Total Maximum Daily Loads for the Big Sandy River, Lower Ohio River, and Twelvepole Creek Watersheds
West Virginia

TECHNICAL REPORT

March 2021

CONTENTS

Acronyms and Abbreviations iv

1.0 Introduction 6
- 1.1 Purpose 6
- 1.2 Physical Considerations in Developing the TMDL Approach 6

2.0 Mining Data Analysis System 7
- 2.1 LSPC Water Quality Modeling Component 7
  - 2.1.1 The Hydrologic Cycle in LSPC. 9
  - 2.1.2 Erosion and Sediment Transport 10
  - 2.1.3 Water Quality 11
- 2.2. Mining Data Analysis System (MDAS) Model Configuration 11
  - 2.2.1 Watershed Subdivision 11
  - 2.2.2 Meteorological Data 12
  - 2.2.3 Stream Representation 13
  - 2.2.4 Hydrologic Representation 14
  - 2.2.5 Pollutant Representation 14
  - 2.2.6 Streambank Erosion Representation 14
  - 2.2.7 Iron Sediment Correlation 15

3.0 MDAS Fecal Coliform 17
- 3.1 Fecal Coliform Nonpoint Sources 17
  - 3.1.1 Wildlife 19
  - 3.1.2 Agriculture 19
  - 3.1.3 Residential/Urban Runoff 20
  - 3.1.4 Failing Septic Systems 20
- 3.2 Fecal Coliform Point Sources 21
  - 3.2.1 CSO Representation 22
  - 3.2.2 Municipal Separate Storm Sewer Systems (MS4) 22

4.0 MDAS Iron and Sediment 23
- 4.1 Landuse 23
  - 4.1.1 Additional Sediment Source Landuse Categories 24
  - 4.1.2 Additional Residential/Urban Pervious and Impervious Landuse Categories 27
  - 4.1.3 Other Nonpoint sources 27
- 4.2 Sediment and Metals Point Sources 27
  - 4.2.1 Construction Stormwater General Permit 28
  - 4.2.2 Other Individual and General NPDES Permits 28

5.0 MDAS for Aluminum and pH 28

5.1 Overview of MDAS pH and Aluminum Model 29
5.2. Overview of Land Components pH and Aluminum MDAS Model 29
5.3 Land sources in MDAS model 31
 5.3.1 Acid Mine Drainage 31
 5.3.2 Abandoned Mine Lands 32
 5.3.3 Atmospheric Deposition and background loadings 32
 5.3.4 Alkalinity Additions 32
 5.3.5 Permitted sources 33
5.4 Overview of Stream Components in the pH and Aluminum MDAS Model 33
 5.4.1 Water Column 33
 5.4.2 Aqueous Speciation Model in MDAS 34
 5.4.3 Streambed and Suspended Sediment 36
 5.4.4 Kinetics Representations in MDAS 37
5.5 MDAS Instream Model Schematic 37
5.6 Instream Sources and Sinks Controlling Pollutant Fate and Transport 40

6.0 Model Calibration 40
6.1 Hydrology Calibration 40
 6.1.1 Snow 41
 6.1.2 Surface Hydrology 41
6.2 Fecal Coliform Water Quality Calibration 43
6.3 Sediment Water Quality Calibration 43
6.4 Iron Water Quality Calibration 45
6.5 Selenium Water Quality Calibration 46

7.0 Biological Stressor Identification 46
7.1 Stressor Identification Overview 46
7.2 Technical Approach 47
 7.2.1 Development of the Conceptual Model 48
 7.2.2 Data Analysis 48
 7.2.3 Empirical Model Development to Identify Multiple Stressors 49
7.3 Stressor Identification Results 55

8.0 Sediment Reference Watershed Approach 56

9.0 References 57

TABLES

Table 3-1. Fecal coliform bacteria model landuse grouping 18

Table 3-2. Average percentage of pervious and impervious land for NLCD 2011 residential/urban landuse types 18

Table 3-3. Septic failure rates in septic failure zones 20

Table 4-1. Additional modeled sediment/metals landuse categories 23

Table 4-2. Assigned perviousness and estimated width for each type of road 26

Table 5-1. Chemical components and complexes included in previous and updated versions of MDAS. 35

Table 6-1. Comparison of simulated and observed flow from January 2008 to December 2017 (USGS 03206600 East Fork/Twelvepole Creek Near Dunlow, WV) 43

Table 7-1. Stressor identification analysis thresholds 52

Table 7-2. Available data for the evaluation of candidate causes 55

FIGURES

Figure 2-1. Water Budget Schematic illustrating order in which the potential evapotranspiration is satisfied in the LSPC model. 9

Figure 2-2. Conceptual schematic of LSPC sediment erosion and transport model....10

Figure 2-3. Snow Simulation Schematic....13

Figure 2-4. Conceptual diagram of stream channel components of bank erosion model....15

Figure 2-5. Example of instream iron-sediment correlation 17

Figure 5-1. Land components of the LSPC-MDAS model....31

Figure 5-2. Stream components in MDAS....34

Figure 5-3. MDAS module schematic and linkages 39

Figure 6-1. Comparison of simulated and observed flow from January 2008 to December 2017 for East Fork/Twelvepole Creek (WV-OT-45)....43

Figure 6-2. Sediment model parameters and processes 45

Figure 7-1. Stressor identification process....47

APPENDICES

Appendix A TMDL Workload List
Appendix B Bank Vegetative Cover Scores
Appendix C TSS Metals Correlation
Appendix D Modeled Landuse
Appendix E Failing Septics
Appendix F NPDES Permits
Appendix G Forest Harvest and Burn Sites

Appendix H Road Descriptions
Appendix I Hydrology & Water Quality Model Calibration
Appendix J Water Quality Data
Appendix K Stressor Identification
Appendix L Sediment Reference Approach

ACRONYMS AND ABBREVIATIONS

AMD	acid mine drainage
AML	abandoned mine land
BMP	best management practice
BOD	biochemical oxygen demand
CAIR	Clean Air Interstate Rule
CFR	Code of Federal Regulations
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
OGCSGP	Oil and Gas Construction Stormwater General Permit
OOG	WVDEP 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	WVDEP DWWM 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 Purpose

The purpose of this document is to provide supplemental information regarding model selection, technical approaches, specific source representations and relevant supporting data to expand upon the TMDL report. The TMDL report provides a complete overview of the TMDL process, including stream impairment, pollutant sources, model calibration, baseline representations, allocation strategies, TMDLs, future growth provisions, reasonable assurance, implementation, and public comments.

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. This document presents the approaches taken to develop the linkage between sources and instream responses for TMDL development in West Virginia watersheds.

This document refers to supporting data organized into the following appendices:

Appendix A	TMDL Workload List
Appendix B	Bank Vegetative Cover Scores
Appendix C	TSS Metals Correlation
Appendix D	Modeled Landuse
Appendix E	Failing Septics
Appendix F	NPDES Permits
Appendix G	Forest Harvest and Burn Sites
Appendix H	Road Descriptions
Appendix I	Hydrology & Water Quality Model Calibration
Appendix J	Water Quality Data
Appendix K	Stressor Identification
Appendix L	Sediment Reference Approach

1.2 Physical Considerations in Developing the TMDL Approach

The TMDL development approach must consider the dominant processes that affect pollutant loading and instream fate. The primary sources contributing to metals 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 iron, sediment, and fecal coliform bacteria, when applicable in the streams included in this TMDL effort (See **Appendix A** for a complete list). 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. A detailed description of the MDAS model follows in **Section 2.0**.

2.0 MINING DATA ANALYSIS SYSTEM

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 dynamic watershed model component within MDAS is the Loading Simulation Program–C++ (LSPC) (Shen, et al., 2002). The model 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.

2.1 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, and
  - 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:

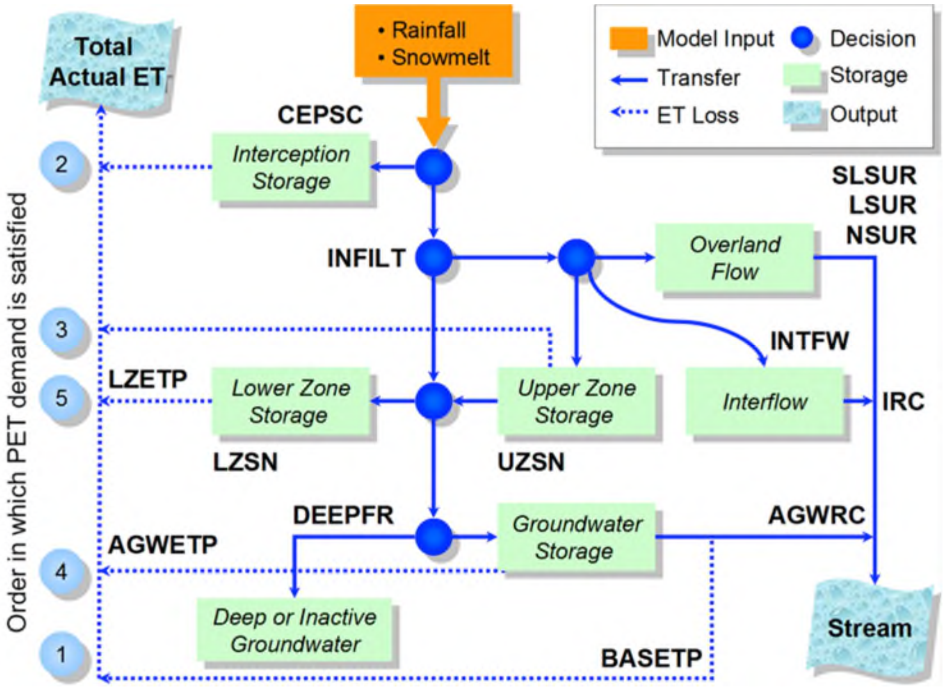
- PERLND - for simulating watershed processes on pervious land areas
- IMPLND - for simulating processes on impervious land areas
- SEDMNT - for simulating production and removal of sediment
- RCHRES - for simulating processes in streams and vertically mixed lakes
- SEDTRN - for simulating transport,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

2.1.1 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 flow paths: surface, interflow, and groundwater outflow. The parameters associated with various stages of the LSPC water budget are shown schematically in **Figure 2-1**.



Key to Parameters

ET is the evapotranspiration.
SLSUR is the overland flow slope.
LSUR 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 2-1. Water Budget Schematic illustrating order in which the potential evapotranspiration is satisfied in the LSPC model.

2.1.2 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 2-2** 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.

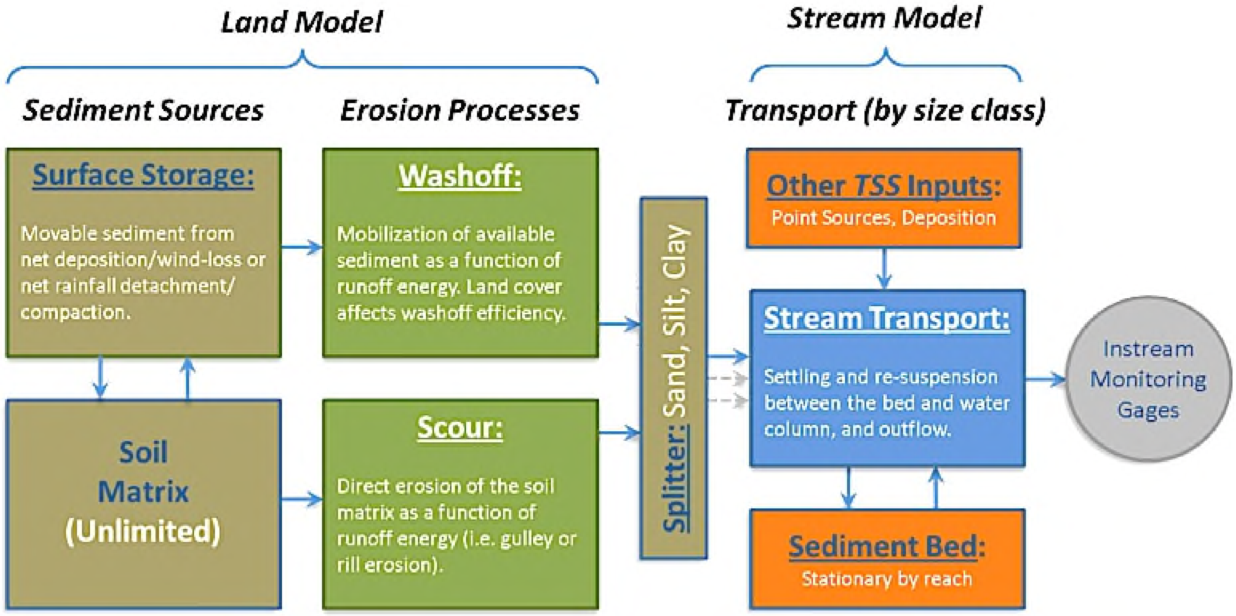


Figure 2-2. Conceptual schematic of LSPC sediment erosion and transport model.

The instream 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.

2.1.3 Water Quality

The GQUAL module in LSPC 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 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.

2.2. 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, sediment, and fecal coliform bacteria. This section describes the configuration process and key components of the model in greater detail.

2.2.1 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.

2.2.2 Meteorological Data

Meteorological data are a critical component of the watershed model. Appropriate representations of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point are 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.

Appropriate spatial resolution of weather data is also important when modeling the hydrology of mountainous watersheds in West Virginia where abrupt changes in topography are common between mountains and valleys. Two grid-based data products were used to develop model weather input files with appropriate spatial and temporal resolution. The Parameter-Elevation Regressions on Independent Slopes Model (PRISM) and the North American Land Data Assimilation System (NLDAS-2) are both publicly available weather datasets. They can be used separately or together to generate comprehensive weather input files at a fine spatial resolution.

The PRISM dataset was developed by Oregon State University's PRISM Climate Group. The PRISM dataset provides daily, monthly, yearly, and single-event gridded data products of mean temperature and precipitation, and max/min temperatures. PRISM uses a combination of climatologically-aided interpolation (CAI) and Radar (National Weather Service Stage 2 unbiased). The dataset uses a robust network of weather station point measurements incorporated into the PRISM statistical mapping system (PRISM Climate Group, 2014). PRISM products use a weighted regression scheme to account for complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other factors. PRISM data features daily weather on 4 km grid spatial scale.

The NLDAS-2 dataset is maintained through a partnership between the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and several large universities (Cosgrove et al., 2003). It combines rain gauge data with Radar observations to predict hourly weather parameters such as precipitation, solar radiation, wind, and humidity. NLDAS-2 data has hourly weather on a 12 km grid scale.

NLDAS-2 and PRISM datasets are broadly used by various user communities in modeling, research, and applications (NCAR, 2013). PRISM was chosen for TMDL modeling purposes because it featured a higher spatial resolution than NLDAS-2. However, hourly precipitation from the NLDAS-2 dataset was also extracted and used along with supporting data from NOAA National Climatic Data Center (NCDC) Surface Airways Stations to manipulate the daily PRISM weather data into hourly model input files.

PRISM daily time series data was downloaded at 2.5 arc minutes (~4 km) resolution from the PRISM website. Precipitation and max/min temperature data for each grid cell that intersected with TMDL watersheds were identified and processed to create a time series for each 4 km x 4 km grid cell. Once the precipitation and temperature time series for the PRISM grid cell files were created, a weather input file was developed for each grid cell. Given that slight variability was observed between the grid cells at the 12-digit Hydrologic Unit Code (HUC) scale and to allow more feasibility when executing the models, one centrally located weather input file per HUC was identified as representative of the weather in the area. Model subwatersheds falling within each 12-digit HUC were then assigned the appropriate weather input file for hydrologic modeling purposes.

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 2-3** is a schematic of the snow process in LSPC).

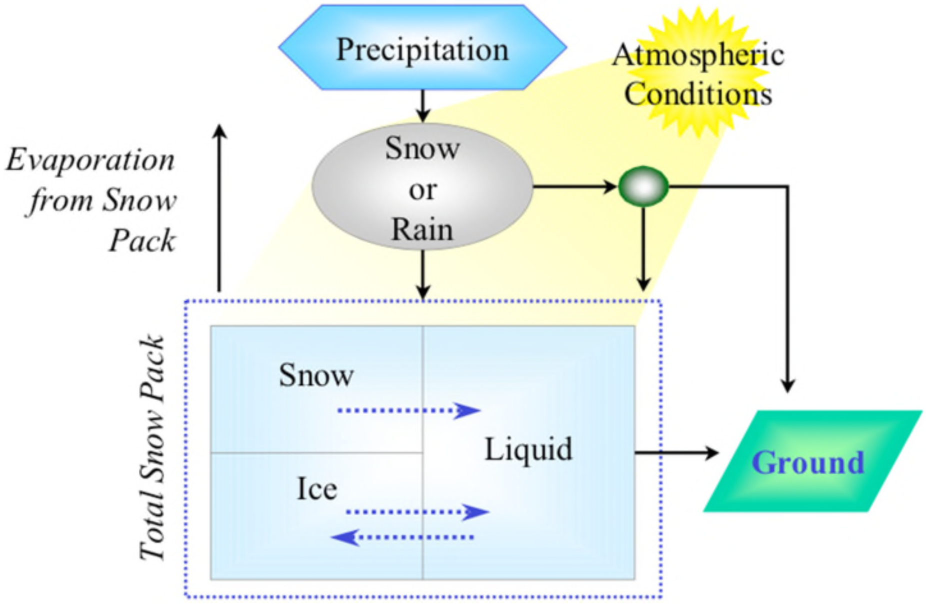


Figure 2-3. Snow Simulation Schematic

2.2.3 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 0.03 (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).

2.2.4 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.

2.2.5 Pollutant Representation

The loading contributions of 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.

2.2.6 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 2-4**). The erodible wetted perimeter is equal to the difference between the actual wetted perimeter (Q Bank Erosion) and wetted perimeter during threshold flow conditions (Q Threshold). 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.

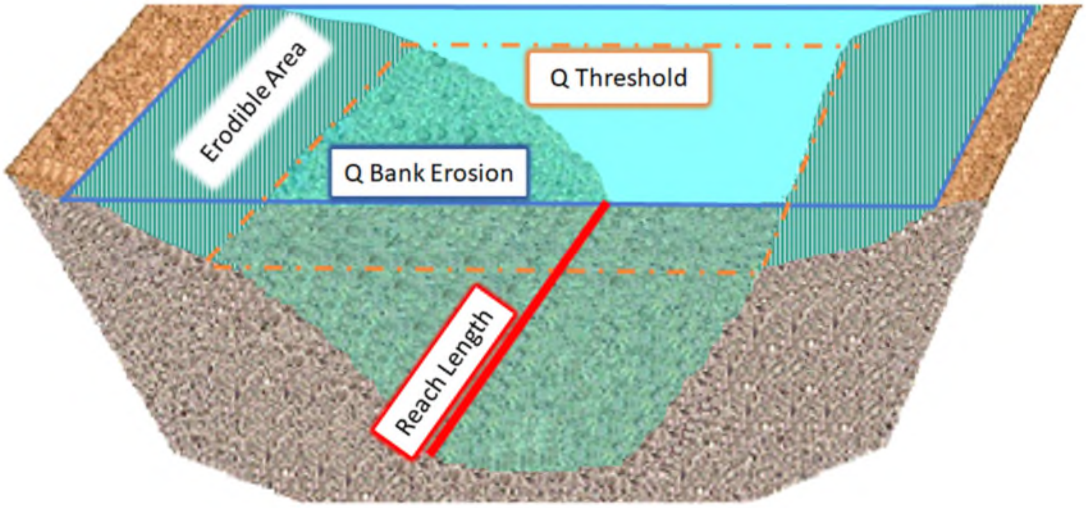


Figure 2-4. Conceptual diagram of stream channel components of bank erosion model

Past quantitative and qualitative field assessments conducted for previous West Virginia TMDLs indicated streambank vegetative coverage was the most important factor controlling bank stability. Streambank soil type also plays a role in determining rates of streambank erosion, as certain soil types are more prone to erosion than others. The coefficient for scour of the bank matrix soil (kber) was determined by considering the additive effects of streambank vegetative cover plus the erodibility factor of the dominant soil type in each subwatershed.

Overall bank stability was initially characterized by assessing and rating vegetative cover based on National Agriculture Imagery Program aerial photography. 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. **Appendix B** provides the bank vegetative cover scores and example subwatersheds for each score.

GIS analysis of the NRCS STATSGO dataset was performed to identify the RUSLE2 erodibility coefficient (Kf) particular to the dominant soil type in each modeled subwatershed. Subwatersheds were stratified into high, medium, and low categories based on the Kf of the dominant soil type. The Kf soil erodibility score was used together with the bank vegetative cover score to establish the initial conditions for model calibration. In the model, the kber parameter controls the streambank erosion intensity in each subwatershed. Calibrating the bank erosion component of the watershed model was performed by adjusting initial kber values through an iterative process that compared model results to pre-TMDL monitoring observations for iron and TSS.

2.2.7 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.

Sedimentary rock strata in West Virginia date predominantly within the Paleozoic era, with the majority of surface formations found within the mid-Paleozoic Mississippian and Ordovician periods having above average iron concentration. Many sandstone formations in West Virginia contain banded-iron deposits which greatly increase the availability of iron. Other surface formations including shale, limestones, clays, and siltstones are potential secondary sources of iron. Sedimentary rocks become a source of iron by natural weathering processes. Earth moving activities such as mining, road building and general development fracture rocks and expose surface area of these iron rich strata, making iron available through erosion and sedimentation.

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. Linear regression analyses were performed on in-stream TSS and total iron data collected at individual WAB monitoring stations. In our representation, 204 WAB monitoring stations were organized into two slope groups to calculate potency factors used in the MDAS modeling. An example of one station is shown in **Figure 2-5**. Potency factors indicating the iron loads relative to the sediment produced from soil and stream bank erosion were calculated from the average Fe/TSS slope of each slope group. 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 subwatersheds is displayed graphically in the GIS project.

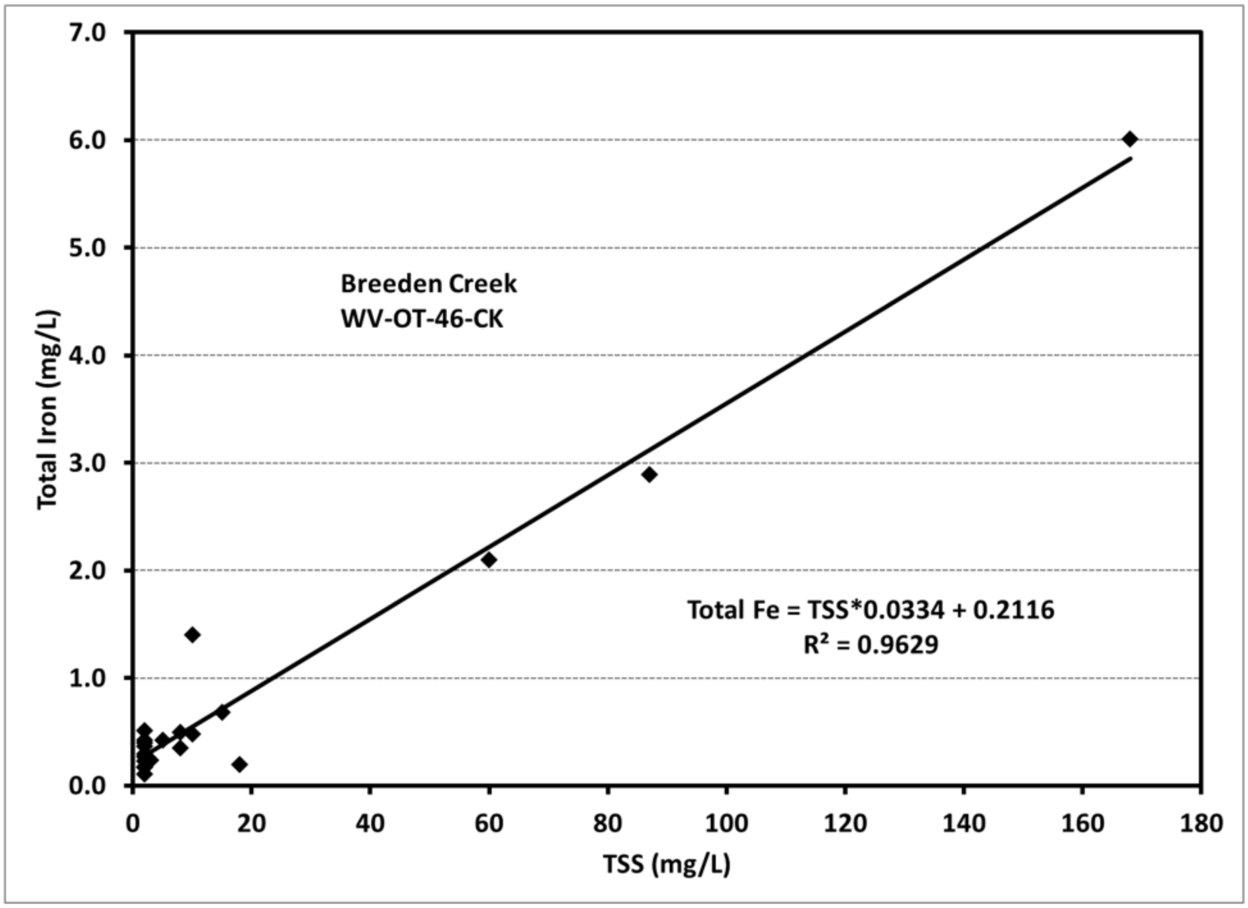


Figure 2-5. Example of instream iron-sediment correlation

3.0 MDAS FECAL COLIFORM

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.

3.1 Fecal Coliform Nonpoint Sources

To explicitly model non-permitted (nonpoint) sources of fecal coliform bacteria, the existing NLCD 2011 landuse categories were consolidated to create model landuse groupings, as shown in **Table 3-1**. Modeled landuses contributing to bacteria loads include pasture, cropland, urban pervious lands, urban impervious lands, forest, 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 D**.

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 3-2.**

Table 3-1. Fecal coliform bacteria model landuse grouping

Model Category	NLCD 2011 Category
Barren	Barren Land (Rock/Sand/Clay)
Cropland	Cultivated Crops
Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Dwarf Scrub
	Shrub/Scrub
Pasture and Riparian Pasture	Grassland/Herbaceous
	Pasture/Hay
Residential/Urban Impervious (See **Table 3-2**)	Developed, Open Space
	Developed, Low Intensity
	Developed, Medium Intensity
	Developed, High Intensity
Residential/Urban Pervious (See **Table 3-2**)	Developed, Open Space
	Developed, Low Intensity
	Developed, Medium Intensity
	Developed, High Intensity
Water	Open Water
Wetlands	Palustrine Forested Wetland
	Palustrine Scrub/Shrub Wetland
	Emergent Herbaceous Wetland

Table 3-2. Average percentage of pervious and impervious land for NLCD 2011 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

3.1.1 Wildlife

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. 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.

Landuses that experience bacteria accumulation due to wildlife include the following: wetlands, forest, grassland, shrubland, and barren. 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. Based on the low fecal accumulation rates for forested areas, the stormwater sampling results, and model simulations, wildlife is considered to be a natural “background” source of fecal coliform bacteria that does not alone cause violations of the state water quality criteria. For this reason, TMDL reductions are not prescribed for wildlife sources.

3.1.2 Agriculture

Pasture and cropland landuses accumulate bacteria when livestock are present, or when manure is applied as fertilizer. Modelers used storm sampling data, literature values, and previous fecal coliform TMDLs to develop initial fecal coliform bacteria loading rates for the model (Miertschin, 2006). However, these initial estimates did not apply uniformly to the entire watershed area being modeled. To accommodate this variation, the fecal coliform modeling parameters for bacterial build-up and accumulation limit were fine-tuned during model calibration to produce model output that more closely matched available pre-TMDL stream 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 and accumulation 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.

3.1.3 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.

3.1.4 Failing Septic Systems

Failing septic systems represent non-permitted (nonpoint) sources that can contribute fecal coliform to receiving waterbodies through surface or subsurface flow. Although categorized as nonpoint sources (part of the load allocation in the TMDL equation), for modeling purposes it was most practical to model failing septic systems as continuous flow sources in the MDAS. To calculate source loads, values for both wastewater flow and fecal coliform concentration were 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 3-3** shows the percentage of homes with septic systems in each of the four septic zones experiencing septic system failure.

Table 3-3. 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, for the Lower Ohio watershed it was assumed that 44 percent of the non-sewered structures in each subwatershed were inhabited homes with septic systems. In areas draining directly to the Big Sandy River, 49 percent of structures were assumed to be homes. In the Twelvepole Creek watershed, 51 percent of structures were assumed to be homes. 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 for the Lower Ohio, Big Sandy, and Twelvepole are presented in **Appendix E**.

3.2 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; and
- 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.

3.2.1 CSO Representation

Municipalities with combined sewer systems are common in West Virginia, and Combined Sewer Overflows (CSOs) are a significant source of fecal coliform during storm events. 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 do 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.

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. Observed data for flow and fecal coliform concentration for each CSO outlet during discharge events is 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 assigned, 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, an intermittent point source CSO time series was constructed 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. The WLAs tab of the TMDL fecal coliform allocations spreadsheet displays a list of CSOs modeled under this effort.

3.2.2 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.

MS4 source representation was based upon precipitation and runoff from landuses determined from the modified NLCD 2011 landuse data, the jurisdictional boundary of the cities, and the transportation-related drainage areas for which DOH has MS4 responsibility. WVDEP consulted with local governments and obtained information to determine drainage areas to the respective systems and best represent MS4 pollutant loadings.

4.0 MDAS IRON AND SEDIMENT

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. This section discusses the existing point and nonpoint sources of sediment and metals in TMDL watersheds and the process used to represent these sources in the MDAS model.

4.1 Landuse

To explicitly model nonpoint sources in the sediment and metals impaired watersheds, the existing NLCD 2011 landuse categories were consolidated to create the modeled landuse using the method described for fecal coliform in **Section 3-1** above. 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 4-1** 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. Watershed-specific modeled landuse tables for each watershed are presented in **Appendix D**.

Table 4-1. 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	2011 TIGER/Line GIS and WV_Roads shapefiles
Roads_Unpaved	2011 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
Highwall	AML highwall shapefile provided by WVDEP
Construction Stormwater	Construction Stormwater permits provided by WVDEP

Model Category	Source
Industrial Stormwater	Industrial Stormwater permits provided by WVDEP
Future Growth	A certain percentage of each subwatershed’s area was set aside for future growth

4.1.1 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 G**.

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 2011. The harvested forest landuse category represents the total timber harvested in each subwatershed.

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. 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 D** 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.

To appropriately account for runoff and loading characteristics related to oil and gas operations, the NLCD 2011 landuse coverage was modified on a subwatershed basis. Oil and gas areas were first subtracted from the NLCD 2011 barren land landuse. If the barren land area for a particular subwatershed did not account for the entire area needed to represent oil and gas activity in that subwatershed, then the remaining area needed was subtracted from forest. This assured that the total area of the subwatershed remained the same.

Drilling of gas wells targeting the Marcellus Shale geologic formation has increased in the watershed with the development of 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 based on estimated pad areas encompassing multiple wells and road access within close proximity to the well sites. Access roads that are developed to the well sites, may extend beyond the pad area. Areas associated with the access roads were estimated during an analysis of unmapped unpaved roads.

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 2011 TIGER/Line GIS shapefiles from the US Census Bureau, the WV Roads GIS coverage prepared by West Virginia University (WVU), and estimations of unmapped roads using the following methodology.

Initial data on paved and unpaved roads in the watershed was obtained from the Census 2011 TIGER/Line Files. These GIS files provide the location and length of roads for the entire watershed. 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 4-2** and described in further detail in **Appendix H**. 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. Unpaved road areas were subtracted from barren and mature forest lands to maintain the correct total acreage per subwatershed. Paved road areas were subtracted from the residential/urban impervious landuse category and then from forest lands, if necessary.

Table 4-2. Assigned perviousness and estimated width for each type of road

Old Code	New MAF/ TIGER Code	Description	Percent Pervious	Estimated Width (ft)
A1	S1100	Primary Highway with Limited Access	0	35
A2	S1100	Primary Road without Limited Access	0	35
A3	S1200	Secondary and Connecting Road	0	26
A4	S1400	Local, Neighborhood, and Rural Road	40	16
A5	S1500	Vehicular Trail	100	12
A6	S1630	Road with Special Characteristics	0	12
A7	S1750	Road as Other Thoroughfare	0	12

Source: Census 2011 TIGER/Line technical documentation.

The *WV Roads* GIS coverage prepared by WVU was used to identify additional mapped unpaved roads not included in the TIGER/Line Files. Acreage associated with unmapped unpaved roads was estimated using NLCD 2011 landuse, topographic maps, and aerial photos. Unpaved road areas were subtracted from barren and mature forest landuse categories.

4.1.2 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 the same percent pervious/impervious assumptions used to determine residential/urban land categories in the fecal coliform modeled landuse, as shown in **Table 3-2** in the previous section.

4.1.3 Other Nonpoint sources

In addition to land-based sources, pollutant 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. 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.

4.2 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.

4.2.1 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**.

WVDEP also issues an Oil and Gas Construction Stormwater General Permit (OGCSGP) for discharges composed entirely of stormwater associated with oil and gas field activities or operations associated with exploration, production, processing or treatment operations or transmission facilities, disturbing one acre or greater of land area. The areas of disturbance for linear projects extending beyond one subwatershed were estimated for each subwatershed by evenly distributing the proposed project area along the entire centerline.

4.2.2 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.

5.0 MDAS FOR ALUMINUM AND PH

To appropriately address dissolved aluminum and pH TMDLs for TMDL watersheds, it was necessary to apply a MDAS model capable of representing instream chemical reactions coupled with upland chemical mass loadings

In the TMDL watershed, observed instream low pH and elevated metal concentrations (dissolved Al) most likely originate from the following land-based sources:

- Acid mine discharges (seeps) with high pollutant loads directly discharging into nearby streams
- Abandoned mine land
- Atmospheric deposition of strong acid anions acidifying soils and water

- Persistent upstream metals and pH loadings that continuously degrade downstream water quality despite dilution provided by additional flow from clean tributaries downstream
- NPDES permitted sources.

In addition to the land-based source loadings, instream chemical reactions also influence stream water quality. Chemical equilibrium, reaction time scales, and kinetics of the chemical reactions must be considered to evaluate the fate and transport of chemical constituents. It is critical for the model to incorporate reactive transport capability with both thermodynamics and chemical kinetics to assess instream water quality conditions. The remainder of this section describes the pH and aluminum MDAS model functionality, source representation, and model calibration approaches.

5.1 Overview of MDAS pH and Aluminum Model

The MDAS model includes a comprehensive watershed hydrology and source loading functionality with one-dimensional reactive chemical transport capability. The reactive chemical transport code is derived from USEPA’s Metal Equilibrium Speciation Model (MINTEQA2; Allison et al.1991). The equilibrium computational code for ionic speciation of cationic and anionic components in aqueous systems originates from the Massachusetts Institute of Technology’s Chemical Equilibrium Model (MINEQL; Westall et al. 1986, 1974). The non-equilibrium/kinetic reactions concepts are either from chemical kinetics of USGS’s pH-Redox-Equilibrium-Equations in C Model (PHREEQC model; Parkhurst and Appelo, 2002) or published chemical kinetic reactions. The chemical reaction modules in MDAS are seamlessly linked with all of the capabilities of the LSPC model to predict chemical fate/transport on a basin scale. Both the LSPC and aqueous speciation models that are the basis of MDAS have been described in detail in U.S. EPA (2009), Allison et al. (1991) and Westall (1986 and 1974).

5.2. Overview of Land Components pH and Aluminum MDAS Model

Three potential chemical loading sources can be simulated at the modeled land surface in MDAS: atmospheric deposition, potential anthropogenic input, and existing chemical components (background) on the land associated with either natural or anthropogenic origins.

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

The majority of the acid deposition occurs in the eastern United States. In March 2005, the USEPA issued the Clean Air Interstate Rule (CAIR), which places caps on emissions for sulfur dioxide and nitrogen dioxides for the eastern United States. It is expected that CAIR will reduce sulfur dioxide emissions by over 70 percent and nitrogen oxides emissions by over 60 percent from the 2003 emission levels (USEPA, 2005b). For modeling purposes, wet atmospheric deposition was represented as the input of ionic species through precipitation events. Dry deposition was assumed to be included implicitly in the loads being generated at the surface.

Effective January 1, 2015, CAIR was replaced by the Cross-State Air Pollution Rule (CSAPR). Similar to CAIR, CSAPR also places caps on emissions for sulfur dioxide and nitrogen oxides for the eastern United States. Combined with other final state and EPA actions, CSAPR will reduce power plant SO_2 emissions by 73 percent and NOx emissions by 54 percent from 2005 levels in the CSAPR region (USEPA, 2016).

On October 15, 2020, EPA proposed the Revised Cross-State Air Pollution Rule Update in order to fully address 21 states' outstanding interstate pollution transport obligations for the 2008 ozone National Ambient Air Quality Standards (NAAQS). Starting in the 2021 ozone season, the proposed rule would require additional emissions reductions of nitrogen oxides (NOx) from power plants in 12 states, including West Virginia (USEPA, 2021). This new rule does not change SO_2 reduction targets previously established. Because pollution is highly mobile in the atmosphere, reductions based on these rules in West Virginia, Ohio, and Pennsylvania will likely improve the quality of precipitation in the watershed.

Both anthropogenic and naturally-existing chemicals can be observed at the land surface. The mass of these chemicals can be time-variant depending on the source of the chemicals, the chemical evolution paths, source minerals, and past runoff patterns. The time variable loadings functionality of the model can be applied to simulate these sources through MDAS hydrologic components and chemical concentrations of the sources.

As percolation/evapotranspiration occurs during and after the rainfall event, the moisture conditions of the subsurface zone are constantly updated. Due to the transient nature of the subsurface hydrology, the associated chemical loadings from these zones should also display time-variant characteristics. All of the chemical loadings from different flow domains (surface and subsurface) will contribute to the water quality conditions in the stream reach and be subjected to further chemical reactions within the reach. The land components for MDAS are shown in **Figure 5-1**.

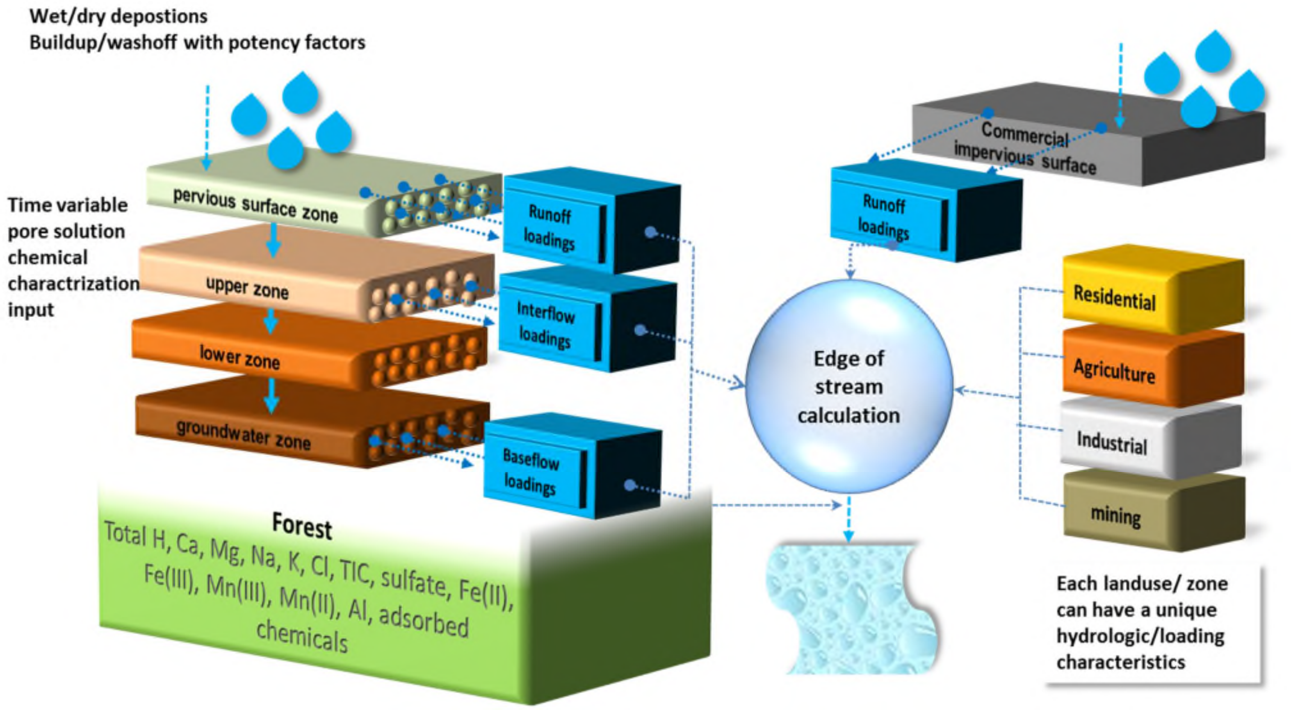


Figure 5-1. Land components of the LSPC-MDAS model

5.3 Land sources in MDAS model

5.3.1 Acid Mine Drainage

Acid mine drainage (AMD) is drainage that flows from open or deep mines and coal refuse piles. Also called “seeps”, these flows tend to be highly acidic and contain high dissolved metals concentrations. The formation of AMD is a function of geology, hydrology, and mining technologies used at the site. When water is exposed to pyrite in coal, refuse, or the overburden of mining operations, complex reactions occur that result in water with high acidity and dissolved metal content. These metals remain dissolved until the pH of the water increases to the level at which the metals precipitate out. The metal precipitation also generates additional hydrogen acidity that could influence solution pH depending on the solution buffering capacity and the metal concentrations.

AMD sources were determined to be one of the important acidic sources to be included in the model. The AMD seeps identified by WVDEP were sampled for pH, cations and anions including targeted metals for the source evaluation purpose. Flow rates from the same sources were also measured simultaneously to estimate the loading contributions. The model incorporates these stationary sources as point sources and assigned constant chemical loadings based on the observed data.

5.3.2 Abandoned Mine Lands

Abandoned mine lands are another potential source of metal/acid loading. In addition to subsurface loadings, higher loadings could be possible during wet weather events through the surface/shallow soil horizons where accumulated metal and hydrogen acidity are being washed off. Therefore, it is important to account for the timing of storm flows to evaluate the total loading from the sources. The magnitude of the loadings is controlled by various mechanisms such as storm intensity, land surface conditions and source minerals. The model's hydrologic and chemical mass loading capability was intended to represent the heterogeneous chemical surface/subsurface loading and transport capability during storm and non-storm events. The initial estimated AML conditions/potential chemical concentrations were derived during the model calibration, the assigned initial model parameter values were refined to evaluate more site-specific loading contributions from the land against nearby water quality data.

5.3.3 Atmospheric Deposition and background loadings

In addition to loadings associated with land-based anthropogenic sources, atmospheric depositions were also considered as a potential source that could alter the background chemical and acidity loadings. The acidity is primarily formed from nitrogen dioxides and sulfur dioxide, which enter the atmosphere through exhaust and smoke from burning fossil fuels such as gas, oil, and coal.

Weekly wet deposition data were retrieved from National Atmospheric Deposition Program station WV04-Babcock State Park in Fayette County from 2000 to the most recent data 2014. The Clean Air Status and Trends Network (CASTNET) was accessed to retrieve dry deposition data from CDR119 in Gilmer County. Dry deposition of major chemical components pertinent to MDAS modeling was implicitly included as a part of surface loadings. Weekly wet deposition data were retrieved from the same source. Wet deposition concentrations were assigned to precipitation events.

In soils, acidity-controlling parameters such as base saturation, cation exchange capacity, dissolution susceptibility of aluminum minerals (aluminum hydroxides), and soil carbon dioxide are known to influence acidification of the soils and land outflows. During the calibration, model soil parameters were refined within literature value ranges by comparing the simulated results with instream background water quality data. The selected background data were based on absence of AML, seeps or dosing applications to eliminate contaminant or human influences on the data. Background model calibration aimed to replicate the relationship between atmospheric deposition and soil conditions that together produce instream conditions.

5.3.4 Alkalinity Additions

AMD affected streams are treated with instream alkalinity dosing at numerous locations in the watershed. There are two dosing methods used in AMD streams. The first is to use hydrated lime (Calcium Hydroxide) or pelletized lime (Calcium Oxide) via a mechanical lime doser. The second method is the dumping of limestone directly into the streambed. The available annual dosage information for these remediation methods was disaggregated, and the daily constant dosage loading was estimated for modeling purposes.

5.3.5 Permitted sources

Model representations of flow and concentration were determined for permitted points sources based on DMR data collected and reported by permittees monthly. The 95th percentile of the observed data concentrations was selected as a conservative estimate of point source loading rates and applied uniformly. The selected permitted sources data were used in source characteristics model calibration aimed to replicate the effluent features from permitted sources. The partition ratio between dissolved and particulate phases of aluminum from permitted effluent were derived during the source calibration process.

5.4 Overview of Stream Components in the pH and Aluminum MDAS Model

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.

5.4.1 Water Column

The chemical loadings from the land were transported to the adjacent stream reach via the hydrologic functionalities in LSPC. The instream 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 are based on thermodynamics and chemical kinetics. The foundation of MINTEQA2/MINEQL is an equilibrium calculation for the major reactions that define the chemical composition of the stream reach during a given time step. Most speciation reactions are fast relative to the time step and the equilibrium assumption is reasonable. However, for certain reactions, such as the oxidation of ferrous iron to ferric iron or the adsorption of metals on iron oxyhydroxides, reactions may be limited by the kinetics, and not necessarily reach equilibrium. The major limitation of the equilibrium approach is mitigated by incorporating simultaneous equilibrium and kinetic (non-equilibrium) calculations within the same computational time step, leading to more precise spatial and temporal representations of non-equilibrium solution conditions for certain processes. To simulate and attain realistic stream chemical conditions, the model includes a variety of chemical reactions to support various stream conditions affected by anthropogenic or natural sources:

- 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;and
- Aging/burial of active/inactive sediment layers related to sediment deposition from the water column and scour from the stream bed.

The precipitation/dissolution and the adsorption/desorption reactions both occur in the water column and streambed sediments. The heat loading into the stream from land and point sources is also considered and can be simulated. The resulting stream temperature is used for all temperature-dependent chemical reactions occurring within the stream. The stream components represented in MDAS are shown in **Figure 5-2**.

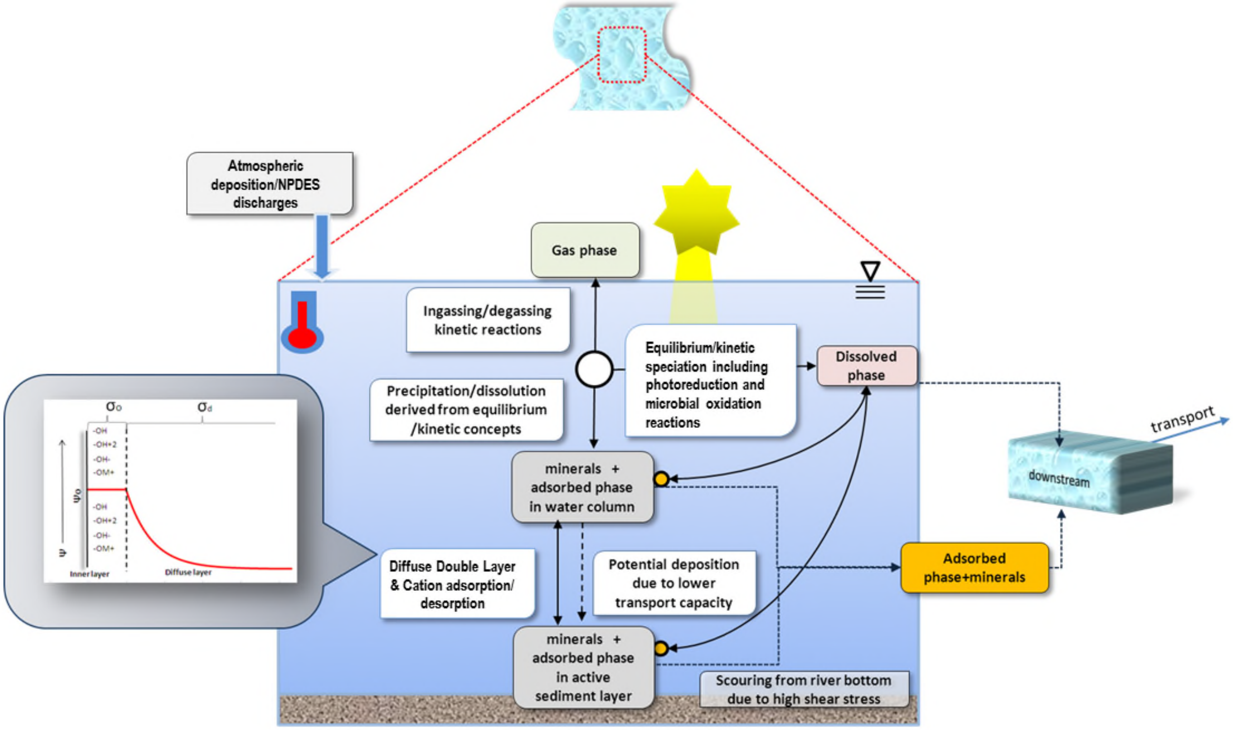


Figure 5-2. Stream components in MDAS

5.4.2 Aqueous Speciation Model in MDAS

The solution to the model equations for the reactions specified in MDAS is 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 are 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 5-1** 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. A comparison is made between the previous version and the updated version of MDAS for chemical components, complexes, species, and solids.

Table 5-1. Chemical components and complexes included in previous and updated versions of MDAS.

Components	Aqueous Species		Adsorbed Species		Solids
H^+	H^+	$Fe(OH)_2^+$	$:FehO^-$	:FehOBe+	Iron
Ca^{+2}	Na^+	$Fe(OH)_3$ (aq)	$:FehOH_2^+$	:FeOBe+	Aluminum
CO_3^{-2}	K^+	$Fe(OH)_4^-$	$:FehOHCa^{+2}$	KX	Manganese
Fe^{+3}	Ca^{+2}	$Fe_2(OH)_2^{+4}$	$:FehOHSO_4^{-2}$	CaX_2	Calcite
Fe^{+2}	Mg^{+2}	$Fe_3(OH)_4^{+5}$	$:FehSO_4^-$	MgX_2	Gypsum
Mn^{+2}	Al^{+3}	$FeSO_4^+$	$:FehOMn^+$	AlX_3	Jurbanite
Mn^{+3}	Fe^{+2}	$Fe(SO_4)_2^-$	$:FehO(FeII)^+$	FeX_2	-
Al^{+3}	Fe^{+3}	$FeCl^{+2}$	$:FehCO_3^-$	MnX_2	-
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)	$:FeOHSO_4^{-2}$	-	-
Be^{+2}	$Al(OH)_2^+$	$MgCO_3$ (aq)	$:FeSO_4^-$	-	-
FeOH(s)	$Al(OH)_3$ (aq)	$MgHCO_3^+$	$:FeOMn^+$	-	-
FehOH (s)	$Al(OH)_4^-$	$MnOH^+$	$:FeO(FeII)^+$	-	-
AlOH (s)	$Al_2(OH)_2^{+4}$	$Mn(OH)_4^{-2}$	:FeO(FeII)OH	-	-
MnOH (s)	$Al_3(OH)_4^{+5}$	$Mn_2(OH)_3^+$	$:FeCO_3^-$	-	-
MnhOH (s)	AlCl+2	Mn_2OH^{+3}	$:FeCO_3H$	-	-
X^-	AlSO4+	$MnSO_4$ (aq)	$:AlO^-$	-	-
-	Al(SO4)2-	$MnCl^+$	$:AlOH_2^+$	-	-
-	$Be(OH)_2$	$MnCl_2$ (aq)	$:AlOCa^+$	-	-
-	CaOH+	$MnCl_3^-$	$:AlOHSO_4^{-2}$	-	-

Components	Aqueous Species		Adsorbed Species		Solids
-	CaSO4 (aq)	$MnCO_3$ (aq)	:$AlSO_4^-$	-	-
-	CaCl+	$MnHCO_3^+$	:$AlOFe^+$	-	-
-	CaCO3 (aq)	NaCl (aq)	:$AlOMn^+$	-	-
-	CaHCO3+	NaOH (aq)	:MnO^-	-	-
-	FeOH+	$NaSO_4^-$	:$MnOCa^+$	-	-
-	Fe(OH)2 (aq)	$NaCO_3^-$	:$MnOMg^+$	-	-
-	Fe(OH)3-	$NaHCO_3$ (aq)	:MnOMgOH	-	-
-	FeSO4 (aq)	HSO_4^-	:$MnOMn^+$	-	-
-	FeCl+	$H_2CO_3^*$ (aq)	:MnOMnOH	-	-
-	FeHCO3+	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).

5.4.3 Streambed and Suspended Sediment

The streambed was configured to contain two virtual model layers in 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 sized 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 pollutant sources. Metal oxides and clay layers provided surface areas for cations and anions to adsorb and desorb based on the DDL model.

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.

5.4.4 Kinetics Representations in MDAS

While the equilibrium approach is suitable for many of the reactions in the model, additional non-equilibrium processes and reactions are represented by kinetic formulations in order to provide a greater accuracy in the stream environment. Kinetics are applied to the following in the model:

- 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.

5.5 MDAS Instream Model Schematic

The model schematic (**Figure 5-3**) illustrates the MDAS model functionality, in other words, how MDAS subroutines and chemical constituents interact with each other. The numbers in the figure correspond with the numbered steps below.

1) The chemical constituents land input will be processed through the edge-of-stream calculation to generate chemical and total hydrogen loadings. The assigned chemical 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.

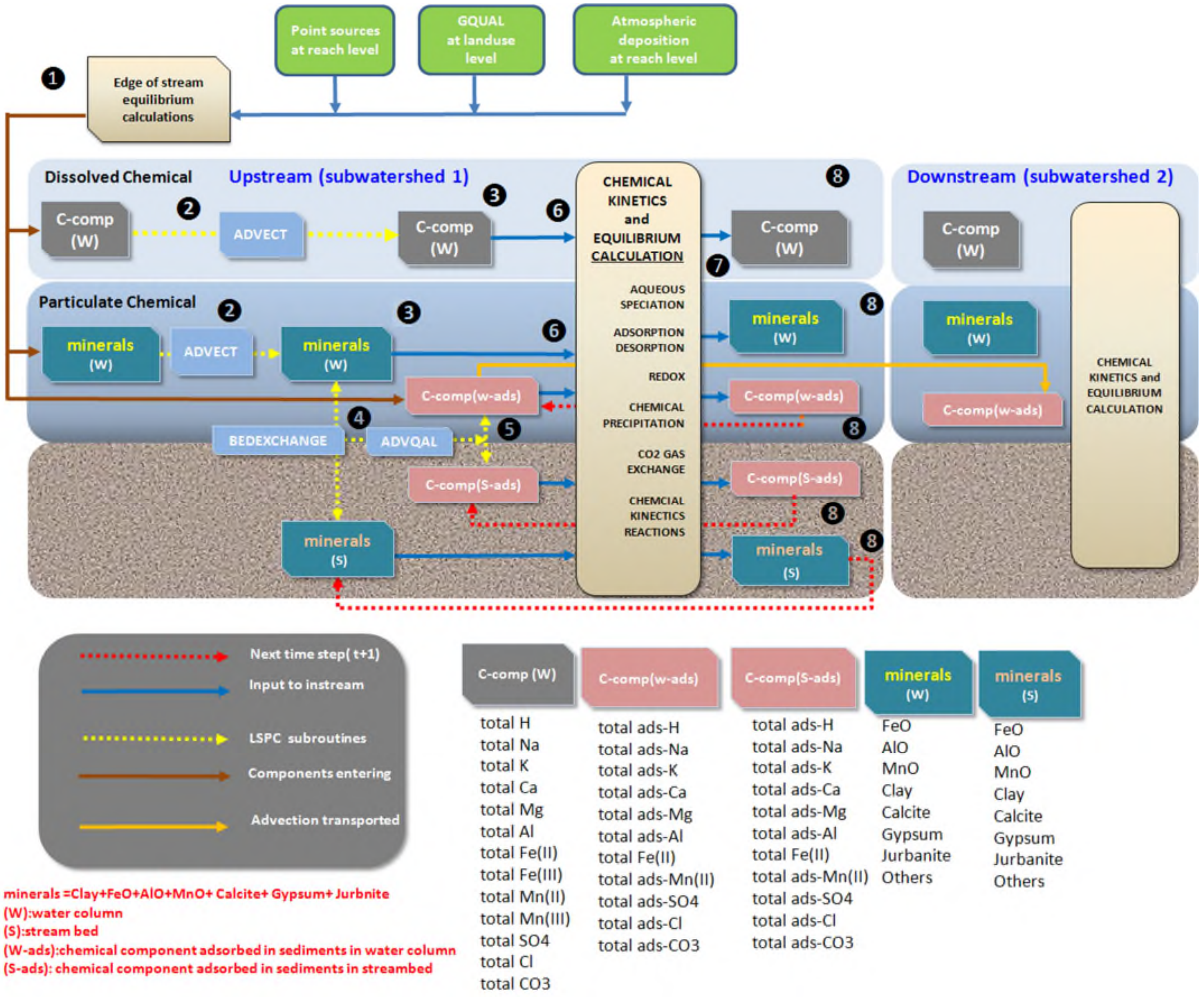


Figure 5-3. MDAS module schematic and linkages

5.6 Instream Sources and Sinks Controlling Pollutant Fate and Transport

All the loadings from the previously described upland loading sources and instream chemical reactions were considered during the model calibration. The upland loadings were discharged to the stream via the hydrologic functionalities of the model. All added loadings were subjected to subsequent instream chemical reactions previously described. Major instream reactions controlling instream pH and dissolved aluminum in impaired streams basin include:

- Mineral precipitation;
- Stream flow in relation to reaction time;
- Stream buffering capacity;
- Deposition of sediments due to low velocity stream conditions.

The model calibration identified that the instream dissolved aluminum/pH conditions were mostly influenced by mineral precipitation as a result of mixing acidic loadings with loadings from surrounding watersheds. The model also indicated that availability of the stream buffering capacity to counteract hydrogen acidity from the precipitation reactions was critical to regulate the current instream dissolved Al and pH. Additionally, the travel time of the pollutants to downstream was also identified to be an important factor as it relates to the kinetic precipitation reactions and leads to the metal deposition during low flow conditions. Available buffering capacity contributed by lime dosing also affected the fate of metals and pH, and helped to improve the stream water quality conditions by raising pH and reducing dissolved Al.

6.0 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.

6.1 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 were 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.

6.1.1 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; then melted snow is added to the hydrologic cycle.

6.1.2 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 must 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 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. The amount of the evapotranspiration demand that can 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 stream flow at selected locations throughout the basin.

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 I**.

The hydrology calibration statistics for the flow gage on East Fork/Twelvelpole Creek are shown in **Table 6-1**. A graphical representation of hydrology calibration results is presented in **Figure 6-1**. Refer to **Appendix I** for additional calibration results.

Table 6-1. Comparison of simulated and observed flow from January 2008 to December 2017 (USGS 03206600 East Fork/Twelvepole Creek Near Dunlow, WV)

Simulated versus Observed Flow	Percent Error	Recommended Criterion[a]
Error in total volume:	0.11	10
Error in 50% lowest flows:	2.63	10
Error in 10% highest flows:	3.09	15
Seasonal volume error - summer:	8.26	30
Seasonal volume error - fall:	7.49	30
Seasonal volume error - winter:	-4.70	30
Seasonal volume error - spring:	0.56	30
Error in storm volumes:	9.48	20
Error in summer storm volumes:	-9.01	50

[a] Recommended criterion: HSPExp.

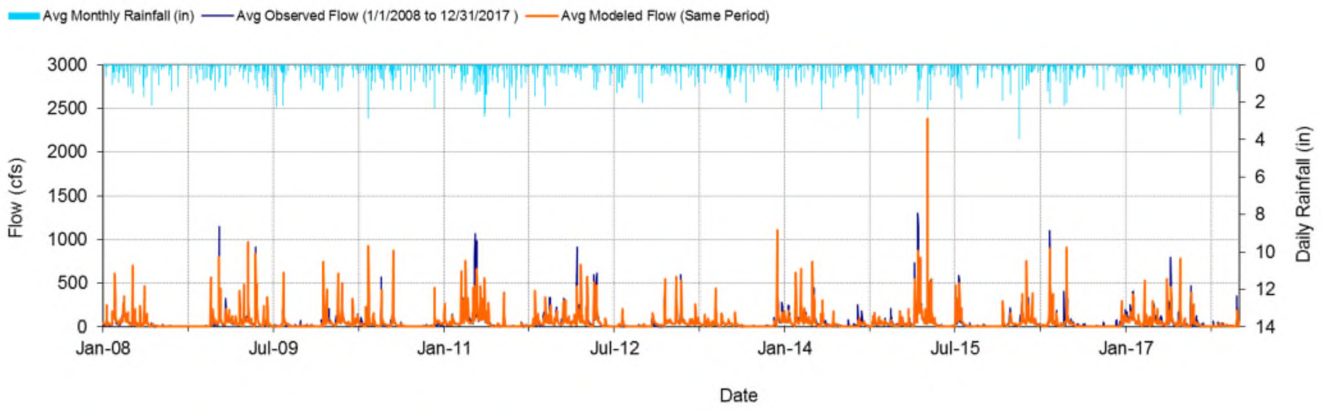


Figure 6-1. Comparison of simulated and observed flow from January 2008 to December 2017 for East Fork/Twelvepole Creek (WV-OT-45)

6.2 Fecal Coliform Water Quality Calibration

For the 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 I**.

6.3 Sediment Water Quality Calibration

A significant amount of time-varying monitoring data was necessary to calibrate the sediment water quality portions of the model. Available monitoring data in the watershed were identified and assessed for application to calibration (**Appendix J**). 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. Permitted discharges that were issued permits after the calibration period were not considered during the calibration process. **Appendix I** presents the results for the calibration of these sampling events.

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.

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. A flow chart depicting the sediment model parameters and processes is shown in **Figure 6-2** below. 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.

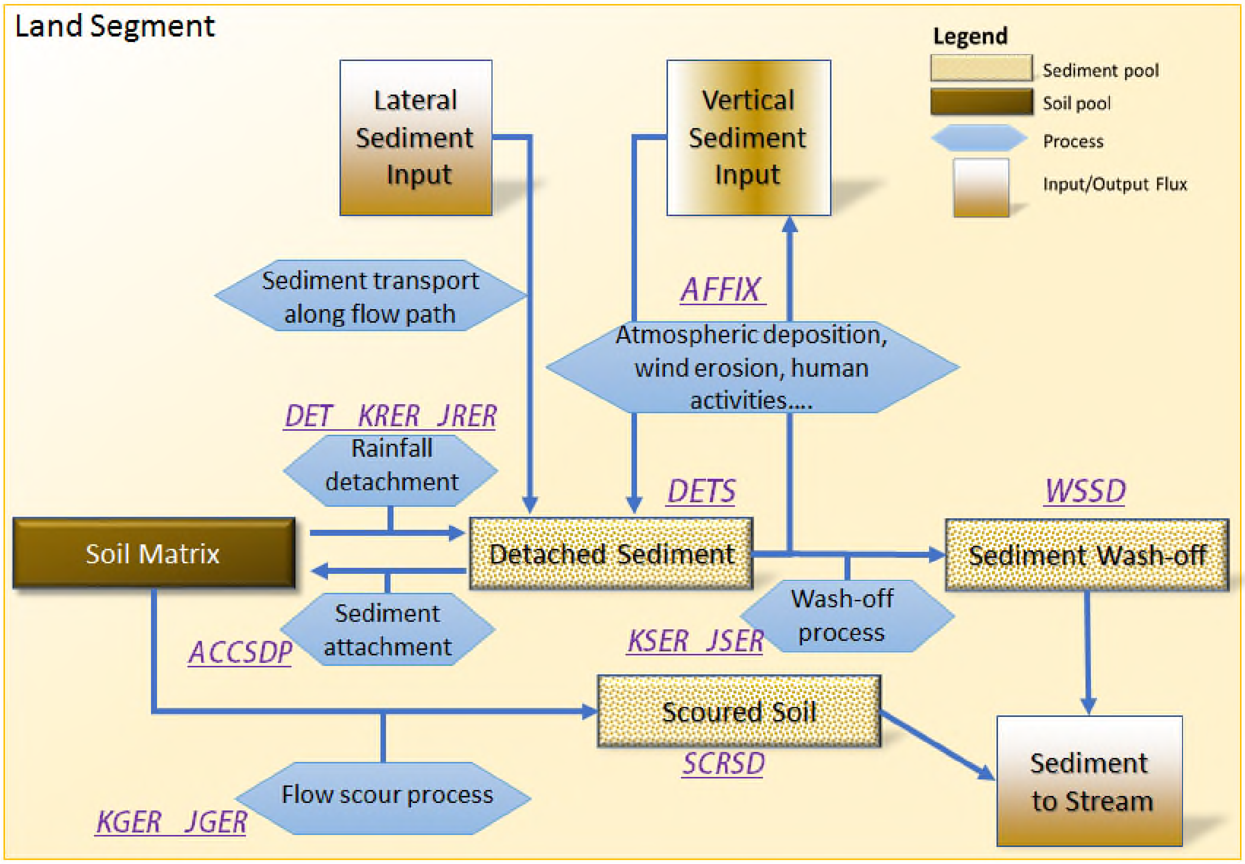


Figure 6-2. Sediment model parameters and processes

6.4 Iron 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.

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 I**.

6.5 Selenium Water Quality Calibration

For the selenium model water quality calibration, selenium concentrations for groundwater, interflow, and surface runoff specific to modeled landuses were adjusted to calibrate the model. Selenium loading rates for background and AML land sources were derived through model calibration to replicate in-stream selenium concentrations observed during pre-TMDL monitoring. AML seep loading rates were developed from WVDEP source tracking sampling during field investigations. Active mining permits were characterized by their contributing acreage for surface mines, or flow volume for deep mines with continuous flow. For mine outlets with selenium permit limits, modeled selenium concentrations were the same as the permit limit. For mine outlets without selenium limits, an estimate of selenium concentration derived from discharge monitoring report data was used, initially. The estimate of selenium concentrations from these mine outlets was adjusted so that modeled selenium concentrations more closely approximated in-stream water quality observations collected during pre-TMDL stream monitoring. Model output was compared graphically to pre-TMDL monitoring observations in impaired streams and tributaries. Results from selenium water quality calibration are presented in **Appendix I**.

7.0 BIOLOGICAL STRESSOR IDENTIFICATION

The Stressor Identification (SI) process analyzes the existing quantitative and qualitative water quality, physical habitat, and biological data available for the watersheds to identify the cause of the impairment, so that pollutants can be controlled. All data are compiled, reviewed, and synthesized into summary tables. The data is reviewed 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 below.

7.1 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 on aquatic life 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 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 SI process establishes a link between the benthic community assessment and pollutant stressors.

Figure 7-1 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.

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 candidate causes, and to diagnose and to compare the strength of evidence of the remaining candidates to identify the significant stressors.

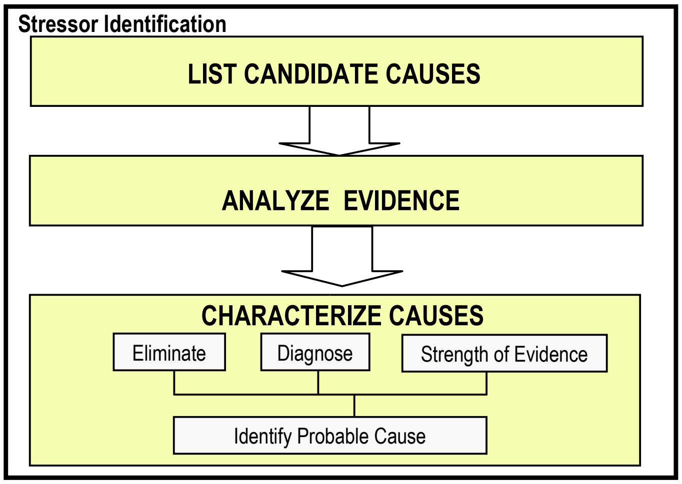


Figure 7-1. Stressor identification process

7.2 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, biological, habitat, and other information contained in the WVDEP Watershed Assessment Branch (WAB) database. Importantly, this database includes information on pollutant source tracking, narrative descriptions of potential stressors sources, and photos of sample locations. SI also includes the examination of pertinent Geographic Information Systems (GIS) data including, but not limited to ; National Pollutant Discharge Elimination System (NPDES) point source data; mining permit coverage, and aerial imagery.

WVDEP interprets water quality and biological information within the state's 32 watersheds on a five-year rotation. Pre-TMDL monitoring is conducted to collect sufficient data for the TMDL modeling. Within the context of this TMDL, pre-TMDL monitoring was conducted for streams in the Group E TMDL watersheds of Big Sandy River, Lower Ohio River, and Twelvepole Creek in 2016 through 2017. Pre-TMDL monitoring is intensive, consisting of monthly sampling for parameters of concern, which captures data under a variety of weather conditions and flow regimes in one year. Habitat assessment and biological monitoring are performed in conjunction with water quality monitoring. Pre-TMDL monitoring also includes an effort to locate the specific sources of impairment, with attention paid to identifying non-point source land use stressors as well as any permitted facilities that may not be meeting their permit requirements. Additional site visits may be made to impaired streams 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 data collected by WVDEP in the impaired watersheds to date.

7.2.1 Development of the Conceptual Model

The first step in the SI process was to develop the list of candidate causes, or stressors. Potential causes were evaluated based on an assessment of watershed characteristics and the likely causes and sources of biological impairment. The relationship between candidate causes of impairment and potential biological effects, were based on initial data analyses, knowledge of these watersheds, and experience in defining impairment causes in similar watersheds. Sources, impairment causes, and the resulting effects on the biological community depend on the stream or watershed in question. In some cases, biological impairment can be linked to a single stressor; in other situations, multiple stressors might be responsible for the impact.

7.2.2 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. 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 data collected for each assessment unit of a stream and upstream tributaries with the threshold levels specified in **Table 7-1**. 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. At least one parameter should exceed the candidate stressor threshold before a stressor can be identified.

7.2.3 Empirical Model Development to Identify Multiple Stressors

Biological data were also used to determine water quality and habitat-related stressor thresholds. Many pollutants have a direct and negative impact on macroinvertebrate presence/abundance; however, some stressors act by more complex means on the biota. For example, an increased abundance of dipterans (true flies) is typical in waters heavily enriched by nutrients; consequently, both the population’s abundance and corresponding information regarding the potential stressor were closely considered.

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, several diagnostic tools have been developed for conducting biological stressor identification. The West Virginia biological, chemical, and habitat data were evaluated with respect to macroinvertebrate community response to conductivity, sediment, acidic/nonacidic metals, and organic/nutrient enrichment environmental stressors.

Dirty Null Model: A top-down diagnostic tool 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 were 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 metal test samples were either correctly classified as metals impaired (87.5%) or were not classified. The majority of the conductivity (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.

Observed / Expected Models: In 2019, a new diagnostic tool using an O/E concept was developed to refine the stressor identification process. O/E is a taxonomic completeness model that assesses biological condition using the ratio of observed taxonomic richness (O) to expected taxonomic richness (E) in the absence of disturbance. Expected (E) taxonomic richness is established using reference site populations. An O/E value of 0.1 means a site contains 10% of the expected taxa richness and a value of 1.0 would indicate all the taxa expected in the absence of disturbance were observed. Expected taxa richness is the sum of the capture probability of each taxon in the reference site population at a given site. This basic concept was followed to develop three models capable of providing stressor specific evidence of biological impacts in WV streams. These were the O/E Sensitive, O/E Opportunistic, and Percent Model Affinity approaches. The stressors for which models were developed included organic enrichment, sediment, ionic strength, acid deposition, and dissolved metals. The following description outlines methods used in the development of the three models.

O/E Sensitive and O/E Opportunistic Taxa Stressor Models: For each sample, these models provide a list of which taxa are expected and with what capture probability as well as which taxa were observed. WVDEP provided a set of streams for which a single stressor (stressed ref sites) was predominant. The average O/E scores indicated that these sites had varying levels of impact, but all of them have mean values more than a standard deviation away from reference. A summation was performed of the capture probability of each taxon across all the samples in each stressor group to get the expected number of observations for each taxon across each population of stressed samples and compared that to the number of times each of those taxa was observed across those same samples. Taxa that were observed much more than expected ($O/E_{stressor}>1.5$) for each stressed sample population were considered opportunistic, whereas those observed much less frequently than expected ($O/E_{stressor}<0.5$) were considered sensitive. Having defined these taxa groups using this approach, additional O/E scores were calculated for each sample using only sensitive or opportunistic taxa for each stressor. Presumptively, this evidence would support an effect by those stressors which have the lowest stressor sensitive O/E scores or highest stressor opportunist O/E scores. For samples with no sensitive or opportunistic taxa, an O/E score could not be calculated, therefore samples could not be assigned to a stressor.

Percent Model Affinity (PMA) Stressor Model: PMA a straightforward assessment model developed and used by the state of New York for biological assessments (Novak and Bode 1992). It is based on a percentage similarity measure developed by Whittaker and Fairbanks (1958):

$$Percentage\ Similarity = 100 - 0.5 \sum |a - b| = \sum \min{(a, b)}$$

Where a is percent of individuals of a taxon from one sample and b is the percent of individuals of the same taxon in a second sample. These are summed across all taxa. In the PMA approach, a is fixed as the average percent of individuals of each taxon in each stressor population defined by WVDEP (i.e. each stressor population becomes the *model* assemblage). Then b is the percent of individuals of each of the same taxa in every other sample. In essence, PMA is estimating the similarity of any sample to the average composition of each stressor population. That stressor population to which a sample has the highest PMA value would provide a line of support for that stressor as a potential cause of impact.

Threshold values were established for each of the three model approaches: O/E Sensitive <0.5, O/E Opportunistic >2.0, and PMA > 0.3. These are approximately the mean of values from correctly assigned stressor samples plus/minus one standard deviation, depending on the direction of response. The primary recommendation with regards to thresholds is that these different methods be used in a weight of evidence approach along with water chemistry, habitat, and other pertinent sources of information.

Over the past decade of their application, DEP has found that the biologically-based diagnostic tools could not be used independently to identify environmental stressors in multiple stressor environments. The tools remain available as components of the strength-of-evidence analysis of stressors and are most often used to confirm decisions resulting from other lines of evidence.

Table 7-1. Stressor identification analysis thresholds

Candidate Cause	Parameter	Elimination Thresholds	Strength of Evidence Candidate Stressor Thresholds
1. Metals Toxicity (Primarily Acid Mine Drainage)	Al (dissolved)	<0.09 mg/L	>0.20 mg/L – Evidence of Stressor[1,4]
	Fe (total)	Fe toxicity to benthic invertebrates is not well established.	
	Mn (total)	Mn toxicity to benthic invertebrates is not well established.	
	O/E Opportunistic Model (AMD)	na	> 2.0 – Evidence of Stressor[2]
	O/E Sensitive Model (AMD)	na	< 0.5 – Evidence of Stressor[2]
	O/E PMA[6] Model (AMD)	na	> 0.3 – Evidence of Stressor[2]
	Benthic Mac Taxa Review	Professional judgment applied to benthic macroinvertebrate taxa and community metrics from sample station.	
	Qualitative Metals Toxicity Evaluation:	Professional judgment applied to combination of station observations including hot acidity, alkalinity, dissolved metals, specific conductance, TDS, sulfate, and other signature ions. Qualitative ratings of metals flocculation and field rating of AMD stress. Station photography, GIS imagery evaluation, and field notes and source tracking observations.	
2. Acidity (Acid Deposition)	pH	>6.3	< 6.0[3]
	O/E Opportunistic Model (Acid Precip)	na	> 2.0 – Evidence of Stressor[2]
	O/E Sensitive Model (Acid Precip)	na	< 0.5 – Evidence of Stressor[2]
	O/E PMA[6] Model (Acid Precip)	na	> 0.3 – Evidence of Stressor[2]
	Benthic Mac Taxa Review	Professional judgment applied to benthic macroinvertebrate taxa and community metrics from sample station.	
	Qualitative Acid Deposition Evaluation:	Professional judgment applied to combination of station observations including hot acidity, alkalinity, dissolved metals, specific conductance, TDS, sulfate, and other signature ions. Station photography, GIS imagery evaluation, and field notes and source tracking observations.	
3. High pH	pH	<8.39	>9[3]
4. Ionic Strength	Specific Conductance	Consider as independent stressor in non-acidic, non-AMD streams. Max value at monitoring station.	
		< 300 µmhos	> 500 – Evidence of Stressor[1]
	O/E Opportunistic Model	na	> 2.0 – Evidence of Stressor[2]
	O/E Sensitive Model	na	< 0.5 – Evidence of Stressor[2]
	O/E PMA[6] Model	na	> 0.3 – Evidence of Stressor[2]
	Benthic Mac Taxa Review	Professional judgment applied to benthic macroinvertebrate taxa and community metrics from sample station.	

Candidate Cause	Parameter	Elimination Thresholds	Strength of Evidence Candidate Stressor Thresholds
	Qualitative Ionic Strength evaluation:	Professional judgment applied to combination of station observations including concentrations of constituent ions alkalinity, calcium, chloride, potassium, sodium, sulfate, magnesium. Concurrent (with bio sample) and mean specific conductance at station also considered. Station photography, GIS imagery evaluation, and field notes/source tracking observations.	
5. Sedimentation	% Fines (sand + silt + clay) - in Kicked Area	<10%	>= 25 - Evidence of Stressor[4]
	RBP: Embeddedness	16.0 - 20.0 (optimal)	< 9 - Evidence of Stressor[4]
	RBP: Sediment Deposition	16.0 - 20.0 (optimal)	< 8 - Evidence of Stressor[4]
	RBP: Bank Stability	16.0 - 20.0 (optimal)	< 12 - Evidence of Stressor[4]
	Silt Deposition Rating - in 100m Assessment Reach	Qualitative evaluation based on field rating of magnitude:	
		<2	> 2 – (high or extreme)- Evidence of Stressor[1]
	Sand Deposition Rating - in 100m Assessment Reach	Qualitative evaluation based on field rating of magnitude:	
		<2	> 2 – (high or extreme) -Evidence of Stressor[1]
	O/E Opportunistic Model (Sedimentation)	na	> 2.0 – Evidence of Stressor[2]
	O/E Sensitive Model (Sedimentation)	na	< 0.5 – Evidence of Stressor[2]
	O/E PMA[6] Model (Sedimentation)	na	> 0.3 – Evidence of Stressor[2]
	Benthic Mac Taxa Review	Professional judgment applied to benthic macroinvertebrate taxa and community metrics from sample station.	
	Qualitative Sedimentation evaluation:	Professional judgment applied to combination of RBP embeddedness, sediment deposition, bank stability, bank vegetation, riparian vegetation, and total scores; supplemented with watershed erosion rating, reach substrate particle characterization, sediment layer profile, and field rating of sediment stress. Station photography, GIS imagery evaluation, and field notes/source tracking observations.	
7. Metals flocculation (habitat alteration)	Embeddedness due to metals flocculation	16.0 - 20.0 (optimal)	< 9 - Evidence of Stressor[4]
	Metal Flocculation Rating	Qualitative evaluation based on field rating of magnitude:	
		<1 (none)	> 1 – (moderate or extreme) Evidence of Stressor[1]
8. Organic Enrichment	Filamentous Algae	Qualitative evaluation based on field rating of abundance:	
		<2 (none or low)	> 2 – (high or extreme) Evidence of Stressor[4]
	Diatom Growth	Qualitative evaluation based on field rating of abundance:	
		<2 (none or low)	> 2 – (high or extreme) Evidence of Stressor[4]
	Dissolved Oxygen	>7.0 mg/L	< 6.0 - Evidence of Stressor[3]
	Total Phosphorus	<0.02 mg/L	> 0.05 – Evidence of Stressor[5]
	Total Nitrogen	<2.0 mg/L	> 2.0 – Evidence of Stressor[5]

Candidate Cause	Parameter	Elimination Thresholds	Strength of Evidence Candidate Stressor Thresholds
	Fecal coliform	<150 counts/100 mL	> 500 - Evidence of Stressor[4]
	O/E Opportunistic Model (Organic Enrichment)	na	> 2.0 – Strong Indication of Stressor[2]
	O/E Sensitive Model (Organic Enrichment)	na	< 0.5 – Strong Indication of Stressor[2]
	O/E PMA[6] Model (Organic Enrichment)	na	> 0.3 – Strong Indication of Stressor[2]
	Benthic Mac Taxa Review	Professional judgment applied to benthic macroinvertebrate taxa and community metrics from sample station.	
	Qualitative Organic Enrichment evaluation:	Professional judgment applied to combination of station observations such as atmospheric and water odors, presence of foam/suds, poorly treated domestic sewage, agriculture and livestock, residences, lawns, field biologist/specialist organic enrichment determination, field notes, station photography, GIS imagery evaluation, and information from sources tracking efforts.	
9. Temperature	Degrees F		Max >87 F May through November; or Max >73 F December through April.[3]
10. Chemical Spills	Various chemical parameters	Qualitative supplemental information (field notes and other sources listed below this table).	

Notes:

-Elimination: Screening step to rule out particular stressors, based on unambiguous criteria.

-Strength of evidence: Data that provide evidence for identification of each particular candidate cause as a biological stressor.

-RBP = Rapid Bioassessment Protocol.

-Qualitative: Supplemental evidence to evaluate each candidate stressor.

-Benthic taxa review: Review taxa lists and metrics to find indicators of specific stressor.

-O/E Models: Observed over Expected models using benthic macroinvertebrate taxa; diagnose specific stressor.

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7.3 Stressor Identification Results

A summary of the data available for use in evaluating each candidate cause is presented in **Table 7-2**. 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 K** for analysis results for specific streams and data supporting the SI process determinations.

Table 7-2. 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, macroinvertebrate 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. Chemical spills	Little data available; professional judgment applied to indirect evidence; not identified as stressors in most streams.

Based on the SI process, streams were found to be impacted by various candidate causes. Refer to **Appendix A** for a listing of stream with specific impairments related to water quality criteria. TMDLs developed to attain numeric water quality criteria will result in the reduction of stress to the biological community. Stream for which no pollutant TMDLs are presented in this or a previous TMDL that would address biological stressors, such as ionic strength, will be retained on the 303d list.

Streams with sedimentation impairments, 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 8.0**. Also, the analytical results and statistical information regarding the correlation of iron and TSS are displayed in **Appendix C**.

The SI process identified metals toxicity as biological stressors in waters that also demonstrated violations of the pH and dissolved aluminum water quality criteria for protection of aquatic life. WVDEP determined that implementation of those pollutant-specific TMDLs, including those previously approved in 2009 would address the biological impacts due to metals toxicity.

Where organic enrichment was identified as the biological stressor, the waters or immediate receiving 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 enrichment. 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 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.

8.0 SEDIMENT REFERENCE WATERSHED APPROACH

SI results indicated a need to reduce the contribution of excess sediment to many biologically impacted streams. Excessive sedimentation was determined to be a primary cause of biological impact 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 impacted 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 impacted watershed. Stream conditions in the reference watershed are assumed to be representative of the conditions needed for the impacted stream to attain its designated uses. Given these parameters and unimpaired biological scores, the baseline sediment loads for Bull Branch (WV-OT-46-CF) and UNT/Bear Hollow Creek RM 1.20 (WV-OL-12-Q-2) were evaluated.

Sediment loading rates were determined for impacted and reference watersheds through modeling studies. Both point and nonpoint sources were considered in the analysis of sediment sources and in watershed modeling.

Upon finalization of modeling based on the reference watershed approach, it was determined that, in select streams, sediment reductions necessary to ensure compliance with iron criteria are greater than those necessary to correct the biological impacts associated with sediment. As such, the iron TMDLs presented for the subject waters are appropriate surrogates to address impacts related to sediment. For affected streams, **Appendix L** contrasts the sediment reductions necessary to attain iron criteria with those needed to resolve sedimentation impacts under the reference watershed approach. Only those streams in which a pollutant TMDL could resolve a 303d listing were presented.

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