

- LSPC is able to simulate
  - A wide range of pollutants
  - Both rural and urban land uses
  - Both stream and lake processes
  - Both surface and subsurface impacts to flow and water quality
- The time-variable nature of the modeling enables a straightforward evaluation of the cause and effect relationship between source contributions and waterbody response, as well as direct comparison to relevant water quality criteria.
- The proposed modeling tools are free and publicly available. This is advantageous for distributing the model to interested stakeholders and amongst government agencies.
- LSPC provides storage of all modeling and point source permit data in a Microsoft Access database and text file formats to allow efficient manipulation of data.
- LSPC presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- LSPC provides post-processing and analytical tools designed specifically to support TMDL development and reporting requirements.
- A comprehensive modeling framework using the proposed LSPC approach facilitates development of TMDLs not only for this project, but also for potential future projects to address other impairments in the basin.

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. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the individual project. The model includes these major modules:

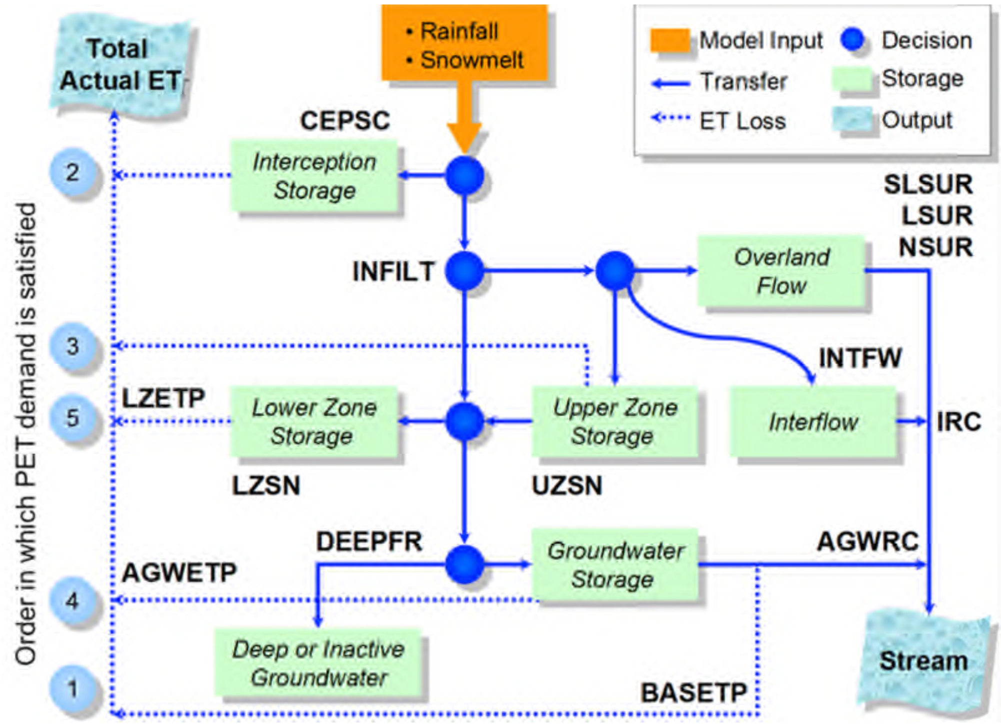
- PERLND - for simulating watershed processes on pervious land areas
- IMPLND - for simulating processes on impervious land areas
- SEDMNT - for simulating production and removal of sediment
- RCHRES - for simulating processes in streams and vertically mixed lakes
- SEDTRN - for simulating transport, deposition, and scour of sediment in streams

All of these modules include many submodules that calculate the various hydrologic, sediment, and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins or subwatersheds representing the drainage areas that contribute to each of the stream reaches. These subwatersheds are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into pervious and impervious fractions. The stream network links the surface runoff and subsurface flow contributions from each of the land segments and subwatersheds, and routes them through the waterbodies using storage-routing techniques. The stream-routing component considers direct precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals and diversions can also be accommodated.

The stream network is constructed to represent all the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur. Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple, first-order decay approaches. Decay may be used to represent the net loss due to processes like settling and adsorption.

3.1.1 The Hydrologic Cycle in LSPC

The hydrologic (water budget) process in LSPC is a fairly comprehensive representation of the natural hydrological cycle. Rainfall or snowmelt is routed to constructed landscapes, vegetation, and/or soil. Varying soil types, which depend on model parameterization by land use, allow the water to infiltrate at different rates, while evaporation and plant matter exert a demand on available water. Water flows overland and through the soil matrix. The vertical land profile in the LSPC model environment is represented by three significant flowpaths: surface, interflow, and ground water outflow. The parameters associated with various stages of the LSPC water budget are shown schematically in **Figure 3-1**.



Key to Parameters

ET is the evapotranspiration.
SLSUR is the overland flow slope.
UR is the surface runoff length.
LZETP is the lower zone ET parameter.
UZSN is the upper nominal storage.
IRC is the interflow recession.
DEEPFR is the fraction to deep GW.
BASETP is the baseflow ET parameter.
CEPSC is the interception storage capacity.
INFILT is the index to the infiltration capacity of the soil.
NSUR is the Manning's *n* for the assumed overland flow plane.
LZSN is the lower nominal moisture.
INTFW is the interflow inflow.
AGWETP is the active groundwater ET
AGWRC is the base groundwater recession.

Figure 3-1. Water Budget Schematic illustrating order in which the potential evapotranspiration is satisfied in the LSPC model.

3.1.2 Erosion and Sediment Transport

The sediment module in LSPC is composed of two models working in tandem: (1) a land-based erosion prediction model and (2) an in-stream sediment transport model. There are a number of physical processes that can be represented by parameters in the model. **Figure 3-2** presents a conceptual schematic of the sediment model in LSPC. From the land side, these include (1) splash erosion as a function of rainfall intensity, (2) net atmospheric deposition of sediment particles onto the land surface or the snowpack, which considers losses associated with wind mobilization, (3) sheet erosion or wash-off of the detached or deposited sediment as a function of runoff energy, and (4) direct scour from the soil matrix, such as gulley and/or rill erosion on the landscape. All of these processes are simulated by model land segment (i.e. land use type), providing some flexibility to represent known or likely differences in erosion potential as a function of differences in land use, topographic features, exposure, or vegetative cover. The model simulates one bulk quantity of sediment from the land surface, but this is divided into different particle size classes (i.e. sand, silt, and clay) before it is routed to the stream.

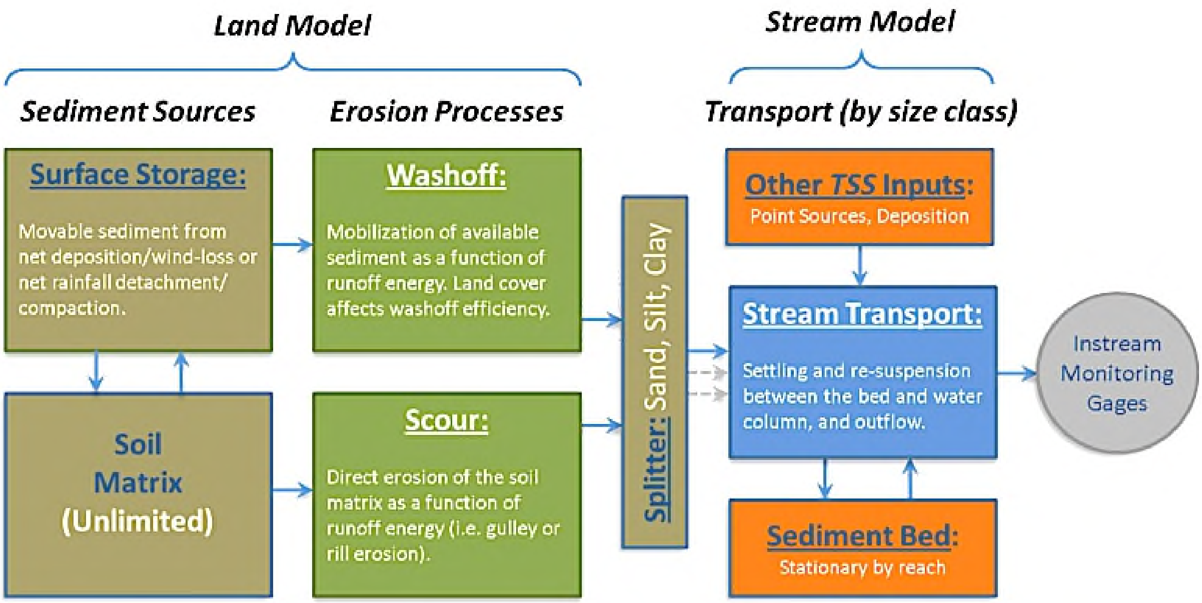


Figure 3-2. Conceptual schematic of LSPC sediment erosion and transport model.

The in-stream transport model simulates each particle class independently of others, which provides the flexibility to simulate preferential deposition of larger particles and/or perpetual suspension of smaller particles as hydrologic and hydraulic conditions permit. Each reach segment has a stationary sediment bed for each particle class that is modeled, meaning that the bed itself does not migrate from reach to reach. However, if conditions are such that sediment from the bed is resuspended into the water column, it becomes available to be transported to downstream segments where it may subsequently be deposited as conditions permit.

In most cases, the only site-specific data available for sediment model calibration are in-stream samples of total suspended sediment. Literature values for sediment yield (i.e. export coefficients) by land use are also sometimes used to validate the intermediate prediction of land-based sediment mass before it is routed for in-stream transport. This data limitation places a burden on the modeler to adequately parameterize and justify all the intermediate processes leading up to the ultimate point of comparison between modeled and observed in-stream total suspended solids.

3.1.3 Water Quality

The GQUAL module is generalized enough to represent any pollutant from the land surface. In addition to surface accumulation and wash-off processes, different concentrations can be associated with interflow and baseflow hydrology. The fate and transport of GQUAL constituents can also be modeled using temperature-dependent first order decay or sediment-associated sorption/desorption of dissolved or particulate pollutant forms. This flexibility allows a wide range of general pollutants to be modeled, including bacteria, metals, nutrients and other toxics.

LSPC also offers the reach quality (RQUAL) module from HSPF, which addresses the fate, transport, and transformation of nutrient species in the water column. RQUAL includes routines for modeling ammonia volatilization, nitrification/denitrification, and adsorption/desorption of nutrients during transport. Depending on the requirements of the natural system under consideration, the model can also simulate interaction of nutrients with phytoplankton, impact to in-stream biochemical oxygen demand (BOD), and dissolved oxygen levels.

As will be discussed, the enhanced MDAS enhances LSPC by adding specialized chemical loadings and reactive transport capabilities to permit the modeling of complex and comprehensive chemical processes that are not available in the current LSPC or HSPF, including thermodynamics-based chemical reactions and additional integrated chemical kinetics.

3.2. 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 iron, dissolved aluminum, manganese, pH, chloride, sediment, and fecal coliform bacteria. This section describes the configuration process and key components of the model in greater detail.

3.2.1 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 3-3**.

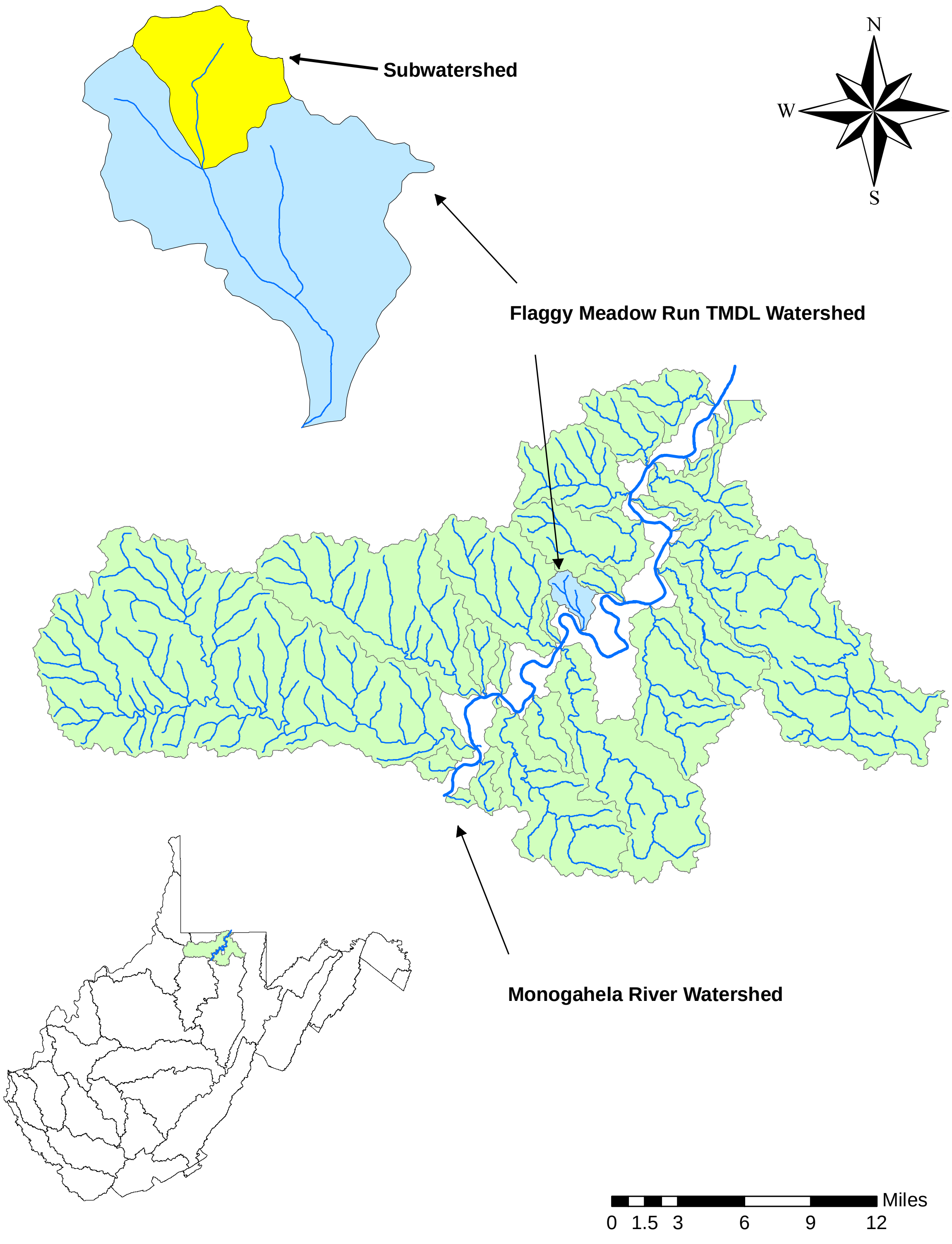


Figure 3-3. Example subwatershed delineation

3.2.2 Meteorological Data

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point 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 station at Morgantown Hart Field (WBAN 13736) was used.

The remaining required meteorological data (wind speed, potential evapotranspiration, cloud cover, temperature, and dew point) were also available from the Morgantown Hart Field weather station. The data were applied to each subwatershed according to proximity.

In certain environments, snowfall and snowmelt have a dominant impact on hydrology and associated water quality. LSPC uses the energy balance method to simulate snow behavior. In addition to precipitation inputs, the energy balance requires temperature, dew point temperature, wind speed, and solar radiation as meteorological drivers. The SNOW module uses the meteorological 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, rain, and conduction from the ground beneath the snowpack. The snowpack essentially acts like a reservoir that has specific thermodynamic rules for how water is released. Melting occurs when the liquid portion of the snowpack exceeds the snowpack's holding capacity; melted snow is added to the hydrologic cycle (**Figure 3-4** is a schematic of the snow process in LSPC).

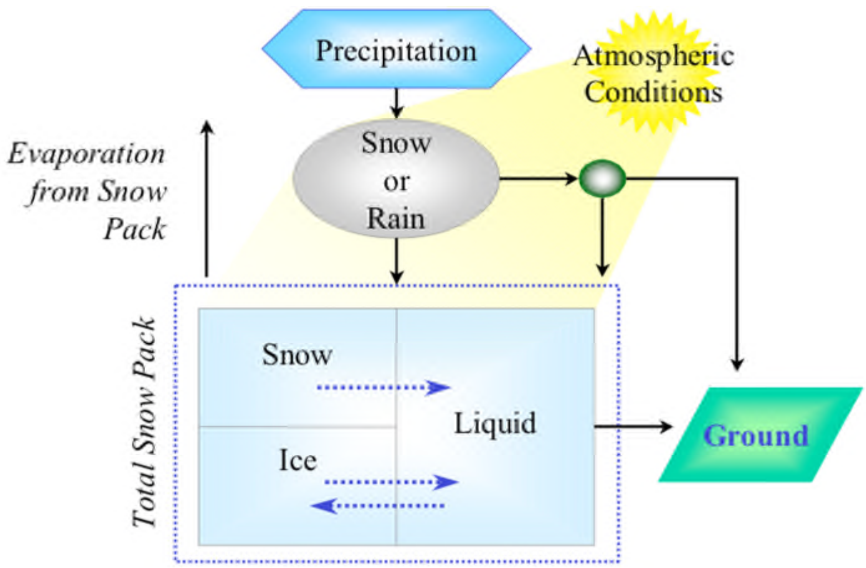


Figure 3-4. Snow Simulation Schematic

3.2.3 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).

3.2.4 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.

3.2.5 Pollutant Representation

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

- Aluminum (particulate &dissolved phases)
- Iron (particulate & dissolved phases)
- pH
- Chloride
- Total Manganese
- 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. Additionally, the enhanced MDAS capability provides thermodynamic-based, time-variable chemical loadings and reactive transport model within the streams.

3.2.6 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 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 3-5**). 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.

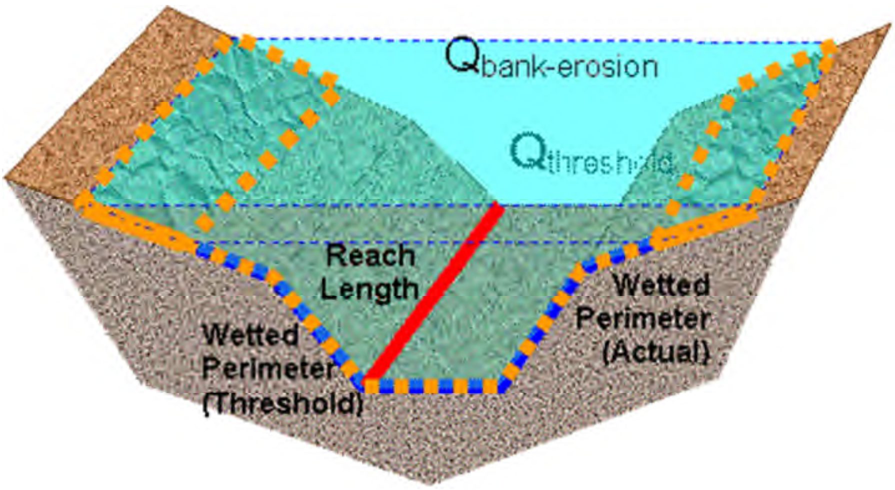


Figure 3-5. Conceptual diagram of stream channel components of bank erosion model

The coefficient for scour of the bank matrix soil (kber) was determined by calibration where modeled bank erosion sediment loads were compared with loads calculated from a pin-study performed in the subject watershed by the WVDEP. The streambank erosion condition was assessed by installing erosion pins on representative streambank sections.

To conduct the pin erosion study, six-ten erosion pins were installed on each stream cross section with three-five pins on right side of bank and five pins on left bank. Two replicate pin sites were setup for selected monitored stream sections. Nine erosion pin sites, five with replicates sites located upstream were established to represent eight stream. Lengths of erosion pin exposures and cross sectional geometry were measured on March 2012 and April 2011. The bank erosion pin data were processed in the following steps to calculate the annual sediment loading of streams.

1. Changes of exposure lengths (DP) between two consecutive measurements were calculated.
2. Cross section erodible lengths (DL) corresponding to each pin locations were calculated from the stream cross section geometry.
3. Changes of exposure lengths (DP) were multiplied with the corresponding cross section erodible lengths (DL) to get the eroded area at the pin location (DA = DL X DP).
4. Eroded area at each pin locations were summed to obtain the eroded area at left bank (LDB) and right bank (RDB) of the pin site.
5. Eroded area of replicate pin sites were averaged to calculate the eroded area at the stream section.
6. Eroded area of the stream section were multiplied by the stream length to calculate the eroded volume of the stream cross section.
7. Eroded volume of stream section were converted to eroded mass by multiplying the bulk density of stream bank soils.
8. Eroded mass of stream section at four time intervals were summed to calculate the annual erosion of left bank and right bank.
9. For modeled stream reaches with multiple stream bank erosion sites, the annual stream bank erosion of the sites were averaged to calculate the annual sediment loading from stream bank erosion at the modeled stream reaches.

The erosion pin study described above provided quantitative and qualitative assessments that indicated vegetative coverage was the most important factor controlling bank stability. Overall bank stability was initially characterized by assessing and rating vegetative cover based on the 2009 National Agriculture Imagery Program aerial photography (1:19,000). The vegetative cover was scored on a subwatershed basis on a scale from one to three, one being the best observed bank vegetative cover and three having the least coverage. The bank vegetative cover score was associated with a kber value to establish the initial conditions for model calibration. **Appendix D** provides the bank vegetative cover scores and example subwatersheds for each score.

Calibrating the bank erosion component of the watershed model was performed by adjusting initial kber values through an iterative process that compared stream size, slope, and riparian condition as assessed through aerial photography. Model performance was evaluated by comparing simulated bank erosion loading against the annual sediment loads calculated from the pin study.

3.2.7 Iron Sediment Correlation

Sediment-producing landuses and bank erosion are sources of iron because of 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 3-6**.

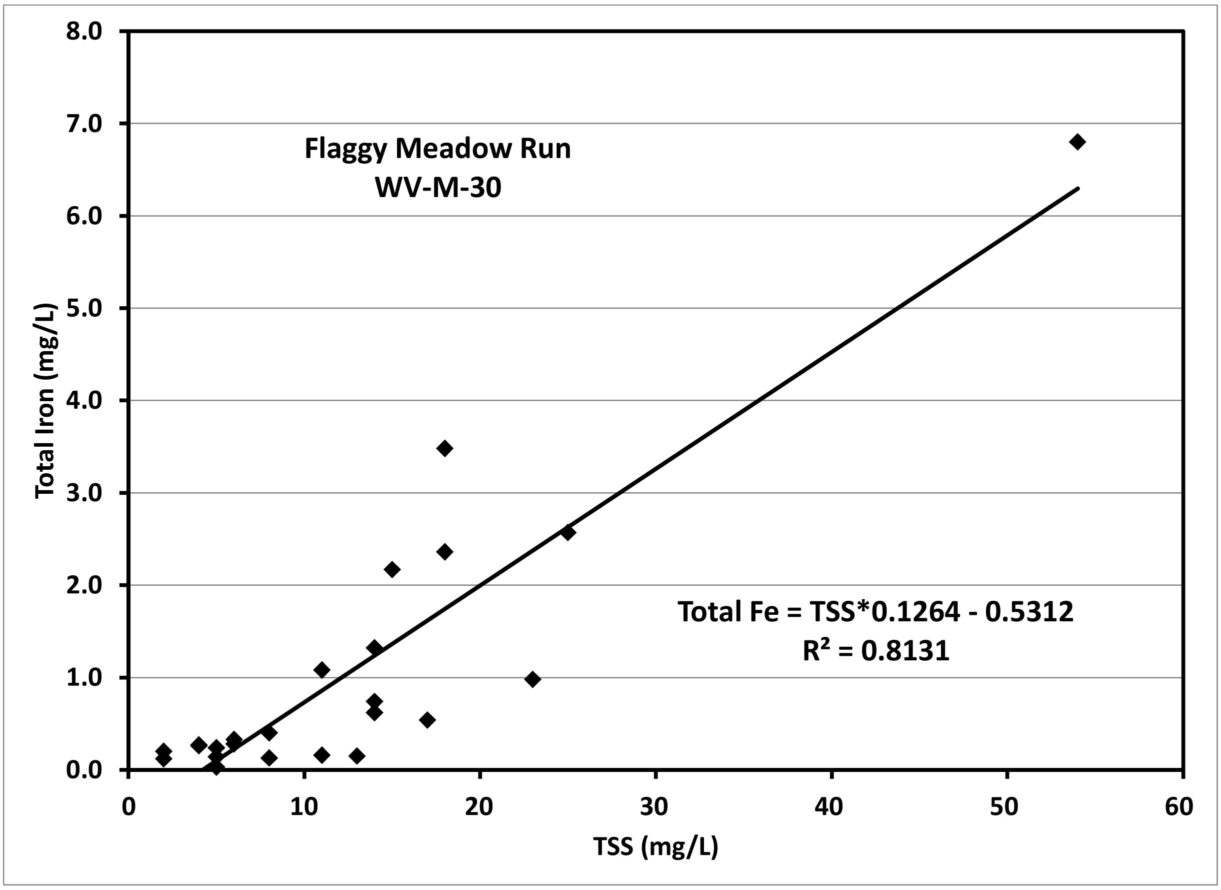


Figure 3-6. Example of instream iron-sediment correlation

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. Effective observations were those with detectable iron associated with TSS concentrations of 2 mg/l or greater. Statistical significance was determined to be R^2 values greater than 0.50. The iron sediment slopes calculated from linear regression analysis for each station was plotted and 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 Monongahela River Watershed are given in

Table 3-1. A slope group was assigned to each modeled subwatershed in the subject watersheds through spatial analysis using GIS. The qualifying stations and results of iron sediment relationship analysis are provided in Appendix C and the relationship category applied to all modeled subwatershed is displayed graphically in the GIS project.

Table 3-1. Average iron sediment slope for slope groups in the Monongahela River Watershed

Slope Group	Fe/TSS Slope	Potency Factor (lbs Fe/ton Sediment)
1	0.0317	64
2	0.0427	85
3	0.0694	139

3.3. 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.

3.3.1 Landuse

To explicitly model non-permitted (nonpoint) sources of fecal coliform bacteria, the existing NLCD 2006 landuse categories were consolidated to create model landuse groupings, as shown in **Table 3-2**. 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 E**.

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 3-3.**

Table 3-2. Fecal coliform bacteria model landuse grouping

Model Category	NLCD 2006 Category
Barren	Barren Land (Rock/Sand/Clay)
Cropland	Cultivated Crops
Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Dwarf Scrub

Model Category	NLCD 2006 Category
	Shrub/Scrub
Pasture	Grassland/Herbaceous
	Pasture/Hay
Residential/Urban Impervious (See **Table 3-3**)	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 3-3**)	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 3-3. Average percentage of pervious and impervious land for NLCD 2006 residential/urban landuse types

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

3.3.2 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.

3.3.3 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. When present within the watersheds, the following types of fecal coliform permitted/point sources were represented in the model:

- Individual POTWs discharge treated effluent at one or more outlets

- Privately owned sewage treatment plants operating under individual NPDES permits discharges at one or more outlets
- Package plants operating under general permits
- Home aeration units operating under “HAU” general permits.

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. See **Appendix F** for a complete listing of NPDES permits.

CSO Representation

In the modeled portion of the Monongahela River Watershed, there are six municipalities with combined sewer systems with a total of 55 CSO outlets that discharge to fecal coliform impaired streams. These systems are: the Town of Barrackville (12 outlets), Town of Farmington (1 outlet), City of Fairmont (10 outlets), Greater Paw Paw Sanitary District (8 outlets), the Morgantown Utility Board (23 outlets), and the City of Westover (1 outlet). CSO discharge events can vary greatly depending on rainfall intensity, storm volume, soil saturation, topographic features, and the overall design of the sewer system. CSO water quality monitoring data is scarce, and historical data often does not reflect recent progress made in eliminating or reducing CSOs. Despite inherent CSO variability and technical constraints, it was necessary to incorporate CSO outlets into the fecal coliform TMDL model to account for those outlets in the WLA portion of the TMDL equation.

Point sources modeled in MDAS are represented by a flow and a concentration over a defined duration. Sewage treatment plant outlets are usually modeled at their permit limits for the purposes of developing TMDL allocations. Unlike other kinds of sewage treatment permits, CSOs do not have typical permit limits for flow and concentration. CSOs are regulated under a Long Term Control Plan that calls for reduction or elimination of CSO discharges in the future. In the Monongahela River Watershed, observed data for flow and fecal coliform concentration for each CSO outlet during discharge events was generally not available. However, because CSO flows are weather-dependent, it was possible to use the hydrologically calibrated watershed model to estimate approximately when and at what rate of flow the CSOs would discharge.

To begin the CSO modeling process, drainage area for each CSO outlet was derived from known sewered areas, as well as other source tracking data. Surface runoff for modeled subwatersheds drained by combined sewer systems was proportionally assigned to CSO outlets using an area-weighted approach. For modeling purposes, a standard concentration of 100,000 counts/100 mL was assigned to all outlets. Source tracking information and best professional judgment provided a rough idea of how many times per year the CSOs would discharge, and roughly what volume of rain would cause CSOs to discharge. A CSO “trigger” for each outlet was assumed, such that whenever observed precipitation exceeded the trigger, the CSO was assumed to flow. At all other times, even during light rain below the trigger threshold, the CSO was assumed to be not discharging because the combined sewer system was assumed to be delivering its entire load to the POTW. Using this method, a 10-year CSO time series was constructed for the years 2000-2009 for all CSO outlets discharging to TMDL watersheds. The average annual load from each CSO outlet was calculated from this time series and used to develop the fecal coliform TMDL WLA.

Municipal Separate Storm Sewer Systems (MS4)

Runoff from residential and urbanized areas during storm events can be a significant fecal coliform source. USEPA's stormwater permitting regulations require public entities to obtain NPDES permit coverage for stormwater discharges from municipal separate storm sewer systems (MS4s) in specified urbanized areas. As such, MS4 stormwater discharges are considered point sources and are prescribed WLAs.

The Morgantown and Fairmont urbanized areas overlap Monongahela River TMDL Watersheds. Four municipalities, 2 universities, a federal prison, and the West Virginia Division of Highways (DOH) own and operate MS4s in subject watersheds of this report. MS4s and their individual registration numbers are City of Fairmont (WVR030038), Fairmont State University (WVR030045), Town of Star City (WVR030023), City of Westover (WVR030022), Morgantown Utility Board (WVR030030), Federal Correctional Institution – Morgantown (WVR030012), and West Virginia University (WVR030042), and the West Virginia Division of Highways - DOH (WVR030004).

MS4 source representation was based upon precipitation and runoff from landuses determined from the modified NLCD 2006 landuse data, the jurisdictional boundary of the cities, and the transportation-related drainage areas for which DOH has MS4 responsibility. In certain areas, urban/residential stormwater runoff may drain to both CSO and MS4 systems. WVDEP consulted with local governments and obtained information to determine drainage areas to the respective systems and best represent MS4 pollutant loadings. The location and extent of the MS4 jurisdictions in the Monongahela River Watershed are shown in **Figure 3-7**.

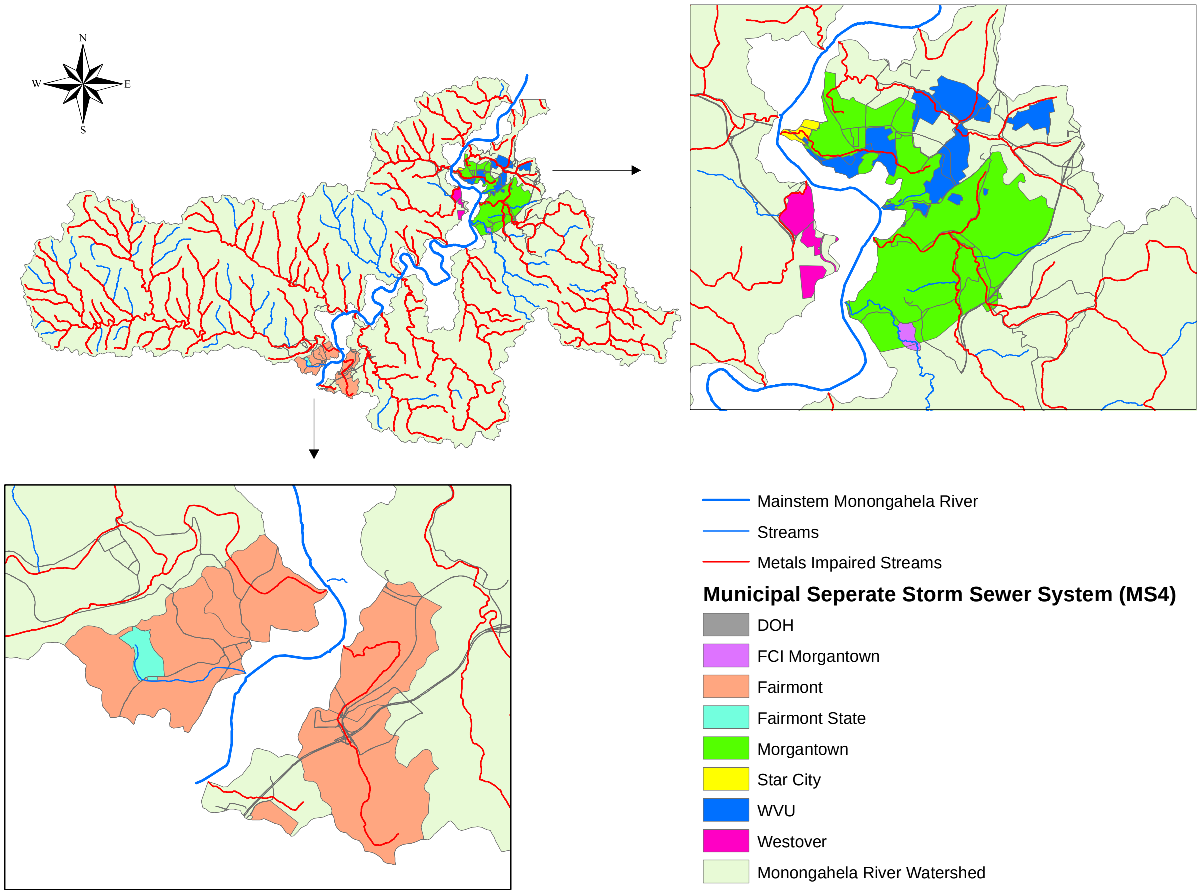


Figure 3-7. MS4 area in modeled portions of the Monongahela River Watershed

3.3.4 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 3.3.1**.

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 continuous flow sources in the MDAS. To calculate 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 3-4** shows the percentage of homes with septic systems in each of the four septic zones experiencing septic system failure.

Table 3-4. Septic failure rates in septic failure zones

Type	Zone			
	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. Second, homes located more than 100 meters from a stream were excluded and not considered significant potential sources of fecal coliform because of the natural attenuation of fecal coliform concentrations that occurs because of bacterial die-off during overland travel (Walsh and Kunapo, 2009). Estimated septic system failure rates across the watershed range from three percent to 28 percent. 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 periodic failure. For modeling purposes, failing septic system flows from multiple houses were totaled and incorporated into the model as a single continuous flow source for each subwatershed.

Once failing septic flows had been modeled, an appropriate 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 G**.

3.4. MDAS Iron 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 Monongahela River Watershed and the process used to represent these sources in the MDAS model.

3.4.1 Landuse

To explicitly model nonpoint sources in the sediment and metals impaired watersheds, the existing NLCD 2006 landuse categories were consolidated to create the modeled landuse groupings shown in **Table 3-5**. 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 and metals loadings associated with land-based precipitation-driven sources.

Table 3-5. Consolidation of NLCD 2006 landuses for the sediment and metals MDAS model

Model Category	NLCD 2006 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 3-8**)	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 3-8**)	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

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 3-6** 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 3-6. 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

Model Category	Source
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
Marcellus Shale Wells	Permit information 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 E**.

3.4.2 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 2006 landuse coverage because specific data regarding these sources was not available from the NLCD 2006 landuse coverage.

To appropriately account for runoff and loading characteristics related to AML sites, the NLCD 2006 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 2006. If the barren land 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 2006 data indicated 900 acres of forested land and 100 acres of barren land in the same watershed. The NLCD 2006 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.

3.4.3 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 H**.

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 2006. 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. Agricultural landuse, even on a small scale like isolated pastures and croplands, may be associated with sediment stress to biologically impaired streams. **Appendix E** presents total areas for cropland and pasture in the streams.

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 conventional 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 3.4.2**.

Recent drilling of new gas wells targeting the Marcellus Shale geologic formation has increased in the watershed with the development of new hydraulic fracturing techniques. Because of the different drilling techniques, the overall amount of land disturbance can be significantly higher for Marcellus wells than for conventional wells. Horizontal Marcellus drilling sites typically require a flat “pad” area of several acres to hold equipment, access roads capable of supporting heavy vehicle traffic, and temporary ponds for storing water used during the drilling process. Horizontal Marcellus drilling sites were identified and represented in the model according to the acres of disturbance indicated by the drilling permit. Because Marcellus drilling sites are frequently hardened with gravel in high-traffic areas and quickly re-seeded with grass to control erosion, the permitted acres were divided into graveled and re-vegetated grass components for modeling. For sites greater than ten acres, 75 percent of the site was assumed to be grass, and 25 percent gravel. For sites less than ten acres, a 50 percent split between grass and gravel was assumed. Sites were assigned grass and gravel differently because field visits and aerial photography confirmed that drilling sites with large permitted acreages tended to have significantly less intensive operations with more grass areas than did smaller permitted sites that generally had a higher proportion of hardened gravel areas. Vertical Marcellus wells have disturbances similar to conventional oil and gas wells without a large pad. Vertical Marcellus well disturbed areas were represented based on the acres of disturbance indicated by the drilling permit. Otherwise, they were modeled using methods described above for conventional wells.

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 2009 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 2009 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 3-7** and described in further detail in **Appendix I**. 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 3-7. 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.

3.4.4 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 3-8**.

Table 3-8. Average percentage of pervious and impervious area for different residential/urban landuse types

NLCD 2006 Landuse Category	Pervious (%)	Impervious (%)
Developed, Open Space	85	15
Developed, Low Intensity	65	35
Developed, Medium Intensity	35	65
Developed, High Intensity	10	90

3.4.5 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 and modeled as a unique sediment source independent of other upland-associated erosion sources. Information regarding the stability of streambanks was provided by WVDEP streambank erosion pin study, described in **Section 3.2.6**. The sediment loading from bank erosion is considered a nonpoint source and LAs are assigned, except in MS4 areas where the loads are categorized with the wasteload allocations. See also Section 10.7.1 of the TMDL document.

3.4.6 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

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 3-9** shows the landuses representing current active mines that were modeled. Details for both non-mining and mining point sources are provided in **Appendix F**.

Table 3-9. 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 2006 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 2006 barren and mature forest landuse areas as described for AML areas in **Section 3.4.2** 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. Typically, the sites are 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 6 unreclaimed bond forfeiture sites located in 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 WLAs.

Construction Stormwater General Permit

WVDEP issues a Construction Stormwater General NPDES Permit (Permit WV0115924, referred throughout this document as CSGP) 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 CSGP 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. Construction sites registered under the CSGP in the watershed that were represented in the model can be reviewed in **Appendix F**.

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.

3.5 MDAS Overview for Modeling Major Ions, Dissolved Aluminum, and pH

To appropriately address dissolved aluminum and pH TMDLs for the Monongahela River tributaries watersheds, it was necessary to include additional MDAS modules capable of representing instream chemical reactions of several water quality components. The following descriptions were intended to give details of MDAS model functionalities and the model configurations.

3.5.1 Land Components in MDAS

The time variable chemical loadings from land were simulated through surface and subsurface hydrologic modeling components in MDAS. The initial assignments of chemical concentrations and pH were derived from the instream observed data and additional modeling results from MINTEQA2/PHREEQC/NETPATH. However, the initially assigned values were adjusted through the calibration processes of MDAS. The modeled chemical/mineral loadings from the land surface were further evaluated through edge-of-stream calculations to determine Total H prior to instream discharges.

Among land uses composed of the basin, the influences of AMD to the instream metal and the acidity loadings are tremendous. The estimated initial values based on the observed and the simulated data were modified for this land as well. The chemical loadings from different loading pathways(surface, interflow and groundwater) from the source were modified to calibrate timing and fluctuation of the loads from AMD sources.

In addition to loadings associated with anthropogenic sources and natural background sources on the lands, atmospheric deposition was also considered. The wet atmospheric deposition was explicitly modeled to represent the input of ionic species through precipitation using averaged monthly data available from Canaan Valley Institute (NADP: National atmospheric deposition program) in Tucker County. Dry depositions of major chemical components pertain to MDAS modeling were implicitly included as a part of surface runoff loadings.

Additional metals and acidity loadings from seeps originated in the land were configured to directly discharge to a near-by stream. The seep’s metal/acidity and heat loadings were based on the observed data collected at the discharge location of the identified seeps.

All of these loadings from various sources were simulated dynamically and linked to the stream reactive transport component of MDAS model. Figure 3-8 shows the land component of Monongahela MDAS model.

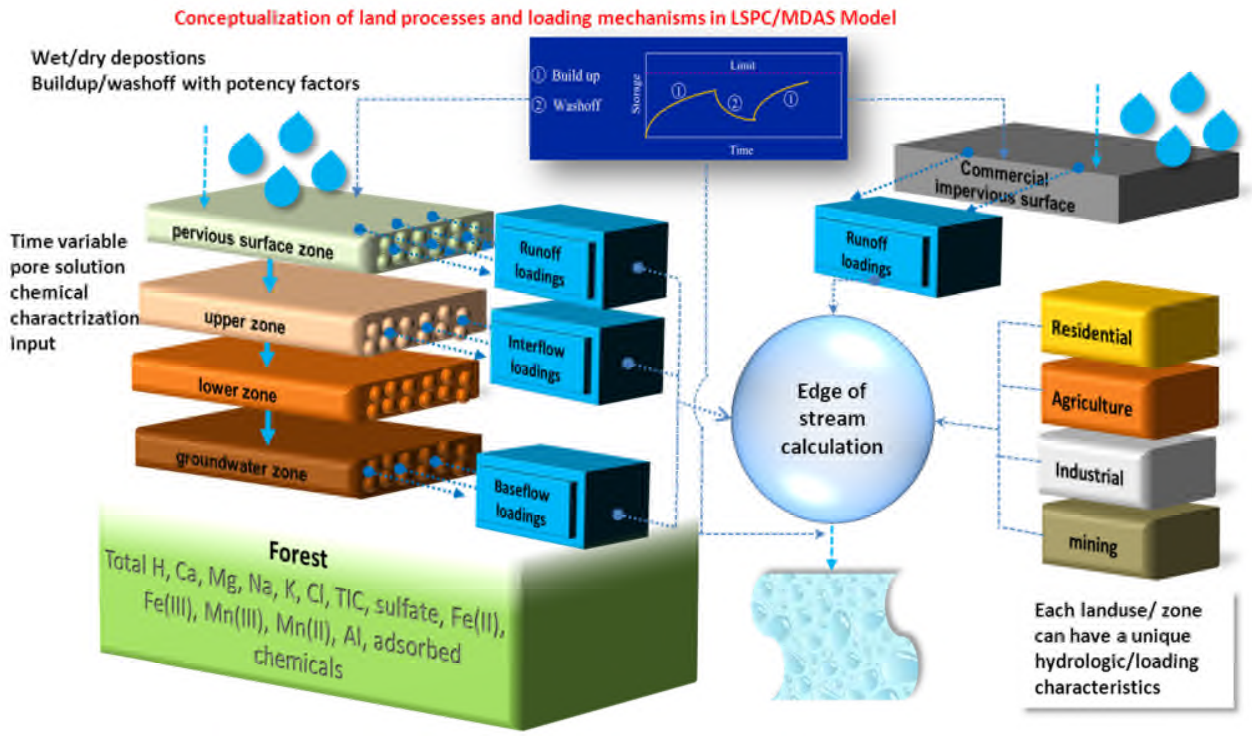


Figure 3-8. Land components of LSPC-MDAS model

3.5.2. Stream Components in MDAS

The stream components in MDAS include the dominant processes regulating the interactions and transport of major ions, metals, adsorbing materials, and mineral phases. Reactions between the water column and the streambed are represented along with the reactions governing the distribution of dissolved and particulate chemicals.

Water Column

The chemical loadings from the land were transported to the adjacent stream reach via the hydrologic functionalities in LSPC. The in-stream hydraulic transport was simulated in LSPC based on the complete-mix, unidirectional flow concept and kinematic wave flow routing method. MDAS's geochemical reactions within the channel were constructed based on thermodynamics and chemical kinetics. To simulate and attain realistic stream chemical conditions, the model was configured to include a variety of chemical reactions to support various stream conditions affected by anthropogenic or natural sources. The following lists of the chemical reactions were included in the configuration of Monongahela MDAS model.

- Chemical speciation, including trace metals
- Acid/base chemical reactions and pH simulations
- CO_2 gas degassing/ingassing kinetics in rivers and lakes

- Redox kinetics including potential photoreduction/microbial oxidation
- Kinetic mineral precipitation/dissolution
- Adsorption/desorption based on diffuse double layer (DDL) modeling
- Cation adsorption/desorption on clay surfaces represented by cation exchange capacity
- Aging/burial of active/inactive sediment layers related to sediment deposition from the water column and scour from the stream bed

The stream components represented in MDAS are shown in **Figure 3-9**.

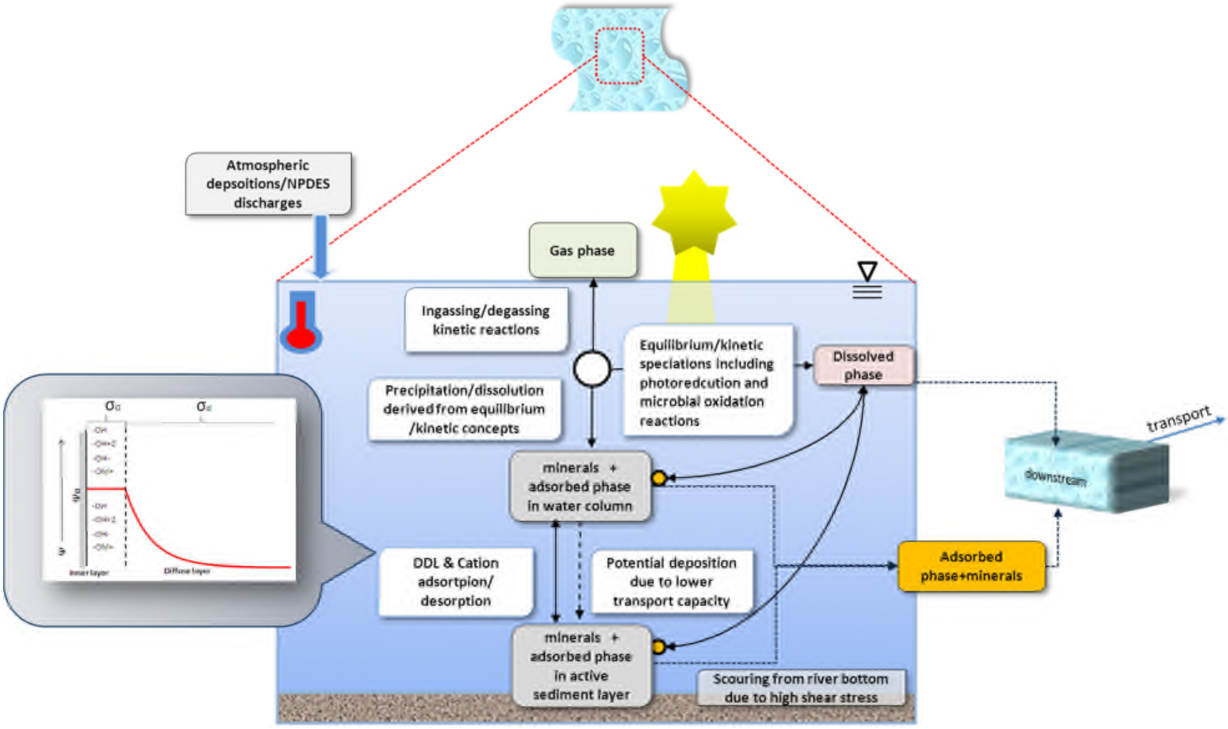


Figure 3-9. Stream components in MDAS

Aqueous Speciation Model in MDAS

The solution to the model equations for the reactions specified in Monongahela MDAS modelwas based on the MINTEQA2/MINEQL models with the thermodynamic database based on the MINTEQA2, Version 4.0 database. The concepts and thermodynamic data for the diffuse double layer (DDL) model for hydrous ferric oxide were based on a study conducted by Dzombak and Morel (1990). Research conducted by Tonkina, et al. (2003) and Karamalidis and Dzombak (2010) for adsorption on hydrous manganese oxide and gibbsite was reviewed and the results were incorporated into the MDAS DDL model data. **Table 3-10** shows all significant chemical species, other than the free ions, currently included in MDAS database for a chemical system based on major ions, aluminum, iron, and manganese, and adsorption/desorption to oxides and clays. The model results of the simulated time variable instream temperature were also linked in the model to adjust the thermodynamic constants assigned to each complexation reactions based on the simulated temperature.

Table 3-10. Chemical components and complexes included in previous and updated versions of MDAS.

Components	Aqueous Species		Adsorbed Species		Solids
H^+	H^+	$Fe(OH)_2^+$	$:FehO^-$	KX	Iron
Ca^{+2}	Na^+	$Fe(OH)_3$ (aq)	$:FehOH_2^+$	CaX_2	Aluminum
CO_3^{-2}	K^+	$Fe(OH)_4^-$	$:FehOHCa^{+2}$	MgX_2	Manganese
Fe^{+3}	Ca^{+2}	$Fe_2(OH)_2^{+4}$	$:FehOHSO_4^{-2}$	AlX_3	Calcite
Fe^{+2}	Mg^{+2}	$Fe_3(OH)_4^{+5}$	$:FehSO_4^-$	FeX_2	Gypsum
Mn^{+2}	Al^{+3}	$FeSO_4^+$	$:FehOMn^+$	MnX_2	Jurbanite
Mn^{+3}	Fe^{+2}	$Fe(SO_4)_2^-$	$:FehO(FeII)^+$	-	-
Al^{+3}	Fe^{+3}	$FeCl^{+2}$	$:FehCO_3^-$	-	-
SO_4^{-2}	Mn^{+2}	KCl (aq)	$:FehCO_3H$	-	-
H_2O	Mn^{+3}	KOH (aq)	$:FeO^-$	-	-
Na^+	SO_4^{-2}	KSO_4^-	$:FeOH_2^+$	-	-
K^+	Cl^-	$MgCl^+$	$:FeOCa^+$	-	-
Mg^{+2}	CO_3^{-2}	$MgOH^+$	$:FeOMg^+$	-	-
Cl^-	$AlOH^{+2}$	$MgSO_4$ (aq)	$:FeOHSO_4^{-2}$	-	-
FeOH(s)	$Al(OH)_2^+$	$MgCO_3$ (aq)	$:FeSO_4^-$	-	-
FehOH (s)	$Al(OH)_3$ (aq)	$MgHCO_3^+$	$:FeOMn^+$	-	-
AlOH (s)	$Al(OH)_4^-$	$MnOH^+$	$:FeO(FeII)^+$	-	-
MnOH (s)	$Al_2(OH)_2^{+4}$	$Mn(OH)_4^{-2}$	:FeO(FeII)OH	-	-
MnhOH (s)	$Al_3(OH)_4^{+5}$	$Mn_2(OH)_3^+$	$:FeCO_3^-$	-	-
X^-	$Al_2(OH)_2CO_3^{+2}$	Mn_2OH^{+3}	$:FeCO_3H$	-	-
-	$AlCl^{+2}$	$MnSO_4$ (aq)	$:AlO^-$	-	-
-	$AlSO_4^+$	$MnCl^+$	$:AlOH_2^+$	-	-
-	$Al(SO_4)_2^-$	$MnCl_2$ (aq)	$:AlOCa^+$	-	-
-	$CaOH^+$	$MnCl_3^-$	$:AlOHSO_4^{-2}$	-	-
-	$CaSO_4$ (aq)	$MnCO_3$ (aq)	$:AlSO_4^-$	-	-
-	$CaCl^+$	$MnHCO_3^+$	$:AlOFe^+$	-	-
-	$CaCO_3$ (aq)	NaCl (aq)	$:AlOMn^+$	-	-
-	$CaHCO_3^+$	NaOH (aq)	$:MnO^-$	-	-
-	$FeOH^+$	$NaSO_4^-$	$:MnOCa^+$	-	-
-	$Fe(OH)_2$ (aq)	$NaCO_3^-$	$:MnOMg^+$	-	-
-	$Fe(OH)_3^-$	$NaHCO_3$ (aq)	:MnOMgOH	-	-
-	$FeSO_4$ (aq)	HSO_4^-	$:MnOMn^+$	-	-
-	$FeCl^+$	$H_2CO_3^*$ (aq)	:MnOMnOH	-	-
-	$FeHCO_3^+$	HCO_3^-	$:MnhO^-$	-	-
-	$FeOH^{+2}$	OH^-	NaX	-	-

Notes: ‘h’ indicates a high affinity site for chemical adsorption. Species with the same combination of components but no ‘h’ have a low affinity site. In reality, species with and without the ‘h’ are physically identical, but the designation is applied within the model to explain observed adsorption behavior.

‘X’ indicates a clay adsorption site.

‘:’ indicates an adsorption surface provided by metals (Fe: hydrous ferric oxide, Al: gibbsite, Mn: hydrous manganese oxide).

Streambed and Suspended Sediment

The streambed was configured to contain two virtual model layers in Monongahela MDAS. The first layer in the model was represented as an active sediment layer that participates in all chemical reactions. The second modeled layer was represented as a non-active sediment layer but contributes to total sediment and mineral mass. The active layer was thought to be either freshly precipitated minerals or shallow sediment layer that reacts with chemicals/minerals in the overlaying water within the modeled computational time step. The non-active layer was assumed to be aged and has lost chemical reactivity. Both layers were subjected to sediment aging and/or burial. The model sediments were represented by sand (as non-cohesive sediment), and silt and clay size minerals (as cohesive sediment). Clay size minerals included clay, calcite, gypsum, jurbanite, and others, that could potentially be present in acidic/post-remedial-solution discharges from mine sources or other sources. All metal oxides provided surface areas for cations and anions to adsorb and desorb based on the DDL model and clay can also adsorb and desorb cations.

Deposition to and scour from the streambed sediments were simulated on both the active and the non-active layer in the stream channel, with full simulated transport with adsorbed chemicals. The exchange between the water column and the streambed of clay, metal oxides, and other minerals was determined in the model based on the shear stress at the sediment surface layer and the hydrogeometry conditions of each reach.

Kinetics Representations in MDAS

Additional non-equilibrium processes and reactions were represented by kinetic formulations in order to provide a greater accuracy in the stream environment. Applied kinetics were as follows:

- Degassing/ingassing of CO_2
- Lake reaeration
- Calcite dissolution and precipitation
- Metal oxides, gypsum and jurbanite dissolution and precipitation
- Metals oxidation/reduction
- Aging/burial of active sediment layer

Initially, reaction rates were selected from literature rates and adjusted during the calibration processes. Adjustments of the rates were justified as the lab derived rates were, in many cases, not directly transferable to natural settings. Descriptions of the kinetic reactions in MDAS are described below.

Degassing/ingassing of Carbon Dioxide. At river confluences, waste discharges and many natural water mixing conditions (i.e. surface water and groundwater), the initial mixed solution could create a non-equilibrium CO_2 gas pressure in the water column relative to the atmospheric composition. Instantaneous CO_2 exchange may not be possible due to the kinetic limitations on gas transfer between the air-water interface. However, CO_2 gas experiences a gradual degassing or ingassing process to equilibrate with the atmosphere, especially if the exchange can be facilitated by the stream turbulence and/or increased stream surface area. In order to calculate

CO_2 exchange, the saturation concentration of CO_2 must be determined and compared to the modeled aqueous concentration of CO_2. The first step involves the calculation of Henry's constant for CO_2 by Equation 1 below. The approach is based on the existing LSPC and HSPF (Bicknell, et al. 2004) functions unless otherwise noted.

$$\log S = \left(\frac{2385.73}{T} - 14.0184 + 0.0152642 * T\right) \tag{1}$$

where:

S = Henry's constant for CO_2 $\left(\frac{moles\ CO_2-C}{L}\right)$

T = water temperature (K)

Using Henry's constant, the saturation concentration of CO_2 is calculated as:

$$SATCO2 = 3.16\ x\ 10^{-4} * S \tag{2}$$

where:

SATCO2 = saturation concentration of CO_2 $\left(\frac{moles\ CO_2-C}{L}\right)$

The CO_2 invasion is then calculated as follows:

$$ATCO2 = KCINV * (SATCO2 - CO2) \tag{3}$$

where:

ATCO2 = CO_2 invasion $\left(\frac{moles\ CO_2-C}{L*interval}\right)$

KCINV = CO_2 invasion coefficient $(interval^{-1})$

CO2 = concentration of CO_2 after longitudinal advection $\left(\frac{moles\ CO_2-C}{L}\right)$

A positive value for ATCO2 indicates addition of CO_2 to the water; a negative value indicates a release of CO_2 from water to the atmosphere. The value calculated for KOREA, the oxygen reaeration coefficient (discussed below), determines the value of KCINV by the following relationship:

$$KCINV = 0.98 * KOREA \tag{4}$$

where:

0.98 = ratio of CO_2 invasion rate to O_2 reaeration rate (Chapra, et al. 2008)

KOREA = O_2 reaeration coefficient $(interval^{-1})$

The value used for KOREA in Equation 4 can be calculated by one of various methods chosen by the user, including:

1) Tsivoglou method

2) Modeled velocity and water depth dependent method, either:
    a. Owen's formula (Owen et al. 1964) for depths of less than 2 feet (REAK = 0.906, EXPREV = 0.67, EXPRED = -1.85),
    b. Churchill's formula (1962) for high velocity situations in depths of greater than 2 feet (REAK = 0.484, EXPREV = 0.969, EXPRED = -1.673), or

c. O'Connor-Dobbin's formula (1958) for lower velocity situations in depths of greater than 2 feet (REAK = 0.538, EXPREV = 0.5, and EXPRED = -1.5).

3) Coefficient as a power function of velocity and/or depth

If method 2 is used, the respective values for REAK, EXPREV, and EXPRED presented above can be applied to the following formula:

$$KOREA = REAK * (AVVELE^{EXPREV}) * (AVDEPE^{EXPRED}) * (TCGINV^{TW-20}) * DELT60 \quad (5)$$

where:

REAK	= empirical constant for reaeration equation (hour^{-1})
AVVELE	= average velocity of water (ft/s)
EXPREV	= exponent to velocity function
AVDEPE	= average water depth (ft)
EXPRED	= exponent to depth function
TCGINV	= temperature correction coefficient for reaeration defaulted to 1.047
TW	= water temperature (° C)
DELT60	= conversion factor from units of (hour^{-1}) to units of (interval^{-1})

If the user defines the reach as a lake, then MDAS uses the lake functions.

Lake Reaeration. In a lake or reservoir, the oxygen reaeration coefficient KOREA depends on surface area, volume, and wind speed. The wind speed factor is determined using the following empirical relationship:

$$WINDF = WINDSP * (-0.46 + 0.136 * WINDSP) \quad (6)$$

where:

WINDF	= wind speed factor
WINDSP	= wind speed (m/s)

For low wind speeds less than 6.0 m/s, the wind speed factor WINDF is set to 2.0 m/s. Then the oxygen reaeration coefficient for lakes is calculated as follows:

$$KOREA = \left(\frac{0.032808 * WINDF * CFOREA}{AVDEPE}\right) * DELT60 \quad (7)$$

where:

CFOREA	= correction factor; for lakes with poor circulation characteristics, CFOREA may be less than 1.0, while lakes with exceptional circulation characteristics may have a value greater than 1.0

Calcite dissolution and precipitation. Depending on the solution composition calculated during the model run, Equation 8 gives either a positive or negative rate for calcite. If the rate is positive, it indicates potential dissolution, otherwise potential precipitation is assumed (Parkhurst and Appelo 1999; Langmuir 1997). Dissolution can only occur if calcite mineral is present in the water column and/or within the active sediment layer. There is no differential treatment of dissolution of calcite if it is in the water column or in the sediment layer. Once the mineral is precipitated/generated in the water column, it will stay in the water column until it is deposited to the streambed.

$$r_k = K1 * (H^+) + K2 * (H_2CO_3^*) + K3 - K4 * (Ca^{2+}) * (HCO_3^-) \quad (8)$$

where:

r_k = dissolution/precipitation rate $\left(\frac{mol}{m^2/s}\right)$

all species are expressed as activities, and

$$\log K1 = 0.198 - \frac{444}{T} \quad (9)$$

$$\log K2 = 2.84 - \frac{2177}{T} \quad (10)$$

$$\log K3 = 5.86 - \frac{317}{T} \quad (11)$$

$$\log K4 = 7.56 + 0.016 * T - 0.64 * \log\left(\frac{H_2CO_3^*}{K_H}\right) \quad (12)$$

T = water temperature (K)

K1…K4 = rate constants

$$R_k = r_k * \frac{A_0}{V} * \left(\frac{m_k}{m_{0k}}\right)^n \quad (13)$$

where:

R_k = overall kinetic reaction rate $\left(\frac{mol}{m^3/s}\right)$

A_0 = surface area of the solid (m^2)

V = unit volume of the waterbody (m^3)

m_k = moles of the solid at a given time

m_{0k} = initial moles of the solid

n = 0.6 (the value given in the literature

Metal oxides, gypsum and jurbanite dissolution and precipitation. During the model calculations, the solubility of mineral phases is verified in relation to the solubility product. Depending on the saturation index (determined from Equation 14 as the ratio of the ion activity product to the solubility product), Equation 15 yields either a positive or negative net rate, R_{net}. If the rate is positive, it indicates potential dissolution and if the rate is negative, potential precipitation is assumed (Brantley, et al. 2008, and Parkhurst and Appelo 1999). Dissolution can only occur if the relevant minerals exist in the water column and/or the active sediment layer. There is no differential treatment of dissolution of minerals in the water column or in the sediment layer. Once the mineral is generated in the water column due to oversaturation, it will remain in the water column until it is deposited to the streambed.

$$\Omega = \frac{Q}{K_{eq}} \quad (14)$$

where:

Ω = saturation index

Q = ion-activity product

K_{eq} = solubility product

$$R_{net} = r_k * |1 - \Omega| \quad (15)$$

where:

R_{net}= net reaction rate $\left(\frac{mol}{m^2/s}\right)$

r_k = user-defined dissolution/precipitation rate

$$R_k = R_{net} * \frac{A_o}{V} * \left(\frac{m_k}{m_{0k}}\right)^n \quad (16)$$

where:

R_k = overall kinetic reaction rate $\left(\frac{mol}{m^3/s}\right)$

and A_0, V, m_k, and m_{0k} are defined as for Equation 12

Metals oxidation/reduction. The various oxidation and reduction kinetics of iron and manganese are incorporated in the model. All species are expressed in activities except where otherwise noted.

Ferrous iron oxidation (Stumm and Morgan 1996):

Below pH 3.5

$$\frac{d(Fe(II))}{dt} = -k * \left(Fe(II)\right) * P_{O_2} \quad (17)$$

where:

k = $10^{-3.2}$ (bar·day)$^{-1}$ (the rate in the literature)

P_{O2} = partial pressure of O_2 (bar)

Above pH 3.5

$$\frac{d(Fe(II))}{dt} = -k * \frac{(Fe(II))*P_{O_2}}{(H^+)^2} \quad (18)$$

where:

H^+ is expressed in moles, and

k $\approx 1.2 * 10^{-11} \left(\frac{mol^2}{bar*day}\right)$ (the rate in the literature)

Microbial oxidation of ferrous iron (McKnight and Bencala 1988):

$$\frac{d(Fe(II))}{dt} = -k_m(Fe(II)) \quad (19)$$

where:

k_m = 0.282 h^{-1} (the rate in the literature)

Photoreduction of dissolved ferric iron (based on David and David 1976; Bicknell et al. 2004; Chapra et al. 2008; McKnight and Bencala 1988):

$$\frac{d(Fe(II))}{dt} = 0.97 * SOLRAD * CONV * R * \left(1 - 0.65 * \left(\frac{CLOUD}{10}\right)^2\right) * (FeOH^{2+}) \quad (20)$$

where:

0.97 is the fraction of incident radiation which is assumed absorbed (3 % is assumed reflected)

SOLRAD = shortwave radiation $\left(\frac{Langley}{hour}\right)$

CONV = conversion factor = 11.63 $\frac{Watts*hr/m^2}{Langley}$

R = scaling factor $\left(\frac{m^2}{Watt}\right)$ to control photoreduction with a function of light intensity, quantum yield, and reoxidation rate of Fe(II) by OH^-

CLOUD = cloud coverage (tenths)

Homogenous Mn(II) oxidation (Grassian 2005):

$$\frac{d(Mn(II))}{dt} = -k_2\beta_2 * K_H * \frac{(Mn(II))*P_{O_2}}{(H^+)^2} \qquad (21)$$

where:

k_2 = $10^{1.7}$ $(mol/L * s)^{-1}$ (the rate in the literature)

β_2 = 10^{-22} $(mol/L)^2$ (the rate in the literature)

K_H = Henry's constant for O_2 $(mol/L * atm)^{-1}$

P_{O2} = partial pressure of O_2 (atm)

Aging/burial of active sediment layer. Aging and burial rate of active sediment layer was simulated using the first order respect with the depth of the sediment layer.

$$\frac{d(L)}{dt} = -K * L \qquad (22)$$

where:

K = user-defined decay rate (day^{-1})

L = depth of the active sediment layer

3.5.3 MDAS Model Schematic

The model schematic (**Figure 3-10**) illustrates the Monongahela MDAS model functionality, in other words, how MDAS subroutines and chemical constituents interacted with each other. The numbers in the figure correspond with the numbered steps below.

1) The user-defined land input will be processed through the edge-of-stream calculation. The method of the calculations will be either fixed pH or charge/mass balance calculations, depending on the user selection. Additionally, variable surface runoff loadings can be added through build-up or wash-off of sediment-associated chemicals. The assigned dissolved total concentrations will be distributed into Dissolved Chemical *C-comp(W)* and Particulate Chemical *C-comp(w-ads)*. The user-assigned *minerals (w)* will provide an adsorption surface in the calculation to estimate the *C-comp(ads-w)* value. No kinetics calculation will be performed at this level.

2) Dissolved/adsorbed chemicals and minerals will go through advection transport via LSPC function, depending on flow conditions and the physical characteristics of the minerals.

3) Some of the minerals will stay in the same reach for the next time step depending on the flow conditions.

4) After minerals are subjected to the advection transport, LSPC applies the BEDEXCHANGE subroutine*)* and redistributes them as suspended *minerals (W)* and sedimentary *minerals (S)* in the river bed.

5) Subroutine ADVQAL in LSPC will inherit the minerals' advection and bed-exchange information derived through ADVECT and BEDEXCHANGE and apply the results to generate suspended adsorbed *C-comp(w-ads)* and sedimentary adsorbed *C-comp(S-ads).* As a result, some portion of *C-comp(w-ads)* will be transported to the downstream reach, and there will be exchange between *C-comp(w-ads)* and *C-comp(s-ads)* based on the minerals' behavior.

6) Next, the stream components within *C-comp (W)*; *minerals (W)* and *(S)*; and *C-comp (w-ads)* and *(S-ads)* will become inputs to the speciation model (chemical kinetics and equilibrium calculation). The model evaluates chemical components in the water column, on the suspended sediments, and on the streambed exposed to overlaying water. Active sediment layer and non-active sediment layer are controlled by both MDAS and LSPC models.

7) The speciation model performs the re-distribution of the chemical components, and the stream composition is updated. Some of the minerals can be either precipitated or dissolved depending on the solution condition.

8) The results will stay in the reach segment and will be subject to renewed transport and reactions once new loadings from point sources, landuse activities, and atmospheric sources are added to them for the next time step.

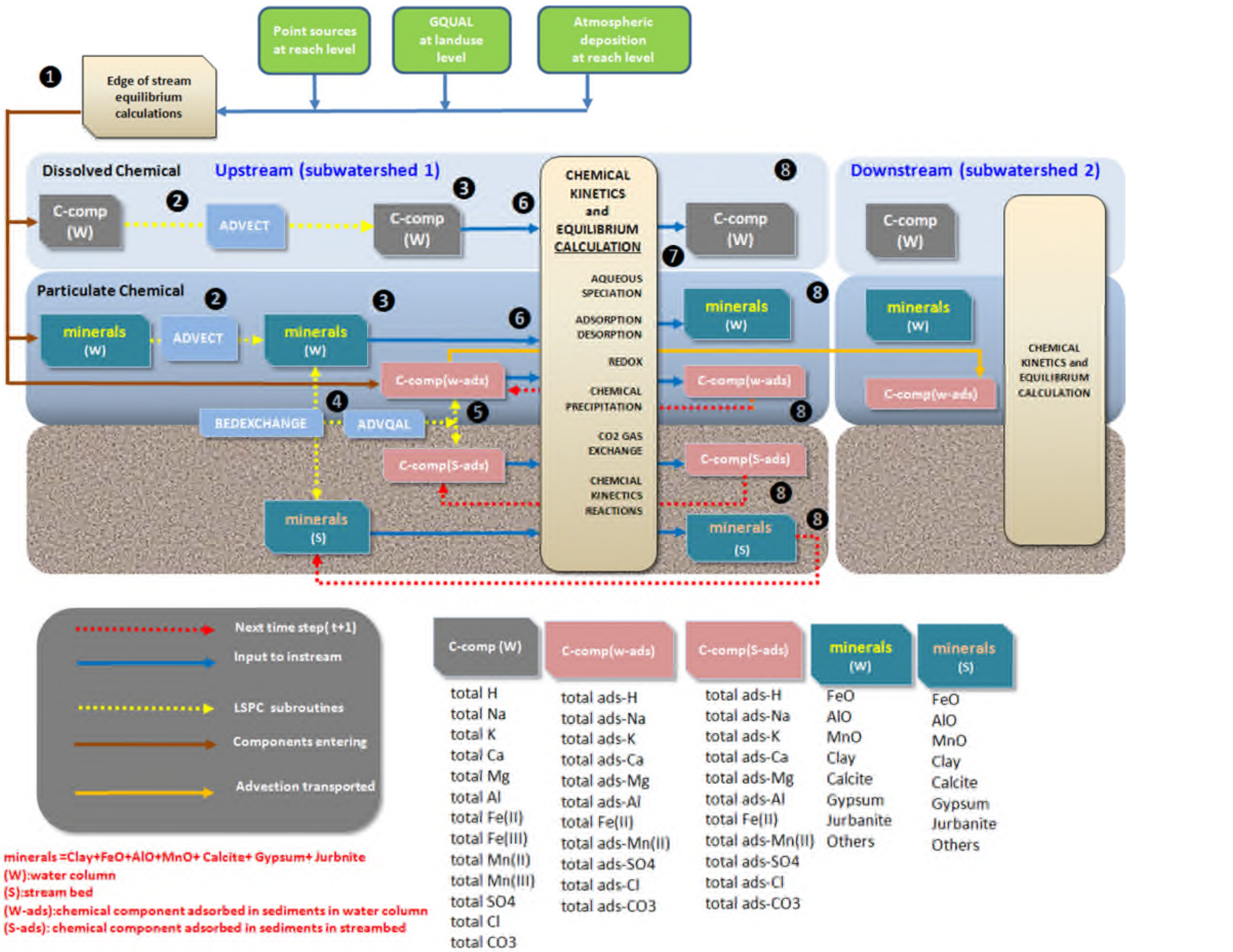


Figure 3-10. MDAS module schematic and linkages

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.

USGS gauging station 03061500 Buffalo Creek at Barrackville, WV and USGS gauging station 03062500 Deckers Creek at Morgantown, WV were USGS flow gauging stations in the modeled portions of the Monongahela River Watershed. Both stations had period of record adequate for hydrology calibration. Hydrology calibration was based on observed data from that station and the landuses present in the watersheds from January 1, 2003 to October 31, 2006.

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 J**. The hydrology calibration statistics for the flow gage on Buffalo Creek are shown in **Table 4-1**. A graphical representation of hydrology calibration results is presented in **Figure 4-1**. Refer to **Appendix J** for additional calibration results.

Table 4-1. Comparison of simulated and observed flow from January 2000 to September 2010 (USGS station ID number 03061500 Buffalo Creek At Barrackville, WV)

Simulated versus Observed Flow	Percent Error	Recommended Criterion[a]
Error in total volume:	• -0.21	• 10
• Error in 50% lowest flows:	• 1.77	• 10
• Error in 10% highest flows:	• -4.42	• 15
• Seasonal volume error - summer:	• 5.09	• 30
• Seasonal volume error - fall:	• -5.26	• 30
• Seasonal volume error - winter:	• -0.64	• 30
• Seasonal volume error - spring:	• 2.49	• 30
• Error in storm volumes:	• -3.17	• 20
• Error in summer storm volumes:	• -0.60	• 50

[a] Recommended criterion: HSPExp.

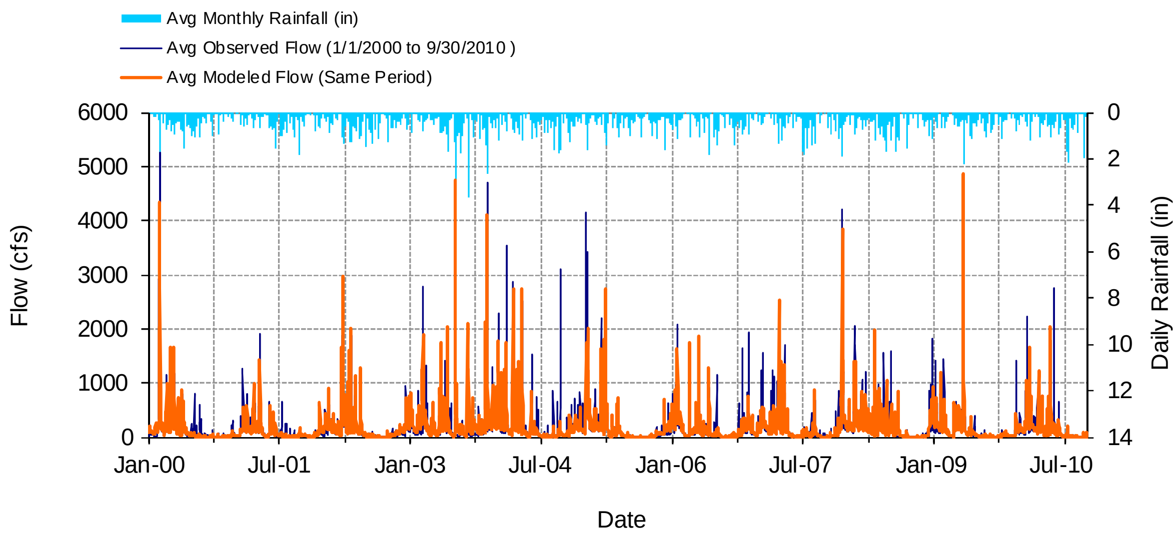


Figure 4-1. Comparison of simulated and observed flow from 2000 to 2010 (USGS station ID number 03061500 Buffalo Creek At Barrackville, WV

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 K**). 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 J** presents the results for the calibration of these sampling events.

The period selected for water quality calibration, June 1, 2009, through June 30, 2010 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.

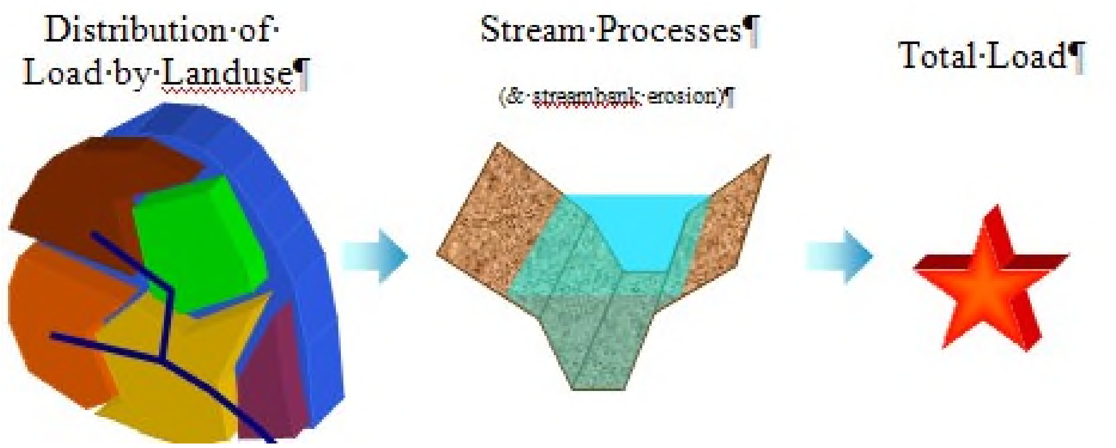


Figure 4-2. Schematic of sediment sources and transport pathways

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.

4.3 Water Quality Calibration

Iron 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 C.**

In addition, non-sediment-related iron 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 J**.

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 J**.

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

A TMDL is the sum of individual 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

$$TMDL = \text{sum of WLAs} + \text{sum of LAs} + MOS$$

To develop aluminum, iron, pH, manganese, chloride 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.

An explicit MOS was not included in selenium TMDLs because little modeling uncertainly exists. Non-attainment is directly related to point sources regulated by WV/NPDES permits and water quality will be met at all locations if point sources achieve prescribed WLAs.

The allocation process prescribes criterion end of pipe WLAs for continuous discharges and instream treatment structures and thereby provides an implicit MOS for criterion attainment at all model assessment locations. Similarly, an explicit MOS was not applied for total iron and chloride TMDLs in certain subwatersheds where mining point sources create an effluent dominated scenario and/or the regulated mining activity encompasses a large percentage of the watershed area. Within these scenarios, WLAs are established at the value of the criteria and little uncertainty is associated with the source/water quality linkage.

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)
Chloride	Aquatic Life	230 mg/L (4-day average)	218.5 mg/L (4-day average)
Total Manganese	Public Water Supply	1.0 mg/L (within 5 upstream miles of a public water intake)	0.95 mg/L
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)
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. 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 presents an example of the annual rainfall totals for the years 1999 through 2010 at the Morgantown Hart Field weather station in West Virginia. Precipitation information from the Morgantown area was used in the Monongahela River Watershed model. The years 2004 to 2009 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.

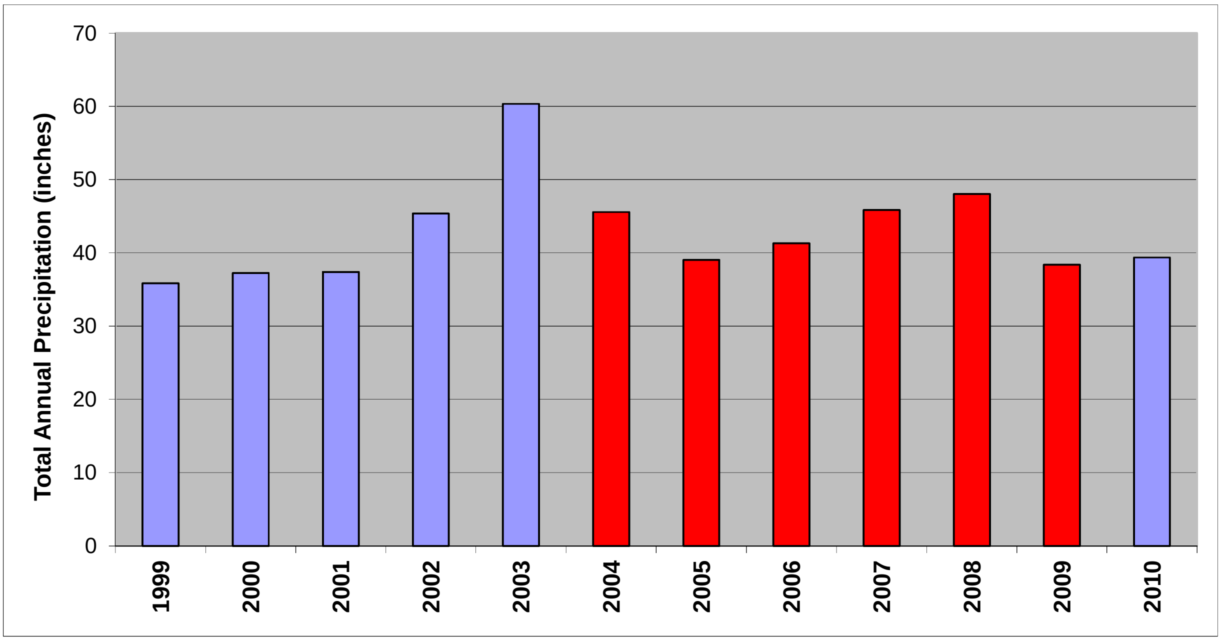


Figure 5-1. Annual precipitation totals for the Morgantown Hart Field (WBAN 13736) weather station

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 2004 to 2009, 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 permit concentrations for technology-based limits are 3.2 mg/L for total iron. In the limited instances where existing effluent limitations vary from the displayed values, the outlets were represented at next higher condition. For example, existing iron effluent limits between 1.5 and 3.2 mg/L were represented at 3.2 mg/L.

For aluminum, most existing permits contain interim effluent limits that are water quality based and reflect achieving water quality criteria end-of-pipe (WLA = 0.75 mg/l), However, discharges are not necessarily compliant with interim limits and the permits allow pursuit of aluminum translators that may result in less stringent final limits. Baseline total aluminum concentrations were equal to the concentration used in calibration (1.45 mg/l). Similarly for chloride, existing discharges are not necessarily compliant with existing water quality based effluent limitations and baseline concetrations were equal to discharge-specific calibration concentrations.

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

Pollutant	Technology-based Permits	Water Quality-based Permits
Aluminum, total	NA	0.75 mg/L
Iron, total	3.2 mg/L	1.5 mg/L
Chloride	NA	NA

An example of model output for a baseline condition and a successful TMDL scenario is displayed in **Figure 5-2**.

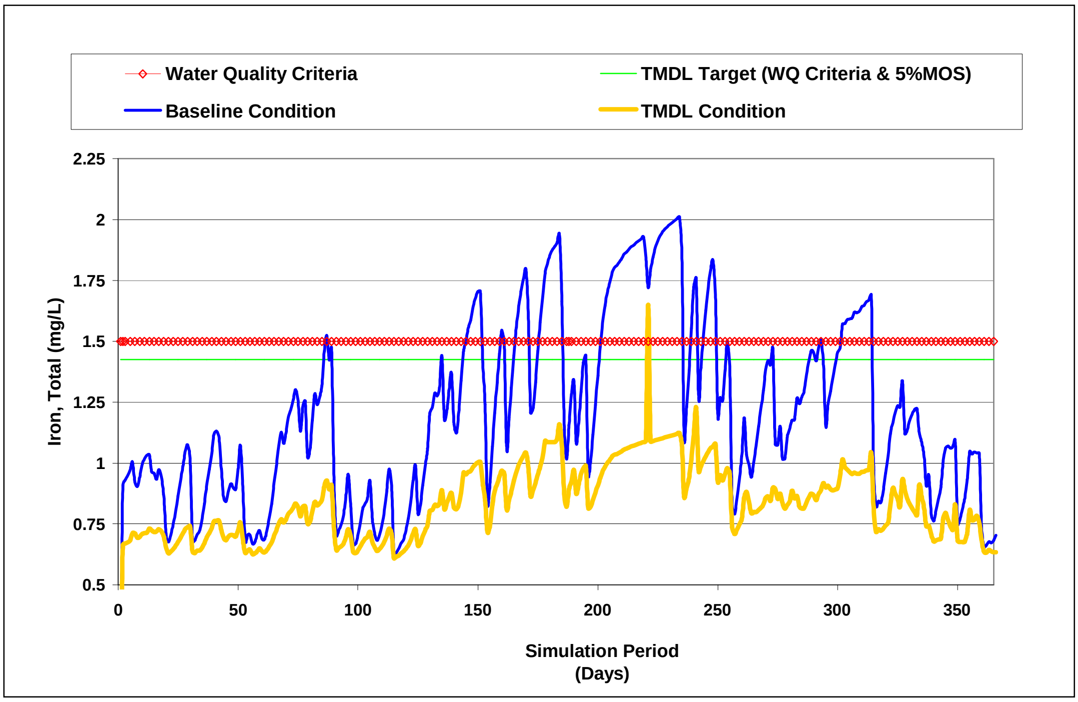


Figure 5-2. Example of baseline and TMDL conditions for iron

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 reduced 100% during the allocation phase of TMDL development. 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 of the Monongahela River Watersheds.-In order to meet iron criterion and allow for equitable allocations, reductions to existing sources were first assigned using the following general rules:

1. The loading from streambank erosion was first reduced to the loading characteristics of the streams with the best observed streambank conditions, as determined by the bank erosion pin study.
2. The following land disturbing sources were equitably reduced to the iron loading associated with 100 mg/L TSS.
   - Abandoned mine lands
   - Barren
   - Cropland
   - Pasture
   - Urban/MS4 Pervious
   - Oil and gas
   - Harvested Forest and Skid Roads
   - Burned Forest
   - Unpaved Roads
3. AML seeps were reduced to water quality criterion end of pipe (1.5 mg/L iron).
4. Traditional mining permits were reduced to water quality criterion end of pipe (1.5 mg/L iron) in watershed when the model indicated non-attainment.

In addition to reducing the streambank erosion and source contributions, activity under the CSGP was considered. Area based WLAs were provided for each subwatershed to accommodate existing and future registrations under the CSGP. Initially, 2.5 percent of the subwatershed area was allocated for CSGP activity in each subwatershed.

After executing the above provisions, model output was evaluated to determine the criterion attainment status at all subwatershed pour points. Where the model indicated non-attainment with the total iron criterion, further reductions to CSGP activity area allowances or iron loading from land disturbing sources were made on a subwatershed basis depending on land cover, concentration of sediment associated iron, and dominant disturbances. The CSGP activity area allowances for subwatersheds contributing to non-attaining downstream subwatersheds were incrementally reduced from 2.5 percent to 0.5 percent area allowances. The iron loads from the dominant source were incrementally reduced below the associated 100 mg/l TSS threshold, but not less than 70 mg/l TSS.

After executing the reductions to iron loads from dominant sources, the model continued to indicate non-attainment at the pour points of a limited number of subwatersheds. In those subwatersheds, further reductions were made to the CSGP activity area allowance to zero percent.

Using this method ensured that contributions from all sources were weighted equitably and that 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. Nonpoint source reductions did not result in allocated loadings less than natural conditions. Permitted source reductions did not result in allocated loadings to a permittee that would be more stringent than water quality criteria.

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)

Runoff from residential and urbanized areas during storm events can be a significant sediment source. USEPA's stormwater permitting regulations require public entities to obtain NPDES permit coverage for stormwater discharges from MS4s in specified urbanized areas. As such, their stormwater discharges are considered point sources and are prescribed WLAs.

USEPA's stormwater permitting regulations require municipalities to obtain permit coverage for stormwater discharges from MS4s. MS4 entities in the Fairmont area are the City of Fairmont and Fairmont State University. MS4s in the Morgantown area are the Town of Star City, the City of Westover, the Morgantown Utility Board, the Federal Correctional Institution – Morgantown, and West Virginia University. These cities and the West Virginia Division of Highways (DOH) have MS4 permits in the modeled portion of the watershed. DOH MS4 area occurs within and between the MS4 boundaries of all the cities. 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 WLAs.

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 WLAs. 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 WLAs results from the predominance of urban/residential/road landuses and impacts in MS4 areas. WVDEP's assumption is that upland 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 WLAs 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 activity under the CSGP are provided at the subwatershed. Allocations from 0 to 2.5 percent of subwatershed area were 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. In certain areas, the existing level of activity under the CSGP does not conform to the subwatershed allocations. In these instances the WVDEP, DWWM permitting program will require stabilization and permit termination in the shortest time possible. Thereafter the program will maintain concurrently disturbed area as allocated or otherwise control future activity through provisions described in the TMDL document, Section 12.

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, 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 Manganese TMDLs

The only identified problematic manganese sources are AML seeps associated with abandoned mine lands and highwalls in the watershed. Reductions of those sources as prescribed in the load allocation component of the TMDL allowed the manganese water quality endpoint to be met.

5.3.4 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 Monongahela River Watershed. Substantive sources (e.g., seeps) of total iron were reduced because existing instream dissolved iron concentrations can significantly reduce pH during precipitation processes. Reduced pH could result in re-dissolution of aluminum minerals (e.g. amorphous aluminum oxides) and could affect instream dissolved aluminum concentrations. During the iron reduction process, the model retained information regarding the phases of total iron, metal acidity, and added alkalinity, that was then linked to dissolved aluminum and pH simulations. If model results predicted non-attainment of the pH and dissolved aluminum criteria, additional reductions were potentially made to total iron, simultaneously with alkalinity additions and total aluminum reductions to source water discharges. Iron reductions were made commensurate with final allocations of the iron TMDL. The following methodology was used to predict necessary alkalinity additions and total aluminum reductions in the model simulation:

- Multiple regressions derived from the observed metal data collected above pH 6.5 in pre-TMDL monitoring were used to estimate realistic dissolved aluminum concentrations associated with the improved source water pH and reduced total aluminum conditions.
- Once the improved pH and the reduced total aluminum concentrations (particulate and dissolved) were determined, the required alkalinity necessary to achieve the improved water quality conditions were quantified and added to the source water discharges. These additions were made throughout the modeling period to simulate instream water quality conditions based on the improved source water loads.
- If the model predicted non-attainment, further total aluminum reduction and/or alkalinity additions were made to source water discharges on a subwatershed basis to the extent necessary to attain dissolved aluminum and pH water quality criteria instream.

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 loading 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 active mining point source discharges regulated by NPDES permits effluent limitations. A WLA is provided for five bond forfeiture site with unreclaimed land disturbance and unresolved water quality impacts. The WLAs for active mining operations and bond forfeiture sites 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.

Baseline loadings from other nonsignificant point sources, including facilities registered under the Multi-sector Stormwater, MS4, and Construction Stormwater General Permits were represented to properly account for aluminum associated with sediment sources. Negligible amounts of acidity or dissolved aluminum are attributed to these sources, thus no reductions were necessary. Aluminum-specific control actions are not prescribed for such sources and grouped WLAs are presented on a subwatershed basis

Load Allocations (LAs)

LAs of total aluminum were determined 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.

5.3.5 Chlorides TMDLs

The top-down methodology was followed to develop the chloride TMDLs and allocate loads to sources. Source allocations were developed for all modeled subwatersheds contributing to the chloride impaired streams in the watershed.

Wasteload Allocations (WLAs)

Individual chloride WLAs were developed for the high-volume, pumped discharge, mining NPDES outlets. The pumped discharges dominate receiving stream flow and necessitate WLAs that are based upon the achievement of the chronic aquatic life protection criterion in the discharge.

Within the watersheds of UNT/Mon River RM 99.49 (Popenoe Run, WV-M-11) and UNT/West Run RM 0.91 (WV-M-7-A), grouped WLAs were developed for MS4 sources and facilities registered under the Multi-Sector Stormwater General Permit. The WLAs prescribe chloride reductions for impervious areas. The WLAs for MS4 sources do not include the influences of the small drainage areas of existing facilities registered under the Multi-sector Stormwater General Permit. The chloride loading of areas associated with the multi-sector permit was represented in the same manner as the MS4 land uses but were differentiated under the presumption that they do not drain to the MS4s and are not subject to MS4 control.

No other point sources of chloride were identified within the watersheds of chloride impaired streams. Certain land uses generally associated with point sources (ex. registered area under the Construction Stormwater General Permit, precipitation-induced mining outlets) were not classified as chloride point sources because they do not contribute chloride appreciably greater than background. Their modeled loadings are contained within the aggregated load allocation for background sources discussed in the following section.

Load Allocations (LAs)

Chloride loadings are represented for multiple nonpoint and background sources and source categories.

Exclusive of runoff from urban/residential impervious surfaces, precipitation- induced nonpoint sources are not characterized as chloride sources because they do not contribute chloride significantly greater than expected background. Continuous flow AML seeps were also found to contribute negligible chloride loadings. The modeled chloride loadings for all “background” sources are contained within the aggregated LA for Background and Other Nonpoint Sources”.

Road and impervious surface de-icing activities contribute non-negligible chloride loads to receiving waters and LAs are presented for the non-MS4 urban residential impervious land use. Chloride reduction is not associated with the urban residential impervious LAs except in UNT/West Run RM 0.91 where reductions are consistent with those prescribed for MS4 areas in that watershed. Elsewhere, point source reduction will result in criteria attainment with nonpoint source loading at baseline conditions.

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.

5.5 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 biological score, the reference stream for the Monongahela River Watershed is Little Paw Paw Creek (WV-M-49-D). The location of the reference stream is shown in **Figure 6-1.**

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.

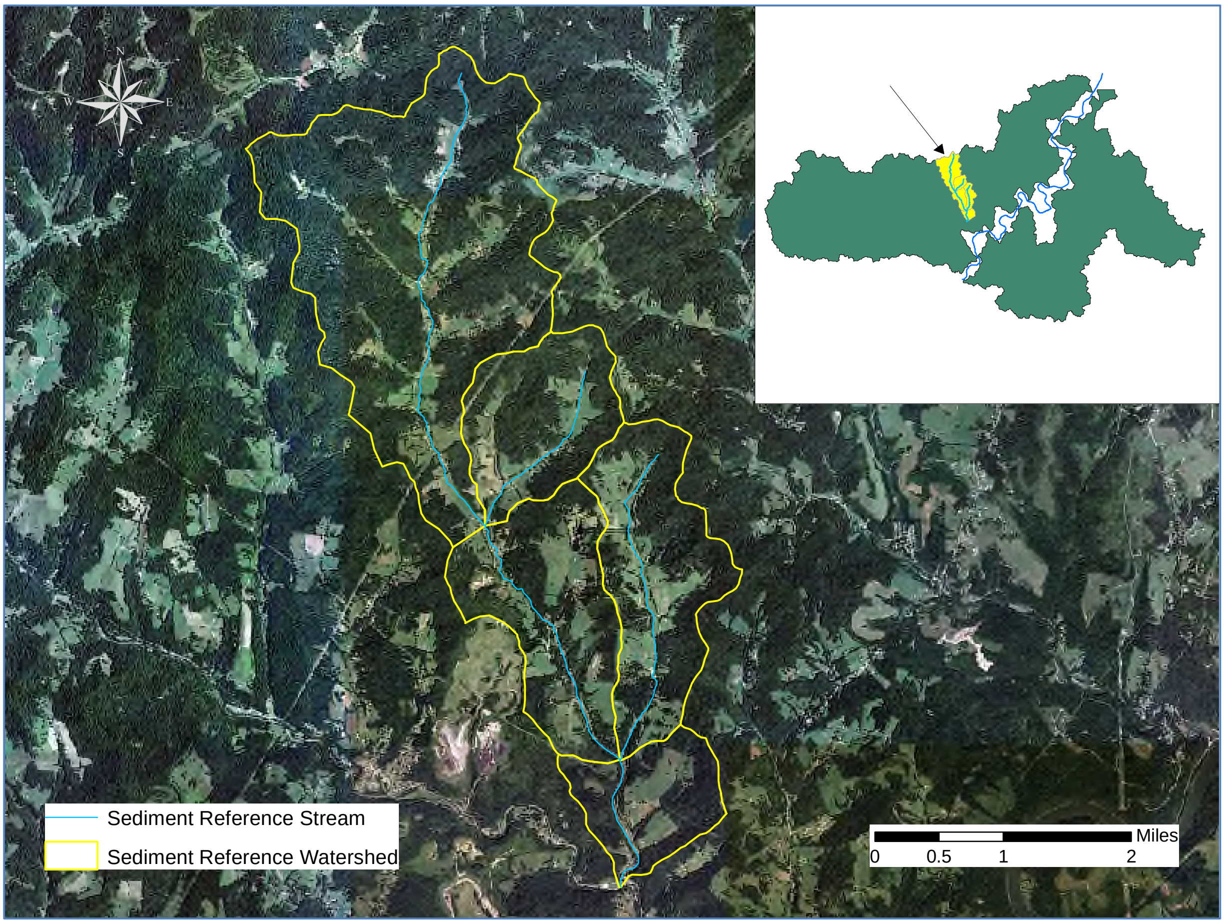


Figure 6-1. Location of the sediment reference stream, Little Paw Paw Creek (WV-M-49-D)

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 for Monongahela River Watershed.

Stream Name	Stream Code	Allocated Sediment Load Iron TMDL (tons/yr)	Allocated Sediment Load Reference Approach (tons/yr)
Aaron Creek	M-14-B	79.96	230.45
Bartholomew Fork	M-54-AK	90.62	266.33
Buffalo Creek	M-54	1512.17	4008.82
Campbell Run	M-54-X-9	55.39	149.41
Deckers Creek	M-14	787.44	2026.96

Stream Name	Stream Code	Allocated Sediment Load Iron TMDL (tons/yr)	Allocated Sediment Load Reference Approach (tons/yr)
Dents Run	M-12	177.83	459.11
Dents Run	M-54-Z	81.91	233.75
Flaggy Meadow Run	M-54-W	26.42	78.62
Flat Run	M-54-X-3	95.01	263.51
Hickman Run	M-55	27.11	86.88
Joes Run	M-54-AC	8.53	27.53
Little Creek	M-42	52.39	164.39
Llewellyn Run	M-54-X-3-A	17.02	60.14
Mahan Run	M-54-U	26.57	85.23
Mod Run	M-54-T	36.44	107.81
Owen Davy Fork	M-54-AI	67.04	181.98
Paw Paw Creek	M-49	481.03	1357.19
Prickett Creek	M-44	270.67	782.12
Pyles Fork	M-54-X	354.36	959.04
Robinson Run	M-8	60.61	237.34
Scratchers Run	M-44-H	23.18	76.03
Sugar Run	M-49-W	16.12	52.38
UNT/Bethel Run RM 0.80	M-54-I-1-A	14.71	41.67
UNT/Crooked Run RM 2.27	M-2-B	14.01	42.64
UNT/Deckers Creek RM 5.70	M-14-E	20.02	60.16
UNT/Finchs Run RM 1.15	M-54-D-2	8.51	32.46
UNT/Monongahela River RM 128.55	M-57	7.35	23.44
Whetstone Run	M-54-AA	28.85	90.31

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