FINAL REPORT

Demonstration and Validation of BASINS Watershed Modeling System Enhanced for Military Installations – AP Hill

ESTCP Project RC-201307

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14. ABSTRACT
The BASINS Modeling System is a GIS-based system and features a well-developed interface for different dynamic watershed models, and numerous pre- and post-processing tools that are shared by the models. Two types of enhancements, using the Hydrological Simulation Program – FORTRAN (HSPF) as the primary modeling code, were developed for the BASINS modeling system for military-specific applications: (1) data and methodologies that address key military land stressors (i.e., urban encroachment, prescribed burning, timber harvesting, military training, and unpaved roads), and (2) software refinements related to model linkages and algorithms.

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ACRONYMS AND ABBREVIATIONS

AFFIX	Sediment fines consolidation factor
BASETP	Evaporation parameter for baseflow
BASINS	Better Assessment Science Integrating point and Nonpoint Sources
BMP	Best Management Practices
CBP	Chesapeake Bay Program
CEPSC	Vegetal interception parameter for canopy cover
COVER	Land covered and protected by vegetation
CTC	Concurrent Technologies Corporation
DEM	Digital Elevation Model
DoD	US Department of Defense
EISA	Energy Independence and Security Act of 2007
EPA	US Environmental Protection Agency
ET	Evapotranspiration
FAPH	Fort AP (Amborse Powell) Hill
FB	Fort Benning
GA	Georgia
GIS	Geographic information systems
HSG	Hydrologic Soil Groups
HSPF	Hydrological Simulation Program–FORTRAN
HSPEXP	Expert system for HSPF
IMPLND	Impervious land segment
INFILT	Infiltration parameter
KRER	Erodibility factor in the sediment soil splash equation
KSER	Soil transport parameter by overland flow
KVARY	Variable groundwater recession parameter
LZSN	Lower zone soil moisture storage
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NDCEE	National Defense Center for Energy and Environment
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLDAS	National Land Data Assimilation System
NLDC	National Land Cover

NVSI	Net vertical deposition input
NWQMC	National Water Quality Monitoring Council
PERLND	Pervious Land
PET	Potential evapotranspiration
RAWS	Remote Automatic Weather Stations
RCHRES	Stream reach and/or reservoir segment in HSPF
SCS	US Soil Conservation Service
SLSUR	Slope of the pervious or impervious land segment in HSPF
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
US	United States
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
USGS	United States Geological Survey
UZSN	Upper zone soil moisture storage
WBD	Watershed Boundary Dataset
WDM	Watershed Data Management
WEPP	Watershed erosion prediction program

1.0 INTRODUCTION

The BASINS Modeling System is a GIS-based system and features a well-developed interface for different dynamic watershed models, and numerous pre- and post-processing tools that are shared by the models. Two types of enhancements, using the Hydrological Simulation Program – FORTRAN (HSPF) as the primary modeling code, were developed for the BASINS modeling system for military-specific applications: (1) data and methodologies that address key military land stressors (i.e., urban encroachment, prescribed burning, timber harvesting, military training, and unpaved roads), and (2) software refinements related to model linkages and algorithms.

BASINS.MIL was used to build a continuous computer simulation model of hydrology and water quality for the watersheds on and surrounding Fort Benning, Georgia (GA). This model is referred to as the FB Model (or FB Enhanced Baseline Model). Preliminary model applications of the FB Model were performed to provide proof-of-principle demonstration of the modeling system and the model enhancements to support watershed management decisions on the installation.

The demonstration/validation of BASINS.MIL is the next step to fully demonstrate the validity of the technology to meet DoD's need for tools to evaluate watershed hydrology and water quality for system-level assessments. As illustrated in Figure 1-1, the technology transfer of BASINS.MIL demonstration/validation leverages the watershed model developed on Fort Benning (FB) by conducting further modeling applications on FB, and by developing a watershed model for another installation that was used to further demonstrate the technology. Fort AP Hill (FAPH), Virginia was selected as the second site since it provides a unique opportunity to (a) demonstrate the transferability of the BASINS.MIL modeling framework to a new installation and (b) demonstrate the ability of BASINS.MIL to address Total Maximum Daily Load (TMDL) and Best Management Practice (BMP) issues at a smaller subwatershed scale.

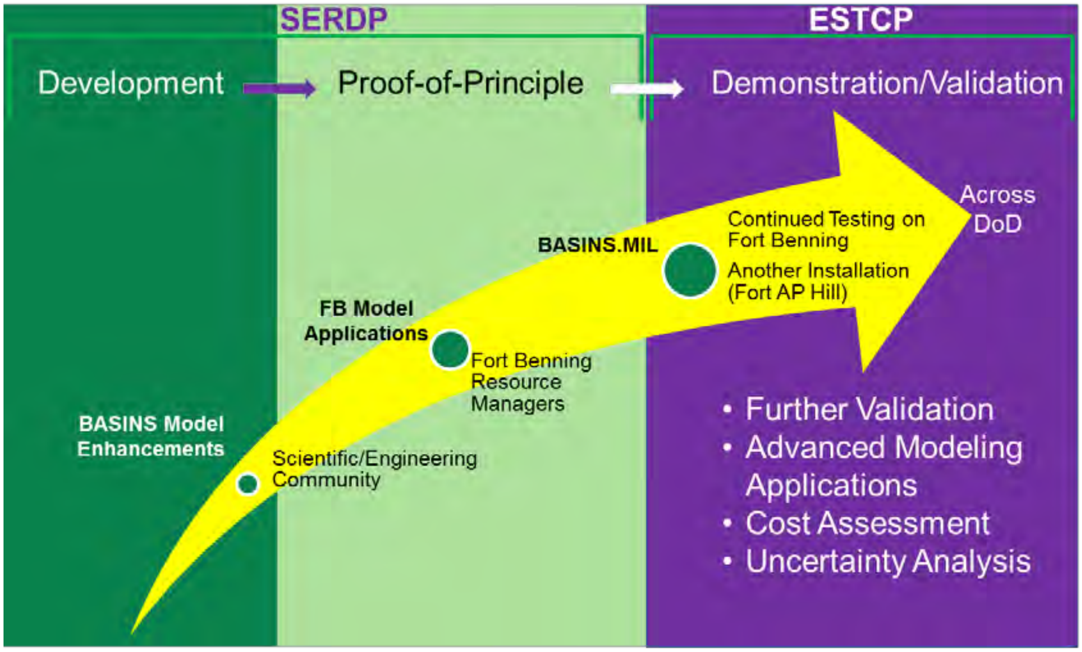

Figure 1-1. Technology Transfer Process for BASINS.MIL.

1.1 BACKGROUND

The DoD uses, and in many cases directly manages approximately 30 million acres of land to accomplish its testing and training missions. Often such use results in direct and indirect physical impacts to soil, vegetation, and water resources. Impacts that result in soil erosion and runoff (whether from rain or snowmelt) with subsequent changes in water flows and loading of sediment, nutrients, and pollutants to receiving water bodies can result in compliance, sustainability, and stewardship problems. In accordance with the guidelines and goals established in the Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management, the DoD Instruction 4715.03 calls for a watershed-based approach to manage operations, activities, and lands to avoid or minimize impacts to wetlands, groundwater, and surface waters on or adjacent to installations. Watershed modeling systems are a critical component of efforts to support this mandate, and maintain military readiness and sustainability of DoD testing and training lands.

In a formal solicitation, ESTCP sought demonstration projects that support the advancement of land and water resources management within a watershed context on DoD installations. The focus was on models and decision support tools associated with watershed hydrology, erosion, and impacts to receiving water bodies and their aquatic receptors. Specifically, ESTCP sought proposals that demonstrate innovative but technically mature technologies, along with associated methodological approaches, that are relevant to a military land use and management context, with the expectation that application of such models/tools would facilitate the ability of DoD installations to sustain their training and testing missions while meeting compliance and stewardship responsibilities.

Use of continuous simulation computer techniques (such as BASINS.MIL) for evaluation of watershed hydrology and water quality offers much promise as a system-level assessment tool. However, this technology has been slow to be embraced by DoD installations due in part to a variety of perceived and real shortcomings such as: 1) uncertainty about costs related to site-specific data needs, 2) expertise needed to apply the modeling system, 3) disparity between the scale of the assessment need and the scale of the model's resolution, and 4) a lack of knowledge regarding the versatility and relevance of the technology to address compliance-specific management issues on installations.[1]

1.2 OBJECTIVE OF THE DEMONSTRATION

The overarching objective of this project was to further demonstrate BASINS.MIL, which was developed under the SERDP-funded Project RC-1547 as a tool for watershed-based decision making on military installations.

The specific objectives of the BASINS.MIL demonstration/validation are related to modeling capabilities, model performance, and cost assessment/comparisons of the technology. The combined host sites offer an opportunity to meet the objectives in each of the three categories. Table 1-1 lists the components of the BASINS.MIL demonstration/validation associated with each host site. Components of the demonstration/validation have been performed on FB and FAPH.

[1] This general perception of reluctance by DoD users to apply continuous simulation computer techniques is most likely related to a set of compounding issues, including budget pressures, regulatory foci, and DoD policies.

The FB portion of the demonstration/validation is focused on demonstration of the BASINS.MIL capabilities and performance, whereas the objective for the FAPH components is focused on the transferability of the BASINS.MIL modeling framework to a new installation, and to demonstrate the ability of BASINS.MIL to address TMDL issues and small-scale assessments. Note that the cost assessment task was removed by ESTCP in mid-2018, and thereby deleted from this effort.

Table 1-1. Components of BASINS.MIL Demonstration/Validation Associated with Each Host Site

Objectives	Components of Demonstration/Validation	Host Installation	
		Fort AP Hill	Fort Benning
Modeling Capabilities	Unpaved road design and maintenance		□
	Climate nonstationary		□
	Small-scale modeling assessment	□	
Model Performance	Validation of WEPP modeling results		□
	Data richness versus model performance		□
	Uncertainty of modeling results		□
Cost Assessment and Advantages	~~Cost assessment of BASINS.MIL application at a new location~~	~~□~~	
	Comparison with other modeling approaches	□	
	TMDL Loading Rate assessment application	□	

1.3 REPORT OBJECTIVE AND CONTENTS

Given the large number and broad variety of demonstrations that were established and performed for this project, during the development of the schedule and deliverables for the Demonstration Plan [Donigian et al., 2014], ESTCP requested that separate reports be developed that describe the collection of demonstrations that were performed at each of the two demonstration sites. Accordingly, this report provides a full account of the demonstrations that were performed at FAPH; it was preceded by a parallel report that provided like material for Fort Benning [Donigian et al., 2018].

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2.0 OVERVIEW OF BASINS.MIL DEMONSTRATIONS AT FORT AP HILL

The demonstrations and validations that were performed at FAPH are the following:

Task 2: Model Set Up and Model Calibration/Validation on FAPH

To demonstrate that BASINS.MIL can be used to effectively set up a model at another installation and be calibrated and validated at a confident level to apply the tool for practical watershed management issues, a hydrologic and water quality model of the watersheds on FAPH were built by applying BASINS.MIL The resulting model is named the FAPH Model. One USGS gage was available for calibration of the initial model. Commencing in the spring of 2014, two new gaging stations were installed and monitored over the next two years. Details of the data collection are provided in Section 3. After the data resulting from the sampling effort were available, a comparison between simulation results and observed data determined the accuracy that the FAPH Model achieved in simulating the hydrology and water quality of the watersheds on and surrounding the installation.

Task 3: Assessment and Comparison of Model Loading Rates at FAPH

As federally-managed land within the Chesapeake Bay Program (CBP) watershed, FAPH must meet the goals established in the Chesapeake Bay TMDL [CBP, 2012]. A necessary responsibility for installations located in the Bay drainage is to build and demonstrate more local-scale (i.e., at the scale of the installation) BMP strategies that are consistent with the regional-scale TMDL allocation strategies. This requires a comparable TMDL assessment effort at the installation scale that considers multiple loading scenarios including existing loading conditions, TMDL loading conditions, and baseline loading conditions (which are representative of existing loading with any permits discharging at their allowable limits). Temporal and spatial effects or patterns of loading scenarios as well as the relative contributions and impacts of different sources (which can be important when considering implementation requirements of a TMDL) are integral to the TMDL assessment. The set up and calibration/validation of the FAPH model (i.e., Task 2) provided the basis for local-scale BMP/TMDL analysis and comparison. Task 3 focused on comparing the FAPH model's watershed representation and water quality modeling results to alternative models/results. Comparisons are made to the results generated by the USEPA's CBP TMDL Model [CBP, 2012] and the National Defense Center for Energy and Environment (NDCEE) spreadsheet model [NDCEE, 2011].

Task 8: Small-Scale Stormwater Runoff Analysis at FAPH

As part of the overall objective to demonstrate capabilities of a BASINS.MIL model, the objective of this task area is to demonstrate how the FAPH Model performs as a tool for small-site stormwater designs and EISA Section 438 compliance. Section 438 requires that all DoD construction projects and redevelopment projects with a footprint of greater than 5,000 gross square feet "maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." BASINS.MIL was applied to a newly-constructed 1.56 acre parking lot at FAPH to cooroborate the adequacy of an on-site detention pond.

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3.0 FORT AP HILL TASK 2: MODEL SET UP AND MODEL CALIBRATION/VALIDATION

Chapter 3 describes the FAPH Watershed model development, including the model setup procedures and assumptions, data sources, calibration time periods, constituents simulated, model scales and resolution, and calibration results.

The FAPH is located in northeastern Caroline County, Virginia, along U.S. Route 301 (Route 301), approximately 40 miles west of the Chesapeake Bay. A small portion of FAPH extends into eastern Essex County, Virginia. To the south and the west, the installation is bordered by forest, farmland, and the Town of Bowling Green. Forests, farmland, and the Town of Port Royal lie to the east and north, as shown in Figure 3-1.

The estimated area of the FAPH is 75,794 acres (117 square miles) and is entirely located within the Chesapeake Bay watershed. FAPH is located along the drainage divide between the Rappahannock River watershed to the north and east and the Mattaponi/York River watershed to the south and west. Approximately two- thirds of the installation drains to the Rappahannock River and one-third drains to the Mattaponi River. Geographically, FAPH is located near the mid-point of the Rappahannock and York River watersheds. The Mattaponi River watershed drains approximately 913 square miles. The overall York River watershed includes an estimated 2,661 square miles. The Rappahannock River watershed contains an estimated 2,848 square miles (Figure 3-1).

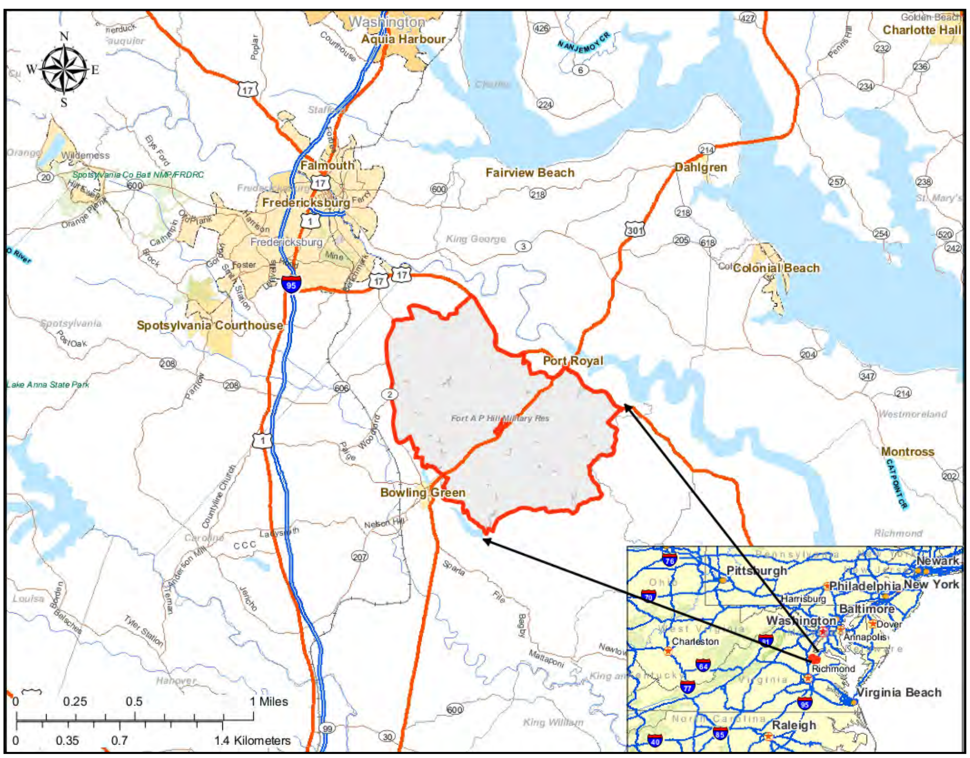


Figure 3-1. Location of Fort AP Hill.

To simulate the hydrology and water quality for the waterbodies in FAPH, the Hydrological Simulation Program–FORTRAN (HSPF) watershed model was selected. HSPF represents a watershed that consists of two primary components: land areas and stream channels or lakes and reservoirs. Each component is represented by a different module(s) within HSPF; the land areas are represented with the PERLND and IMPLND modules for pervious and impervious areas, respectively, and the waterbodies (whether a free-flowing stream or lake/reservoir) are represented with the RCHRES module.

A wide variety of different types of data are required for watershed and waterbody modeling efforts. The watershed managers at FAPH provided watershed data for the installation, which included watershed maps, hydrography, and land use information. The data provided by the installation was used along with the data available through BASINS 4.5 to develop the FAPH Watershed model.

The watershed didn't have long-term flow and water quality gages for long-term model calibration and validation. The United States Geological Survey (USGS) installed two short-term gages to measure flow rates at Mill Creek upstream and downstream of its confluence with the Peumansend Creek. The flow records for the USGS gages were for a period of approximately 2 years (April 2014 to October 2016). The Mill Creek flows eastward towards Rappahannock River. The watersheds that flow towards the Mattaponi River do not have any hydrology and water quality gages. The model parametrization for the watersheds draining to the Rappahannock River was used for the entire watershed model. The watershed model was simulated for a period of 3 years from January 2014 to December 2016.

Simulation of hydrology and water quality within the FAPH Watershed requires the following types of time-series data:

- Precipitation
- Potential evapotranspiration
- Other meteorological data (e.g., air temperature, wind, solar radiation, dewpoint, cloud cover)
- Streamflow
- Water quality observations
- Other data (e.g., points sources, streamflow, water quality, atmospheric deposition)

This section discusses the availability and selection of these time-series data for use in the watershed modeling. Other data types that help to define the inflow, outflow, and quality of water in the watershed, and their use in the modeling effort are also discussed.

3.1 TIME-SERIES DATA AVAILABLE FOR THE FORT AP HILL WATERSHED MODEL

3.1.1 Precipitation

For the hydrology simulation, all watershed models require precipitation time series that are complete records (i.e., no missing data) at a daily or shorter time-step, depending on the selected model, and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models because it drives the hydrologic cycle and provides the foundation for transport mechanisms, for both flow and sediment, that move pollutants from the land to the waterbody where their impacts are imposed.

For this study, long-term precipitation data have been obtained from the following primary sources:

- NLDAS (hourly data) (1979–current year)
- BASINS (hourly data) (1979–2009)

NLDAS data are available up to the current year (within the last few weeks of the download date) and this data were used as the primary sources of precipitation and other meteorological inputs for this watershed model. BASINS provides latest NLDAS data through one of its data download plugins and saves it in a Watershed Data Management (WDM) format. The resolution of NLDAS grids is approximately 11 km for the FAPH Watershed (Figure 3-2).

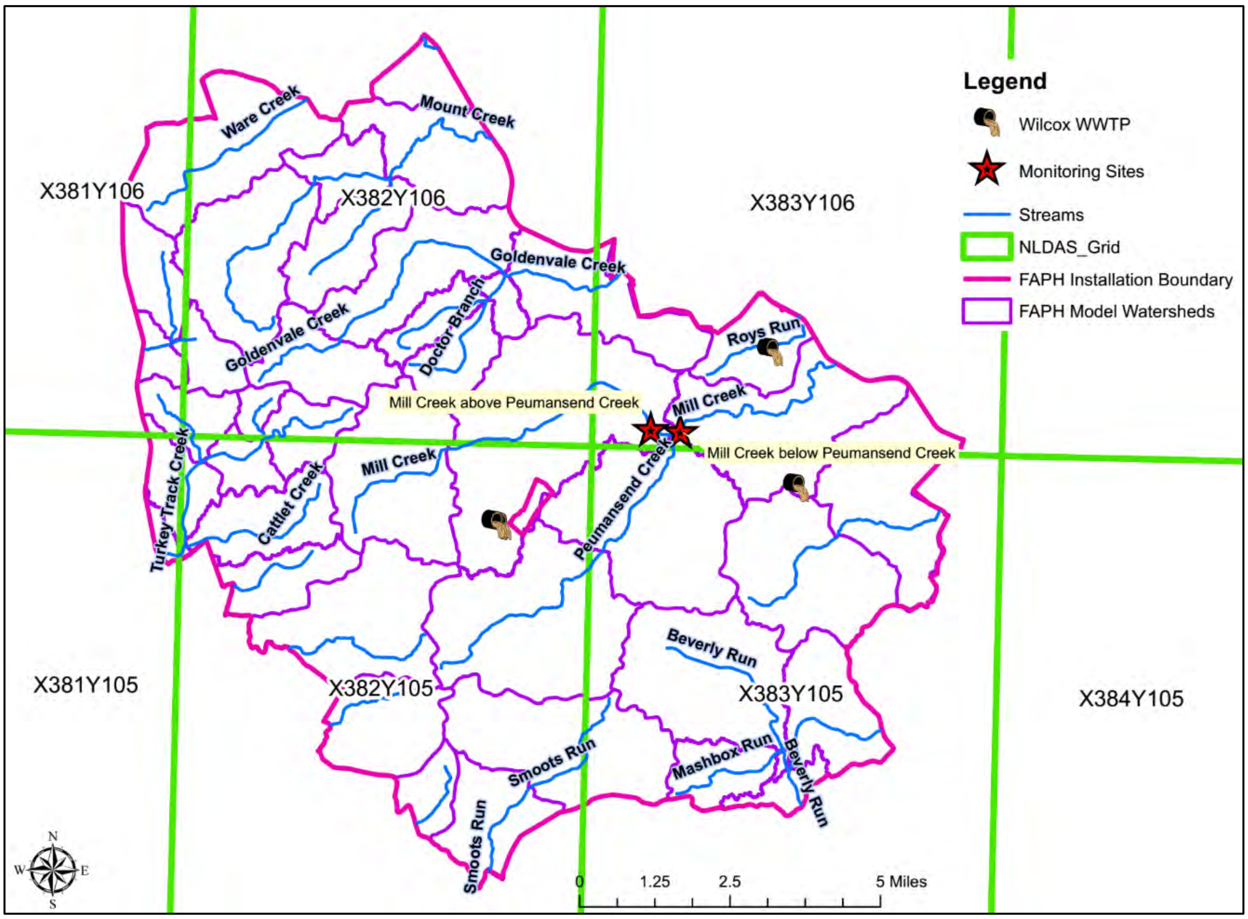


Figure 3-2. North American Land Data Assimilation System Grids Around the Fort AP Hill Watershed, Monitoring Stations, Streams, and Point Source.

BASINS also allows meteorological data download for meteorological stations that have been processed to provide continuous coverage. However, no new data post 2009 is available through BASINS. In FAPH, there are four additional meteorological stations that are part of the Interagency Remote Automatic Weather Stations (RAWS). Some of the meteorological data from these stations was processed for overlapping time- periods to compare NLDAS data.

3.1.2 Evapotranspiration and Other Meteorological Data

Watershed models require evaporation data in addition to precipitation to drive the water balance calculations inherent in the hydrologic algorithms contained in these types of models. Other meteorological time series are also often required in temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These same time series (i.e., air temperature, solar radiation, dewpoint temperature, wind, and cloud cover) are often required if soil and/or water temperatures are simulated. Water temperature is subsequently used to adjust rate coefficients in most water quality processes, and other time series are used in selected calculations (e.g., solar radiation affecting algal growth).

HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by model algorithms, i.e., PET = (pan evap) X (pan coefficient). The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, ET parameters, and the input PET data.

Where pan evaporation is not available, PET can be computed from minimum and maximum daily air temperatures using the Hamon formula [Hamon, 1961]. This method was used to compute the PET data included in the BASINS database of available meteorological time series. The Hamon method generates daily PET (inches) using air temperature (ºF or ºC), a monthly variable coefficient, the number of daylight hours (computed from latitude), and absolute humidity (computed from air temperature). BASINS also includes PET calculations performed from NLDAS data using a modified Penman scheme. However, in our experience, the PET calculations in the NLDAS data typically overpredict the PET by as much as two times. The calculated PET using Hamon methods was used for the hydrological simulation.

BASINS includes additional meteorological data that is either directly provided by NLDAS, or derived by other agencies. All the constituents provided through NLDAS are available through the current date (Table 3-1).

Table 3-1. Availability of Meteorological Data at the North American Land Data Assimilation System Grid Around Fort AP Hill

Data Source	Grid Number	Constituent	Start Date	End Date[(a)]
NLDAS	X381Y106	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017
NLDAS	X381Y105	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017
NLDAS	X382Y106	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017
NLDAS	X382Y105	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017
NLDAS	X383Y106	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017
NLDAS	X383Y105	PREC, ATEM, CLOU, DEWP, PEVT, SOLR, WIND	1/1/1979	6/19/2017

(a) The end date depends upon when the data was downloaded.

3.1.3 Streamflow

Flow data are needed for both calibration and validation of the watershed model to ensure it is reproducing the hydrologic behavior of the watershed. The BASINS download capability provided the means to access all the USGS flow (and water quality) data for sites in the watershed. Figure 3-2 shows the locations of the USGS gaging sites within the watershed, Table 3-2 lists their names, USGS ID numbers, and periods of record. The flow records at the two USGS stations are available for only two years. Typically, the hydrologic calibration is conducted for a flow period of multiple years or even decades to ensure that watershed model reflects the wet and dry years satisfactorily. Fewer years can affect the hydrology calibration as one or two big storms or drought periods could affect the model parametrization.

Table 3-2. List of US Geological Survey Stations and Their Data Availability in the Fort AP Hill Watershed

Station Name	Station ID	Start Date	End Date
Mill Creek above Peumansend Creek near Port Royal, VA	0166818623	04/23/2014	04/07/2016
Mill Creek below Peumansend Creek near Port Royal, VA	0166818985	04/30/2014	10/31/2016

3.1.4 Water Quality Data

Water quality data are used primarily for model calibration and validation, but also to help quantify source contributions and boundary conditions, such as for point sources, selected agricultural sources, and atmospheric deposition. The following list shows the conventional constituents that are modeled whenever nutrients are the purpose of a modeling effort:

- Total Suspended Solids (TSS)
- Water temperature
- Dissolved Oxygen (DO)
- Biological Oxygen Demand ultimate (BODu), or total BOD
- Nitrate- Nitrite (NO3/NO_2) combined
- Total Ammonia (NH3/NH4)
- Total Nitrogen (N)
- Orthophosphate (PO4)
- Total Phosphorus (P)
- Phytoplankton as Chlorophyll a
- Benthic algae (as biomass).

Water quality data for the two USGS gages in the FAPH Watershed were obtained from the Water Quality Portal (*https://www.waterqualitydata.us/*), which is a cooperative service sponsored by the USGS, the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC). The following water quality constituents were downloaded from the portal and were used for water quality calibration.

- Ammonia and ammonium – Dissolved: mg/l as N
- Inorganic nitrogen (nitrate and nitrite) – Dissolved: mg/l as N
- Nitrate – Dissolved: mg/l as N
- Organic Nitrogen – Total: mg/l
- Orthophosphate-Dissolved: mg/l as P
- Phosphorus-Total; mg/l as P
- Temperature, water: deg C

3.1.5 Point Sources

There is only one point source in the FAPH Watershed, Wilcox Waste Water Treatment Plant, which discharges to a tributary to the Mill Creek (Figure 3-2). Multiple years of discharge data from this point source were provided in excel sheets. The point-source data after 2014 were more consistent and easier to process for input to the model. The point-source concentrations and discharge volumes were processed to calculate pollutant loads (Table 3-3). The pollutant loads are input as a time series in the FAPH Watershed model.

Table 3-3. List of Pollutants, Description, and Units That Will Be Calculated from the Point Sources

Pollutant Name	Pollutant Description	Units for Input into the Model per Day
Flow	Effluent Flow	ac-ft
Heat	Heat Energy of the effluent	BTU
TSS	Total Suspended Solids	tons
DO	Dissolved Oxygen	lbs
NO_3/NO_2-N	Nitrate-Nitrite as nitrogen	lbs
NH_3/NH_4-N	Total Ammonia as nitrogen	lbs
ORN	Refractory organic nitrogen	lbs
PO_4-P	Orthophosphorus as phosphorus	lbs
ORP	Refractory Organic phosphorus	lbs
$CBOD_u$	Ultimate carbonaceous organic demand	lbs
ORC	Organic Carbon	lbs

3.1.6 Atmospheric Deposition

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts that focus on nutrient issues. Atmospheric deposition of nitrate and ammonia was explicitly represented as a daily time series in the FAPH Watershed model. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP). Dry atmospheric deposition data were downloaded from the EPA’s Clean Air Status and Trends Network (CASTNet). A summary of these stations is shown in Table 3-4.

Table 3-4. Atmospheric Deposition Site Summary

Site ID	Name	Type	Available Parameters	Start Date	End Date
VA00	Charlottesville	Wet	NH4, NO_2+NO3	1984	Active
VA24	Prince Edward	Dry	NH4, NO_2+NO3	1999	Active

3.2 SEGMENTATION AND CHARACTERIZATION OF THE FORT AP HILL WATERSHED MODEL

Whenever any watershed model is set up and applied to a watershed, the entire study area must undergo a process sometimes referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area. Watershed segmentation is based on individual spatial characteristics of the watershed, including topography, drainage patterns, land use distribution, meteorological variability, and soils conditions. The process is essentially an iterative procedure of overlaying these data layers and identifying portions of the watershed with similar groupings of these characteristics. The results of the land segmentation process are a series of model segments, sometimes call hydrologic response units that demonstrate similar hydrologic and water quality behavior. Over the past few decades, geographic information systems (GIS), and associated software tools, have become critical tools for watershed segmentation. Combined with advances in computing power, they have allowed the development of automated capabilities to efficiently perform the data-overlay process.

GIS data (i.e., coverages) are used to spatially quantify the characteristics of the watershed landscape to develop the model input that informs the model as to how the watershed characteristics change across the study area. GIS data used in the segmentation process that affect the hydrologic and water quality response of a watershed are: topography and elevation, hydrography/drainage patterns, land use and land cover, soils information, and other various types of spatial data.

The FAPH installation staff provided the primary sources for GIS data which included catchments, hydrography, soils, land use, training ranges, prescribed burn patterns, and the point-source location. Additional GIS data for the installation were available through the BASINS automatic data download tool and included the National Hydrography Dataset (NHD) hydrography, catchments, digital elevation model, and census. The following sections describe the development of different coverages required for HSPF model development.

3.2.1 Topography and Elevation

GIS layers of topography are important in setting up HSPF because they provide elevation and slope values for the project area and are needed for characterizing the landscape and the land areas of the watershed. These elevation values are used to delineate subbasins, determine average elevations for each model subbasin, and/or to compute average slopes for model subbasins and land uses within a subbasin. The National Elevation Dataset (NED) available through BASINS 4.2 is a 30-meter digital elevation model (DEM) grid, with vertical units in meters.

3.2.2 Hydrography/Drainage Patterns

Hydrography includes GIS layers of stream segments at various levels of detail, subbasins, drainage boundaries, and waterbodies. A set of coverages that is commonly used in watershed modeling is the NHDPlus dataset. NHDPlus is an integrated suite of geospatial data sets that incorporates many of the best features of the NHD, the NED, the National Land Cover Dataset (NLDC), and the Watershed Boundary Dataset (WBD). The watersheds were provided by the installation staff and were used with the NHDPlus catchments to develop subwatershed and streams coverage (Figure 3-3) for the FAPH model.

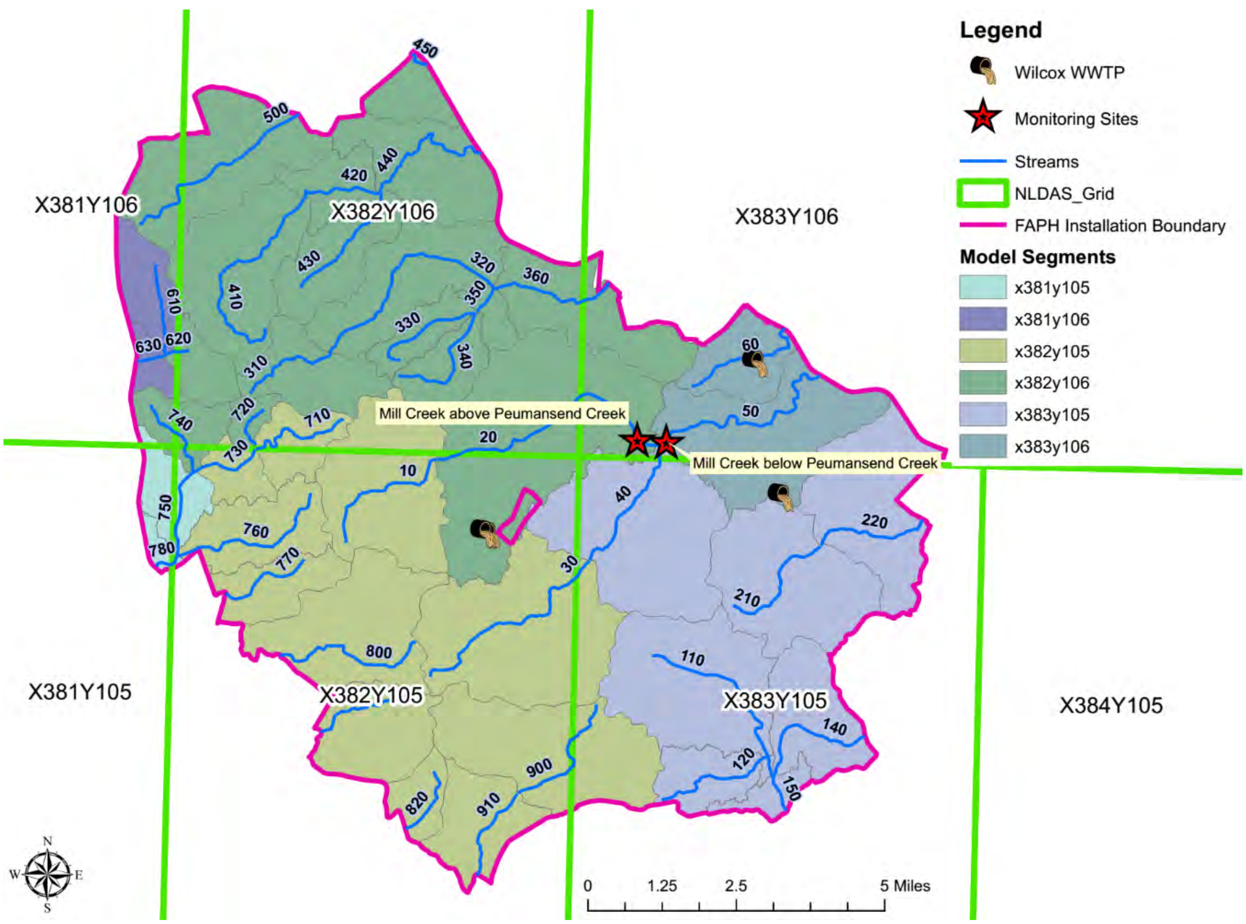


Figure 3-3. Final Subwatershed Segmentation of the Fort AP Hill Watershed.

3.2.3 Land Use

Land use, or land cover, data is a critical factor in modeling complex multi-land use watersheds as it provides the detailed characterization of the potential sources of pollutants entering the reaches as nonpoint source contributions. In addition, the land use distribution has a major determining impact on the hydrologic response of the watershed.

FAPH staff provided detailed land use data from various sources as described in Mishra et al., 2017. The final land use calculations were a result of consolidation of data from various sources and discussions with the FAPH staff. The final land use distribution is presented in the Figure 3-4.

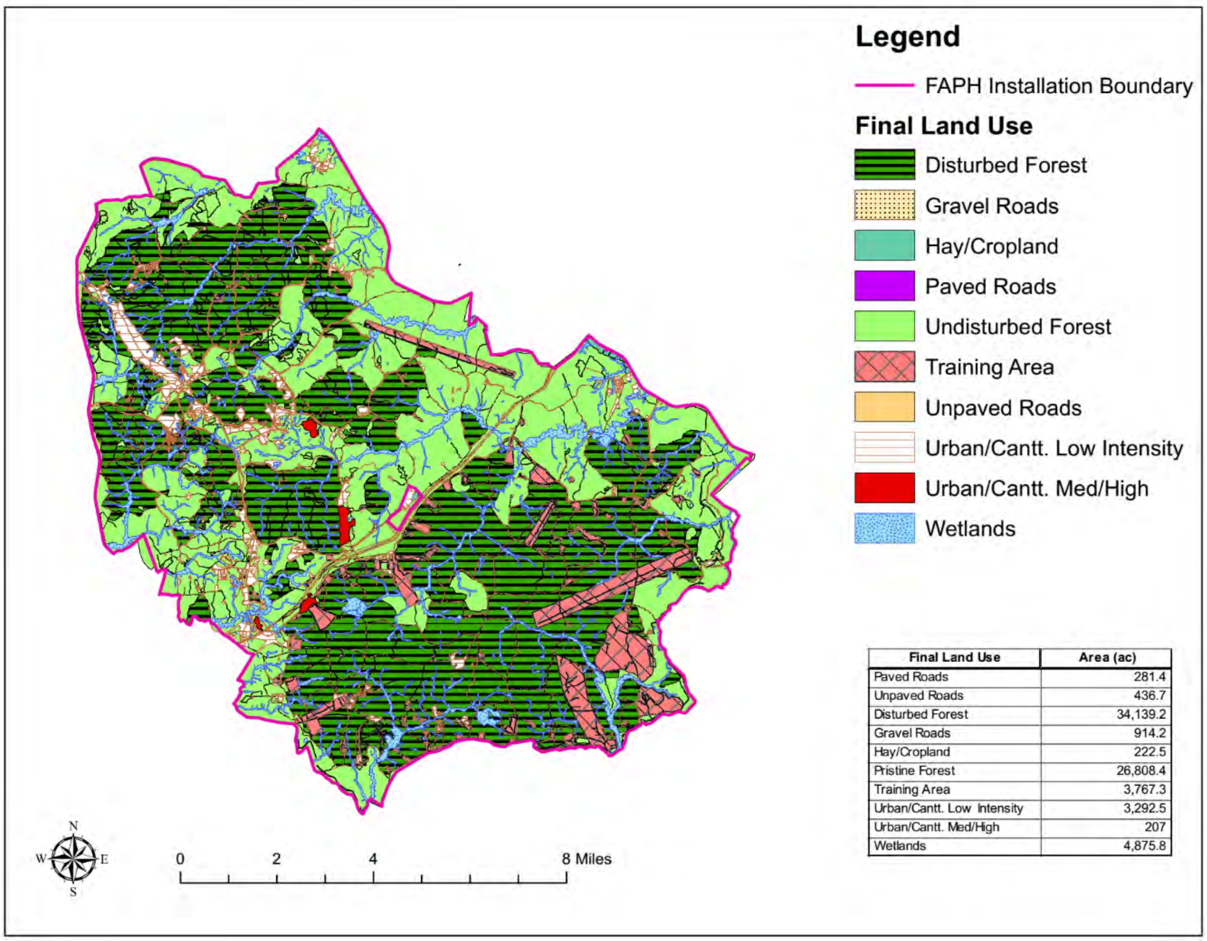


Figure 3-4. Final Land Use Distribution of the Fort AP Hill Watershed.

3.2.3 Soils Data

Soils data are used to characterize the infiltration and soil moisture capacity characteristics of the watershed soils, along with the erodibility parameters for soil erosion. The Gridded Soil Survey Geographic (gSSURGO) Database available from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) [2017] was used as primary soils data for the FAPH model.

The gSSURGO dataset provides information about the soil hydrologic group, drainage class, soil type, and erodibility factor. Spatial data on the SCS Hydrologic Soil Groups (HSG) were obtained and used to generate the spatial distribution of these properties for the FAPH watersheds). The HSG distribution by subwatershed was used as a basis for model parameterization related to infiltration, and soil moisture capacity values in the model. The erodibility factor for each PERLND was used to parameterize the erodibility factor of soils in the watershed. In general, most of the soils in the FAPH are in HSG B, and have a soil K-factor between 0.24-0.32.

3.2.4 Final Segmentation

As noted at the beginning of this section, the purpose of watershed segmentation is to divide the study area into individual land and channel segments that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. Generally, the lower order streams (ditches and order 1) and smaller subwatersheds are merged unless they are of specific interest (e.g., include monitoring locations, impaired waterbodies, point sources, etc.). The merging of small watersheds or subdivision of larger watershed was conducted until the subwatershed sufficiently represented the spatial distribution of various features in the watershed as identified in the preceding sections. Each model subwatershed and corresponding river reach was assigned a unique identification number (Reach ID).

The FAPH Watershed model has six separate model segments and 41 subwatersheds. Each subwatershed has one stream reach. The subwatershed size vary from 55 to 5,900 acres, with a mean area of about 1,800 acres. The stream reaches vary from 0.3 to 4.6 miles with an average length of 2 miles. The primary information used to assign the subwatersheds to the model segments is the NLDAS grids. The land and reach operations in the subwatersheds within the same model segment receive same meteorological input and have the same parameters. The final segmentation is presented in Figure 3-3.

3.3 CALIBRATION OF THE FORT AP HILL WATERSHED MODEL

3.3.1 Calibration Time Period

Selection of time periods for model calibration and validation depends on several factors, including the availability of data for model operations, land use data for model setup, climate variability, and observed data for model-data comparisons. The limiting factor at FAPH was the observed flow data which spans just over 2 years (April 2014–October 2016). The available water quality data also spans the same period. Due to the limited observed data, the model calibration was restricted to the observed data time period, and the model simulation was limited to January 2014 to December 2016. Because of the limited data, the hydrologic and water quality data validation was not conducted.

3.3.2 Hydrology Calibration/Validation Procedures and Comparisons

Calibration of the FAPH Watershed model was an iterative process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. This process was first conducted for hydrology, then water quality. The calibration procedures have been well established over the past 30 years as described in the HSPF Application Guide [Donigian et al., 1984] and summarized by Donigian [2002].

The hydrology calibration process is greatly facilitated with the use of the HSPEXP+ [Mishra et al., 2017], an enhanced expert system for HSPF model. HSPEXP+ gives hydrology calibration advice, such as which model parameters to adjust and/or input to check based on predetermined rules, makes model runs, produces calibration statistics and a variety of comparison plots.

Simulated results were compared with recorded data for the entire calibration period, including both wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions. By iteratively adjusting specific calibration parameter values, within accepted and physically-based ranges, the model parameters were changed until acceptable comparison of simulation and recorded data was achieved.

The standard HSPF hydrologic calibration is divided into four phases:

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flow (in inches) and is governed primarily by the input rainfall and evaporation and the parameters LZSN (lower zone nominal storage), LZETP (lower zone ET parameter), and INFILT (infiltration index).
- **Adjust low-flow/high-flow distribution.** This is generally done by adjusting the groundwater or baseflow, because it is the easiest to identify in low-flow periods. Comparisons of mean daily flow are utilized, and the primary parameters involved are INFILT, AGWRC (groundwater recession), and BASETP (baseflow ET index).
- **Adjust stormflow/hydrograph shape.** The stormflow, which is compared in the form of short time-step (1 hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the UZSN (upper zone storage), INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters (LSUR, NSUR, and SLSUR). INFILT also can be used for minor adjustments.
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), LZETP, UZSN. Adjustments to KVARY (variable groundwater recession) and BASETP are also used.

The detailed description of procedures and parameter adjustments involved in these phases is available in Donigian et al. [1984], and the enhanced HSPF hydrologic calibration expert system (HSPEXP+) [Mishra et al., 2017].

The specific comparisons of simulated and observed values include:

- Annual and monthly runoff volumes (inches)
- Daily time series of flow (cfs)
- Storm event periods (e.g., hourly values) (cfs)
- Flow frequency (flow duration) curves (cfs).

In addition to the above comparisons, the water balance components (input and simulated) were reviewed. This effort involves displaying model results for individual land uses, and for the entire watershed, for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)

- Overland flow
  - Interflow
  - Baseflow
- Potential Evapotranspiration
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- Deep Groundwater Recharge/Losses

Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to ensure that land use categories and the overall water balance reflect local conditions.

Table 3-5 lists general calibration/validation tolerances or targets that have been provided to model users as part of HSPF training workshops over the past 10 years (e.g., Donigian [2000]). The values in the table attempt to provide some general guidance, in terms of the percent mean errors or differences between simulated and observed values, so that users can gage what level of agreement or accuracy (i.e., very good, good, fair) may be expected from the model application. In FAPH; however, due to the limited observed data, it was difficult to achieve good to very good simulation.

Table 3-5. General Calibration/Validation Targets or Tolerances for HSPF Applications [Donigian, 2000]

	Percent Difference Between Simulated and Recorded Values		
	Very Good	**Good**	**Fair**
Hydrology/Flow	< 10	10–15	15–25
Sediment	< 20	20–30	30–45
Water Temperature	< 7	8–12	13–18
Water Quality/Nutrients	< 15	15–25	25–35
Pesticides/Toxics	< 20	20–30	30–40

CAVEATS:
Relevant to monthly and annual values; storm peaks may differ more
Quality detail of input and calibration data
Purpose of model application
Availability of alternative assessment procedures
Resource availability (i.e., time, money, personnel)

The caveats at the bottom of the table indicate that the tolerance ranges should be applied to **mean** values, and that individual events or observations may show larger differences, and still be acceptable.

In addition, the level of agreement to be expected depends on many site and application-specific conditions, including the data quality, purpose of the study, available resources, and available alternative assessment procedures that could meet the study objectives.

Figure 3-5 provides value ranges for both correlation coefficients (R) and coefficient of determination (R^2) for assessing model performance for both daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows, given the uncertainties in the timing of model inputs, mainly precipitation.

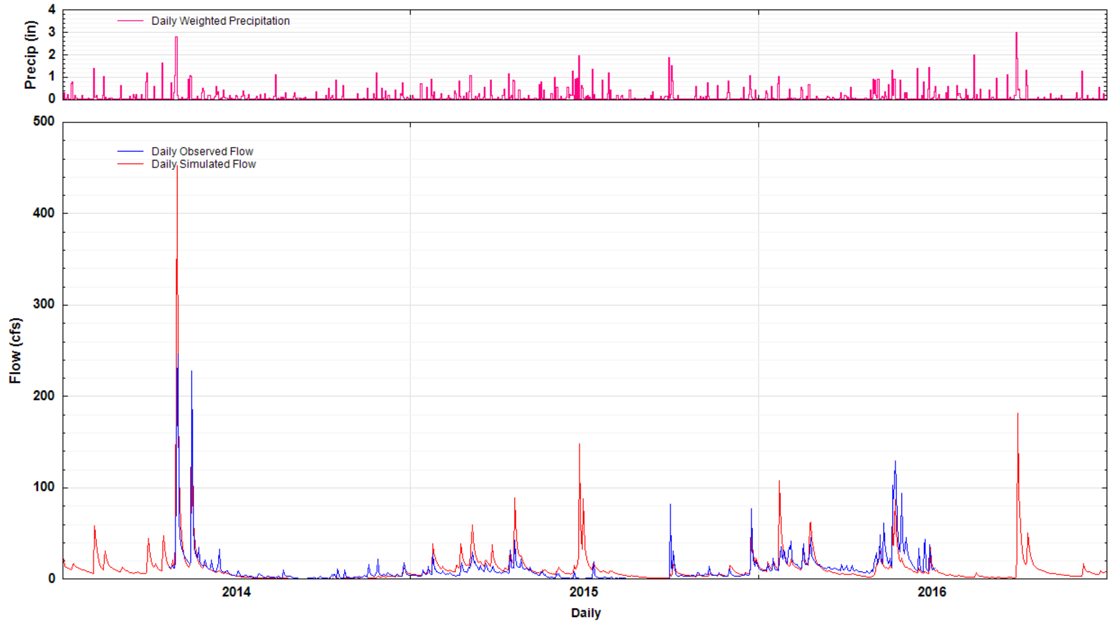
Figure 3-5. R and R2 Value Ranges for Model Performance.

3.3.3 Hydrology Calibration Results for Fort AP Hill Model

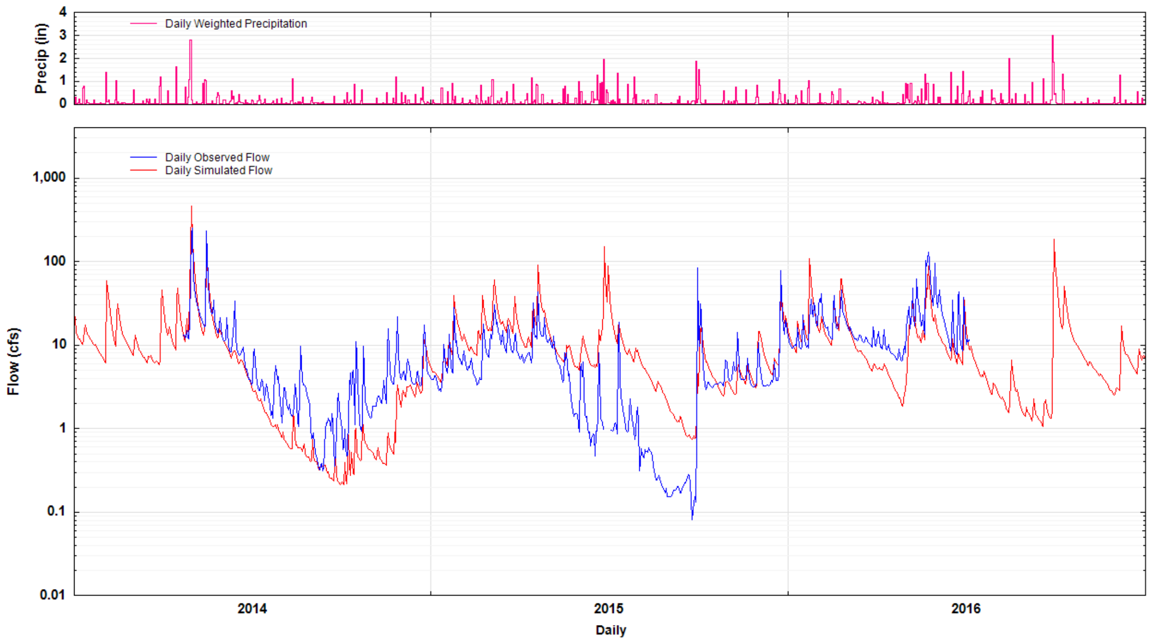
The flow hydrographs for the model simulation compared to observed data are presented in Figures 3-6 and 3-7. The hydrographs show an acceptable hydrologic calibration. However, the flow hydrograph at the log scale illustrate the difficulty in simulating some low flows, especially in summer and fall of 2015. At the end of June 2015, the precipitation data from NLDAS (primary input data) suggested a rainfall of about 4 inches; however, the observed data didn’t show any response during that period. This period affected the hydrology calibration statistics and parameter evaluation. The precipitation value during that time was cross-checked with the gage data from NCDC (*https://www.ncdc.noaa.gov/cdo-web/*), and MesoWest (*https://mesowest.utah.edu/*) stations, and all the stations suggested significant precipitation during that time. Adjusting the parameters to match this anomaly affected the entire calibration; therefore, 5 days of observed data during the end of June 2015 was ignored for the calibration process. Flow frequency duration curves for both the calibration locations show that the model replicates most of the flow profile except some extreme events and very low flows (Figure 3-8).

The expert statistics for the model calibration (Tables 3-6 and 3-7) suggest that the model results are within the acceptable criteria for most of the error terms. Some low-flow volumes do not meet the criterion, and these mostly correspond to flows less than 5 cfs. As noted earlier, these issues are encountered frequently when the period of record is short. The daily and monthly statistics suggest that model performance was better for monthly simulation compared to daily simulation. According to the Figure 3-5, the daily flow simulations are between poor and fair, and monthly flow simulations are good.

Any improvement in hydrologic calibration will require longer term flow data at the USGS gages. The current calibration was considered adequate to start water quality calibration with complete acknowledgement that poor hydrologic calibration will affect water quality calibration results.

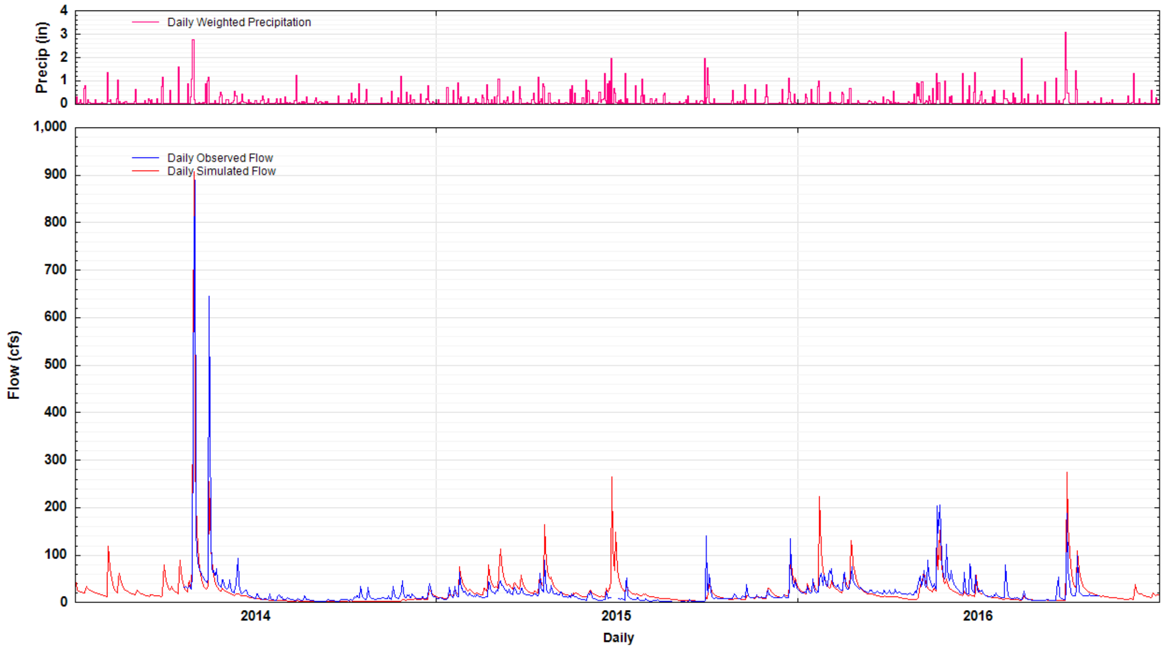


(A)

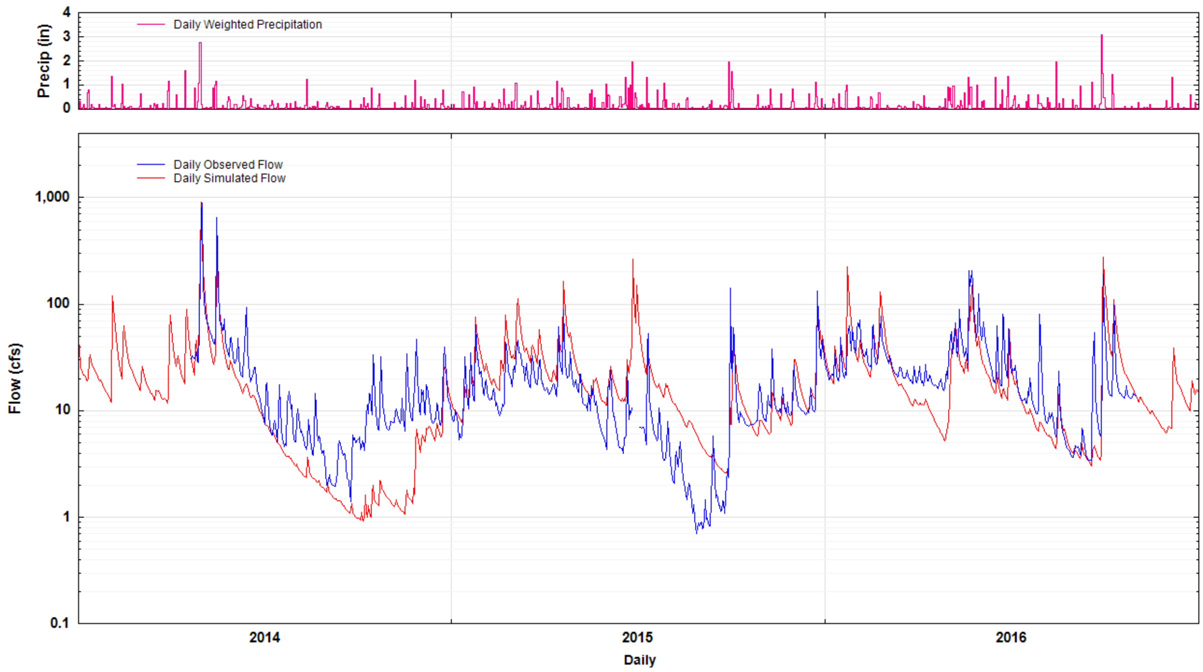


(B)

Figure 3-6. Observed and Simulated Flow at Mill Creek Above Peumansend Creek (Reach 20) at (A) Normal and (B) Log Scale.

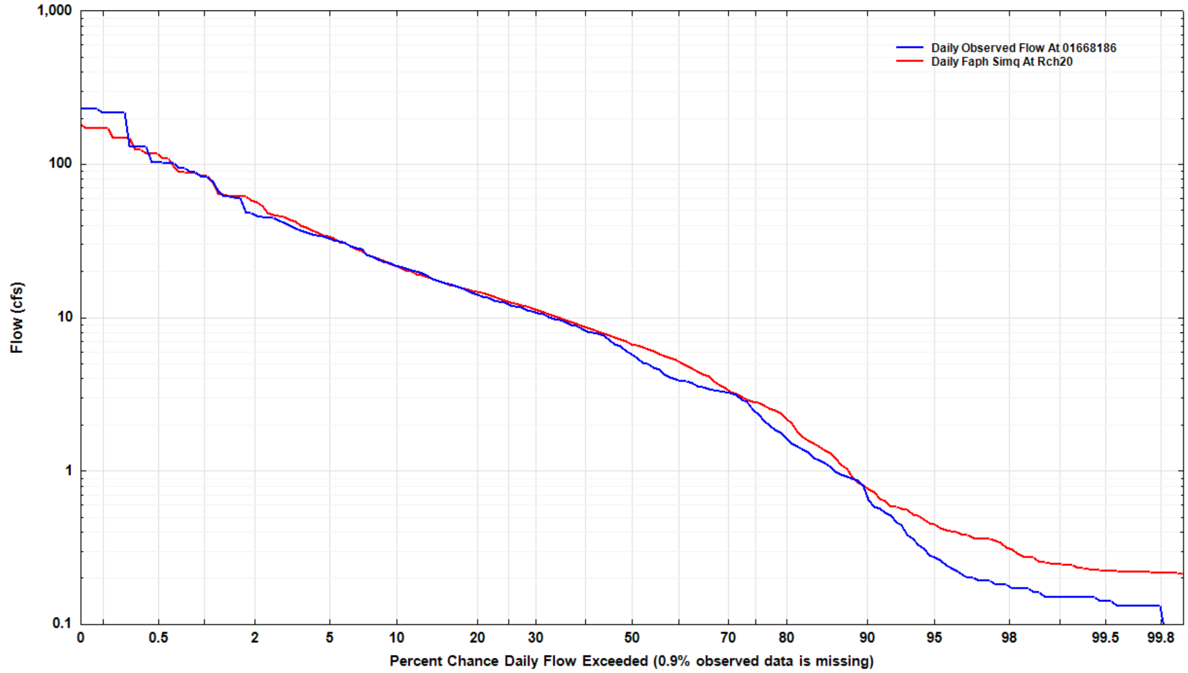


(A)

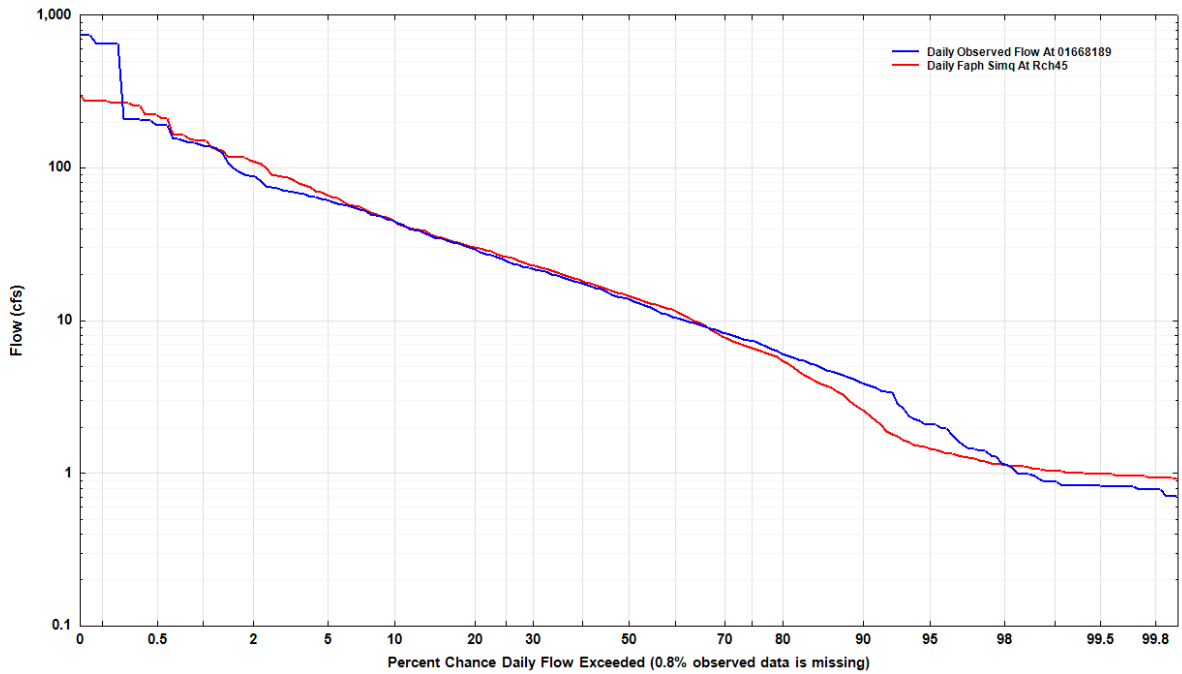


(B)

Figure 3-7. Observed and Simulated Flow at Mill Creek Below Peumansend Creek (Reach 45) at (A) Normal and (B) Log Scale.



(A)



(B)

Figure 3-8. Flow Frequency Duration Curve for Observed and Simulated Flow at (A) Mill Creek Below Peumansend Creek (Reach 20) and at (B) Mill Creek Above Peumansend Creek (Reach 45).

Table 3-6. Expert Statistics for Hydrologic Calibration Results at US Geological Survey Gages in the Fort AP Hill Watershed

Error Term	Criteria	Mill Creek Above Peumansend (Reach 20)	Mill Creek Below Peumansend (Reach 45)
Error in total volume (%)	10	3.3	-1.9
Error in 10% highest flows (%)	15	0.2	-2.0
Error in 25% highest flows (%)	10	0.8	-0.3
Error in 50% highest flows (%)	10	2.3	0.6
Error in 50% lowest flows (%)	10	11.4	-15.1
Error in 25% lowest flows (%)	15	-2.2	-31.0
Error in 10% lowest flows (%)	20	20.1	-37.0
Error in low-flow recession	0.03	0.01	0.0
Error in storm volumes (%)	15	1.2	-6.5
Seasonal volume error (%)	20	-26.4	12.6
Error in average storm peak (%)	15	-12.2	-22.8
Summer volume error (%)	20	-33.2	-3.2
Winter Volume Error (%)	15	-6.8	-15.8
Summer Storm Volume Error (%)	15	-45.6	-39.7
Winter Storm Volume Error (%)	15	20.7	24.6

Table 3-7. Daily and Monthly Flow Statistics for the Hydrology Calibration

Parameter	Mill Creek Above Peumansend (Reach 20)		Mill Creek Below Peumansend (Reach 45)	
	Daily	Monthly	Daily	Monthly
Correlation Coefficient	0.75	0.89	0.77	0.89
Coefficient of Determination	0.56	0.79	0.60	0.79
Mean Error (cfs)	0.3	-0.6	-0.6	-1.8
PBIAS/Mean Percent Error (%)	2.4	-5.8	-2.5	-7.8
Mean Absolute Error (cfs)	5.8	4.2	11.2	8.6
RMS Error (cfs)	13.7	5.8	29.6	11.7
Nash-Sutcliffe Efficiency	0.46	0.71	0.62	0.72
RMSE-Observations Standard Deviation Ratio (RSR)	0.74	0.54	0.62	0.53

3.3.4 Water Quality Calibration Procedures and Comparisons

Water quality calibration is an iterative process; the model predictions are the integrated result of all the assumptions used in developing the model input and representing the modeled sources and processes. Differences in model predictions and observations require the model user to reevaluate these assumptions for the estimated model input and parameters, and consider the accuracy and uncertainty in the observations.

The following steps were performed at the two calibration stations after the hydrologic calibration and after completing the input development for point source, atmospheric, and other contributions:

1. Estimate all model parameters, including land use specific accumulation and depletion/ removal rates, wash-off rates, and subsurface concentrations
2. Tabulate, analyze, and compare simulated annual nonpoint loading rates with the expected range of nonpoint loadings from each land use (and each constituent) and adjusted loading parameters when necessary
3. Calibrate instream water temperature to observed data
4. Compare simulated and observed instream concentrations at each of the calibration stations, and compare simulated and estimated loads where available
5. Analyze the results of comparisons in steps 2, 3, and 4 to determine appropriate instream and/or nonpoint parameter adjustments needed until model performance targets are achieved.

3.3.5 Sediment Calibration

Sediment was the first constituent that was calibrated because the sediment simulation only depends upon hydrology simulation. The sediment calibration started with the estimation of the parameter KRER (detachment coefficient dependent upon soil properties). The FAPH staff provided a GIS shapefile of soil properties and the KRER parameters from that shapefile were extracted for each land use in each model segment. The COVER factor is the fraction of land surface that is shielded from rainfall erosion. Earlier studies were used to estimate starting parameter values for all the land uses.

Following the initial parameterization, the model was simulated and loading rates for the land uses were calculated and compared with each other. Other parameters, including the coefficient for transport of detached sediment (KSER), vertical input of sediment (NVSI), and fraction of sediment storage decrease due to soil compaction (AFFIX) were adjusted to reflect the effect of land uses on sediment loading rate. The sediment loading rate following model calibration is presented as a box-whisker plot in Figure 3-9. In this plot and following box-whisker plots, boxes represent the central quartile (25% and 75%) and whiskers represent the minimum and maximum.

Instream calibration of sediment simulation followed the sediment simulation on land surface. The hourly simulated shear stress of all the streams in the watershed was exported as time series and the 2, 5, 95 and 98 percentiles of the shear stress were extracted. These values were used as critical shear stress thresholds for deposition and scour for silt and clay, respectively. All other parameters including sediment particle diameter, settling velocity and erodibility coefficient were kept at default values.

After initial parameterization, observed and simulated TSS were plotted at normal and log scales. The primary calibration parameters for TSS simulation included erodibility coefficient and critical shear stress. These parameters were adjusted to obtain reasonable simulation of TSS (Figure 3-10). As evident in the plots, some extreme concentrations were not simulated by the model. The Mill Creek gage below Peumansend Creek recorded a TSS concentration of 11,100 mg/l in September 2015. At that high concentration, water is effectively a slow-moving sludge. These high concentration values correspond to low-flow events which were not modeled very well as noted in hydrologic calibration.

It must also be noted that these observed values refer to grab sample event as opposed to continuous average daily time series of simulated data, and therefore accurately matching individual events may not be possible. Despite these limitations, the simulated TSS concentrations matched observed concentration for multiple events at both the calibration locations.

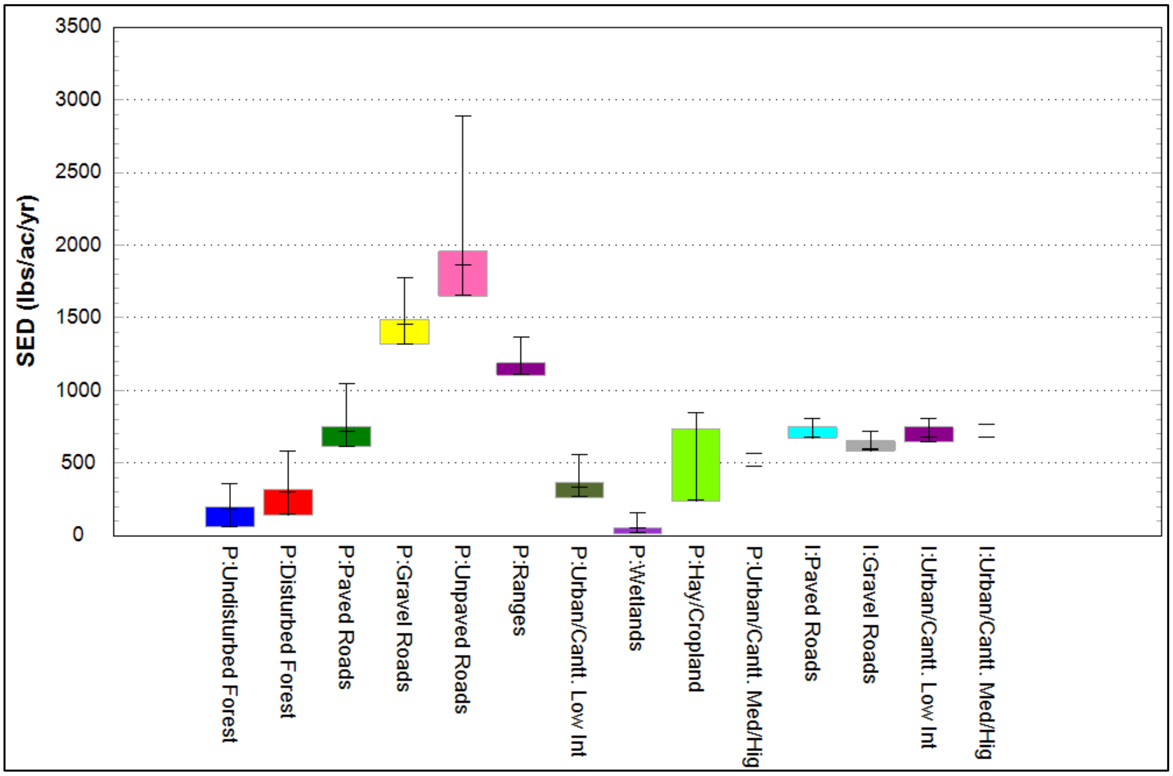
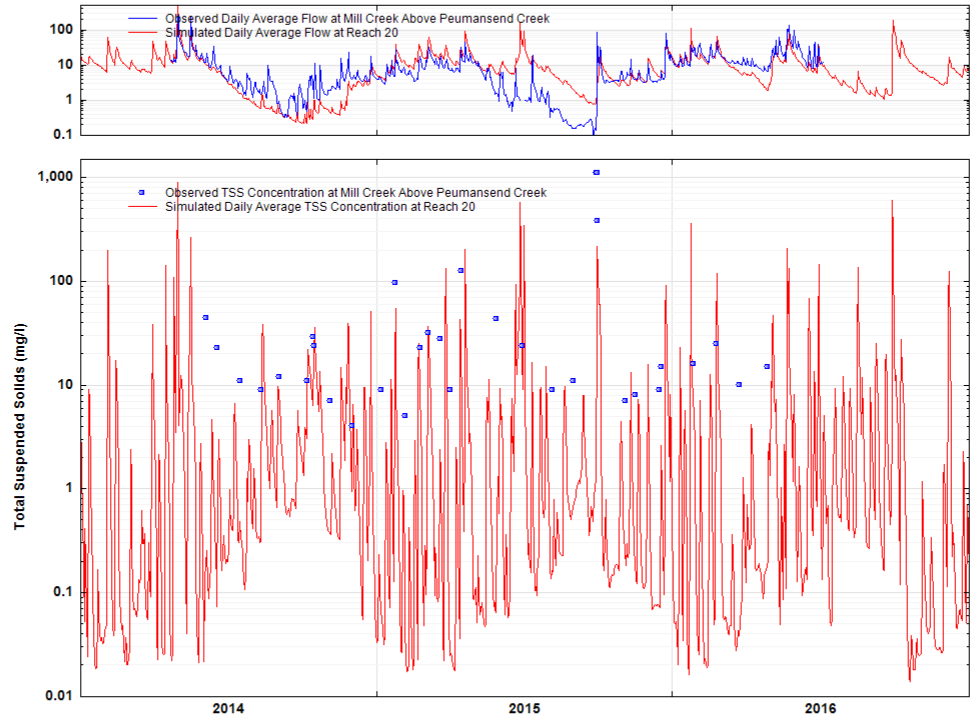


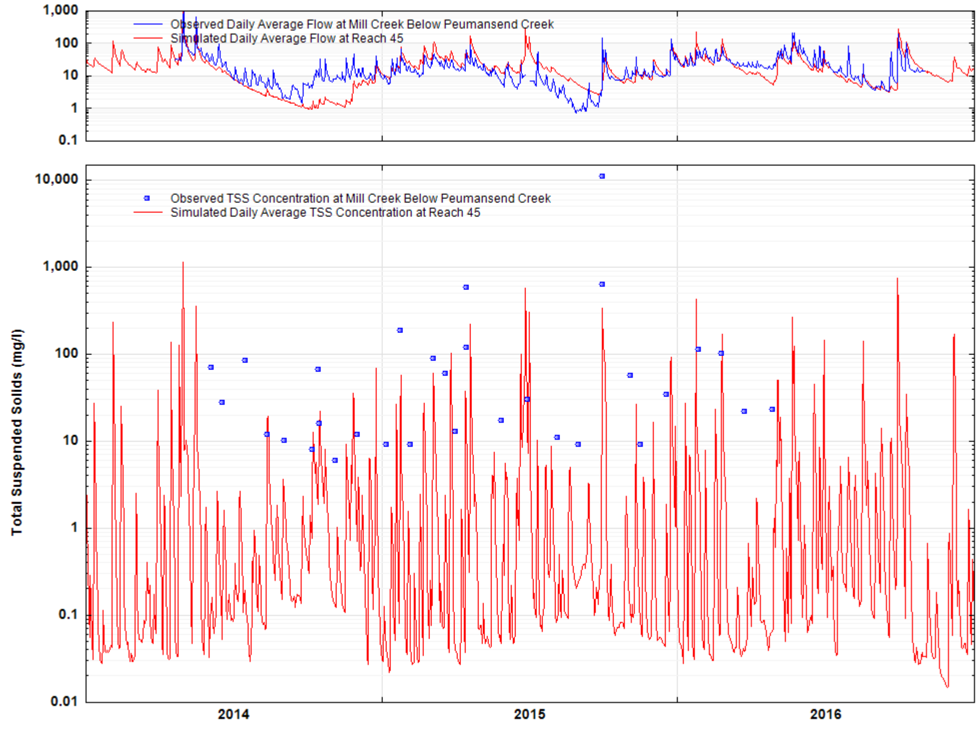
Figure 3-9. Box-Whisper Plot of Simulated Sediment Loading Rates (Pounds/Acre/Year) for Various Land Uses in the FAPH Watershed.

3.3.6 Water Temperature Calibration

Water temperature calibration followed the sediment calibration. The water temperature calibration required parameterizing surface soil temperature, upper layer temperature, interflow temperature, groundwater temperature and the effect of air temperature on these parameters. For waterbodies, a shade factor is the primary calibration parameter. Observed water temperature data is available at 15-minute time interval for a significant period of simulation. The daily observed and simulated water temperature is presented in the Figure 3-11, and the comparison of hourly data is provided in Appendix A. The simulated water temperature follows the trend of observed water temperature and its range. The diurnal pattern of simulated water temperature also follows the trend of observed water temperature. Following the satisfactory simulation of water temperature, nutrient and DO calibrations were conducted.

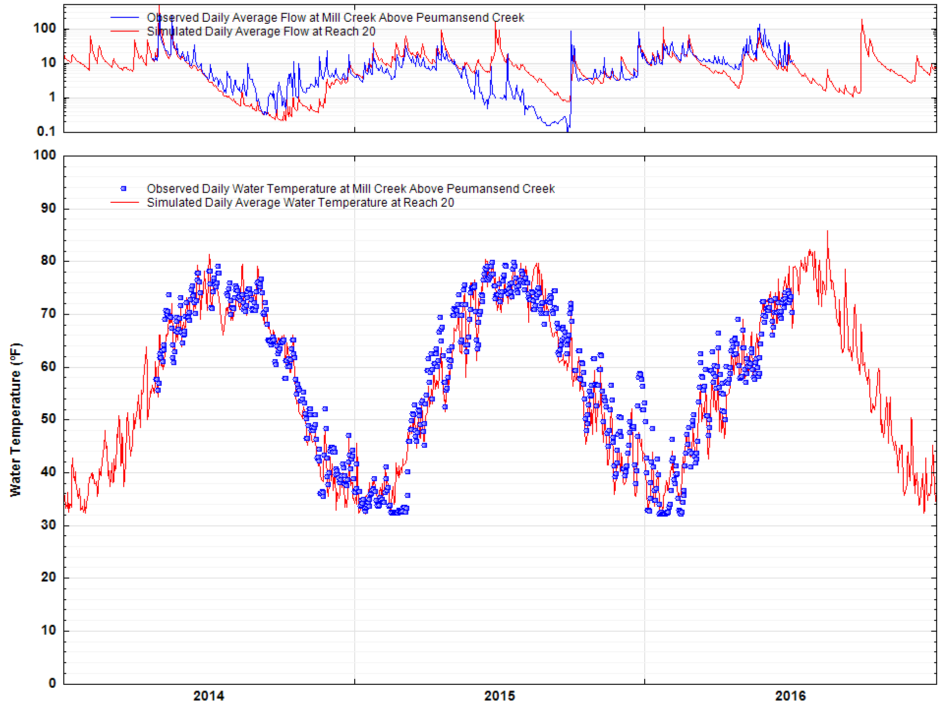


(A)

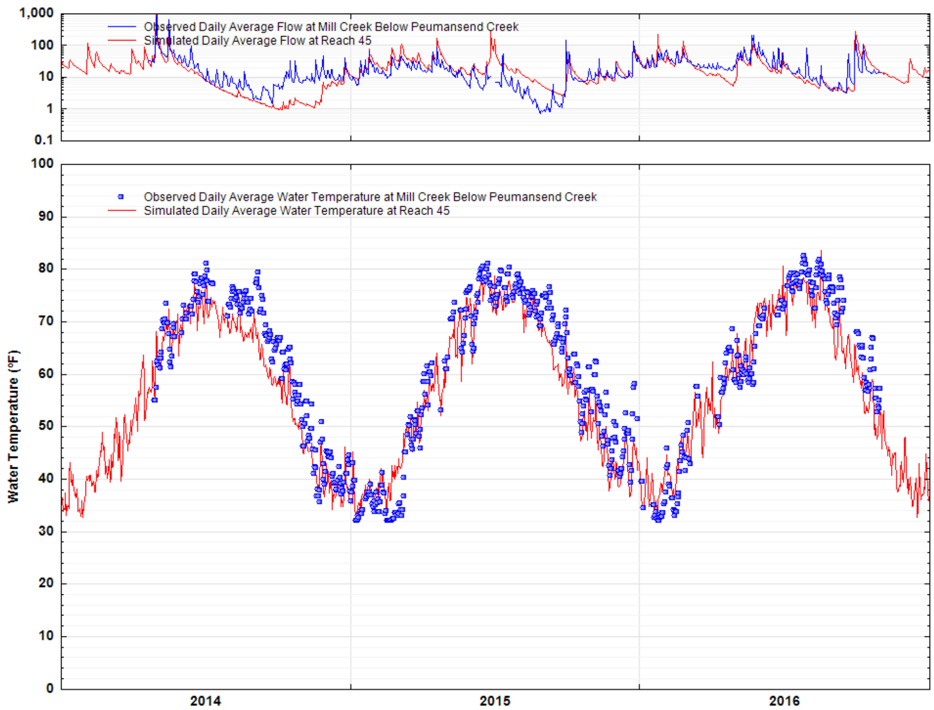


(B)

Figure 3-10. Observed and Simulated Total Suspended Solids Concentration (Mg/L) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.



(A)



(B)

Figure 3-11. Observed and Simulated Daily Average Water Temperature (Degrees Fahrenheit) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.

3.3.7 Dissolved Oxygen Calibration

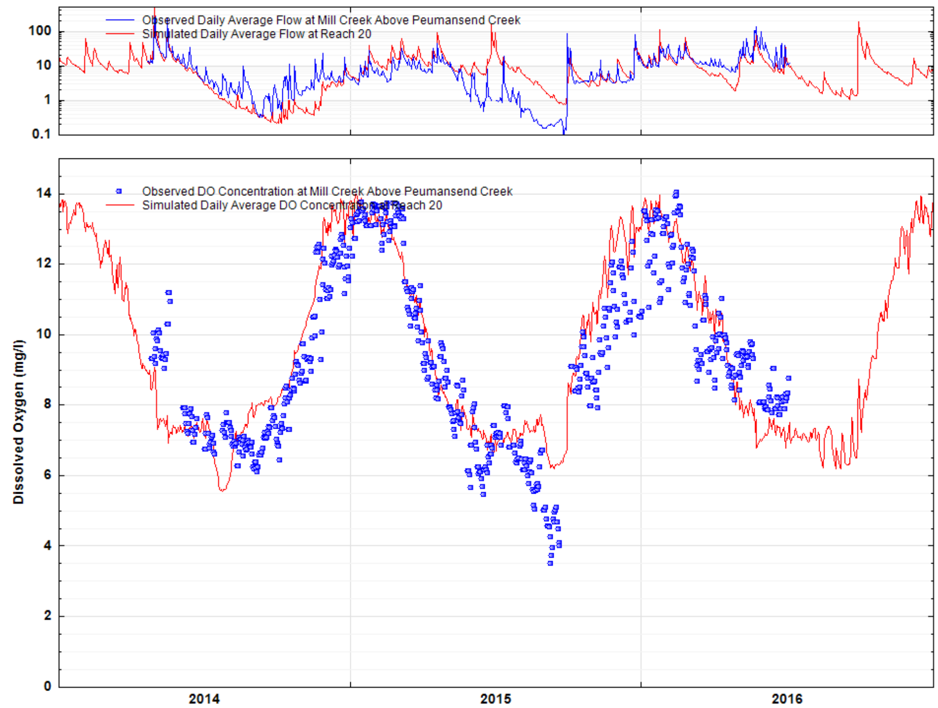
The DO calibration followed the water temperature calibration. DO in surface water runoff is mostly dependent upon the temperature. In waterbodies, DO is a function of temperature and other biological activities that include phytoplankton growth and respiration. Although DO is listed earlier than other nutrients in this report, the calibration of DO and nutrients was conducted in tandem. The dissolved oxygen data is also available at 15-minute interval for a significant period of simulation. Overall, simulated daily average DO concentrations matched the range and trend of observed concentration at both the calibration locations (Figure 3-12). In fall 2015, observed DO at the Mill Creek above Peumansend went below 6 mg/l for a stretch of about 2 months. These observations coincided with low observed flow during that period. Without accurate hydrologic calibration for this period, it is difficult to match the observed conditions.

3.3.8 Nutrient Calibration

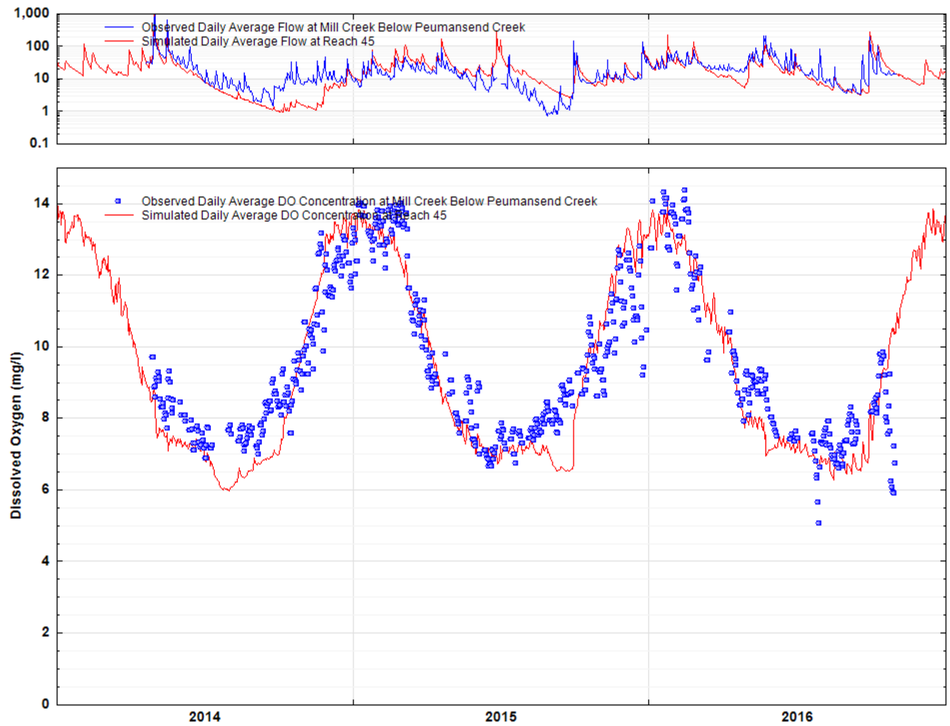
As noted earlier, the nutrient calibration was conducted in tandem with the DO calibration. The nutrient calibration process starts with parametrizing the accumulation and runoff rates of nutrients on the land surface and comparing the simulated loading rates with the target loading rates for the region. Not all the land uses have a target loading rate, but professional judgement was exercised to parameterize the accumulation and runoff rates such that the loading rates reflect the differences in the properties of the land uses. Calibrated loading rates of TN and TP are shown in Figure 3-13 as box-whisker plots. The box-whisker plots of loading rates of individual constituents that include nitrate as nitrogen (NO_3-N), ammonia as nitrogen (NH_3-N), orthophosphorus as phosphorus (PO_4-P) for all land uses are presented in Appendix A. Table 3-8 shows the area-weighted loading rates of multiple constituents from all the land uses contributing to the USGS gage at Mill Creek below Peumansend Creek.

Following the satisfactory calibration of loading rates, the instream calibration of nutrients was conducted. During the nutrient calibration, it was noticed that NO_3-N concentrations increased by at least two orders of magnitude in the fall of 2014 at both USGS calibration gages and stayed at elevated concentrations for the remainder of the year. That increase was not supported by the observed data. The point-source data was investigated for this period and the point-source data did show an elevated nutrient load during that period. The elevated concentrations could possibly be due to the way different constituents of nitrogen were filled and calculated from the provided data. The missing data were filled using interpolation so the nutrient concentrations may have decreased between some high values, but there is no way to quantify without data. To reduce the effect of NO_3-N loading from point source, the entire time series was multiplied by 0.5. The effect of point-source reduction is illustrated in Figure 3-14. The reduction in NO_3-N loading from point-source loading improved the NO_3-N and TN calibration at both USGS gages.

The nutrient calibration process also involved adjusting the initial nutrient concentrations, rates of biological process, concentration of adsorbed nutrients, adsorption and desorption coefficients, and release of nutrients and organic materials from reach bed. The simulated and observed concentration of TN and TP at Mill Creek below Peumansend are shown in Figure 3-15. Water quality plots at Mill Creek above Peumansend Creek and for other constituents are presented in Appendix A. In general, the graphs show that simulated nutrient concentrations matched the observed nutrient concentration for most of the simulation. In the fall of 2014, the simulated nutrient concentrations increased, and could be mostly attributed to point-source input.

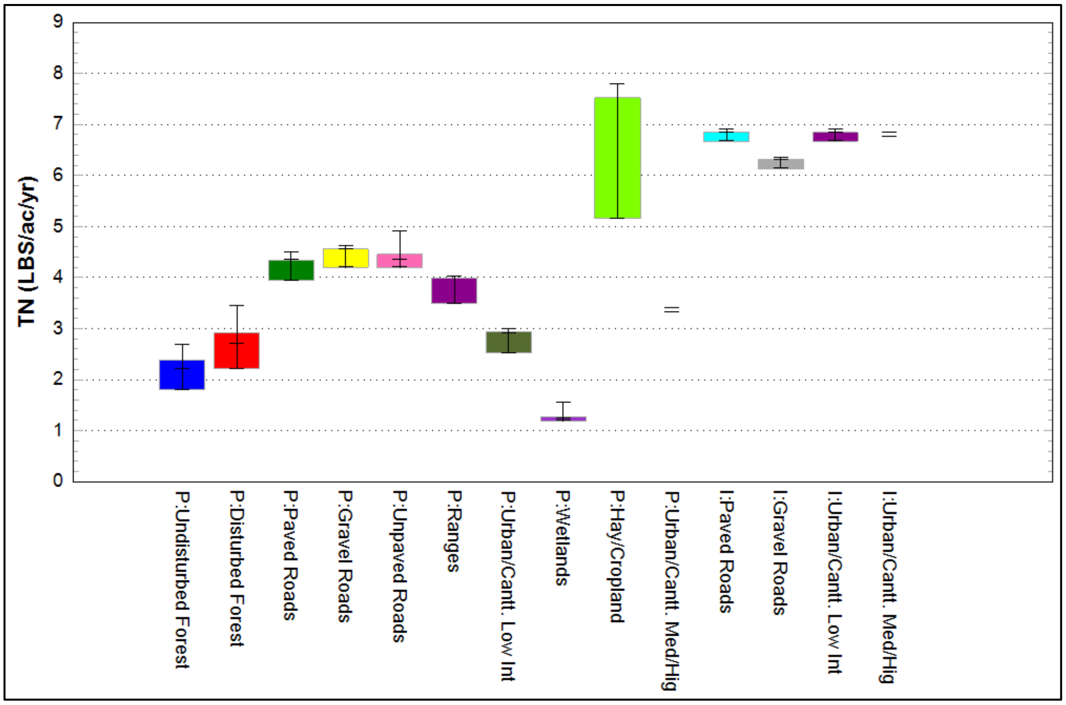


(A)

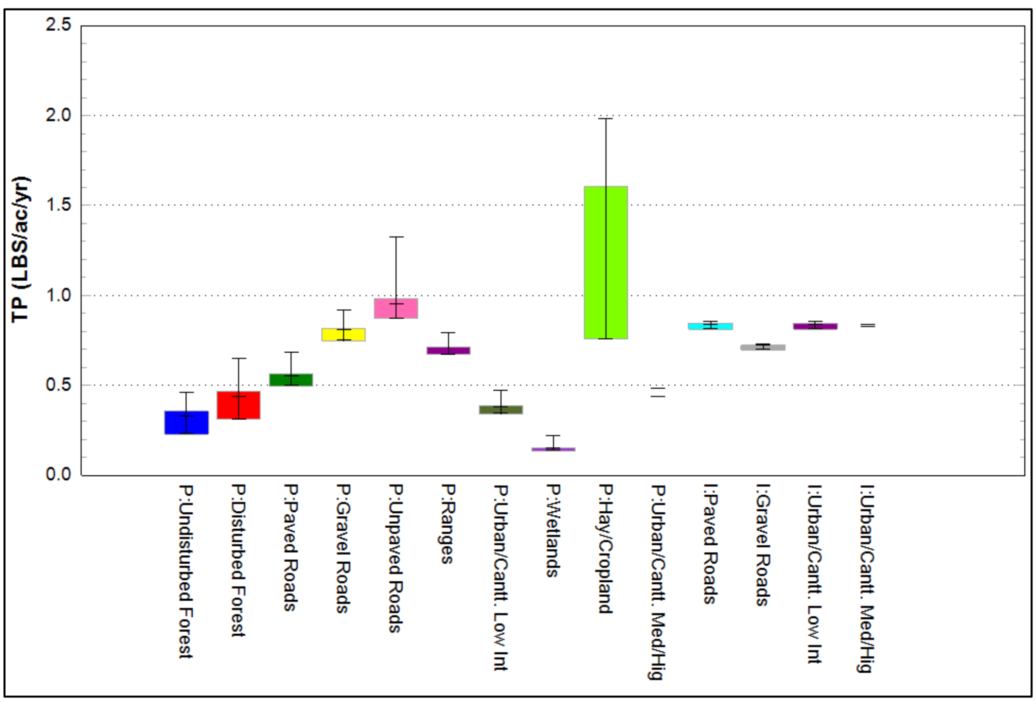


(B)

Figure 3-12. Observed and Simulated Daily Average Dissolved Oxygen (Mg/L) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.



(A)



(B)

Figure 3-13. Box-Whisker Plot of Loading Rates (Pounds/Acre/Year) of (A) Total Nitrogen, and (B) Total Phosphorus From all the Land Uses in the Fort AP Hill Watershed.

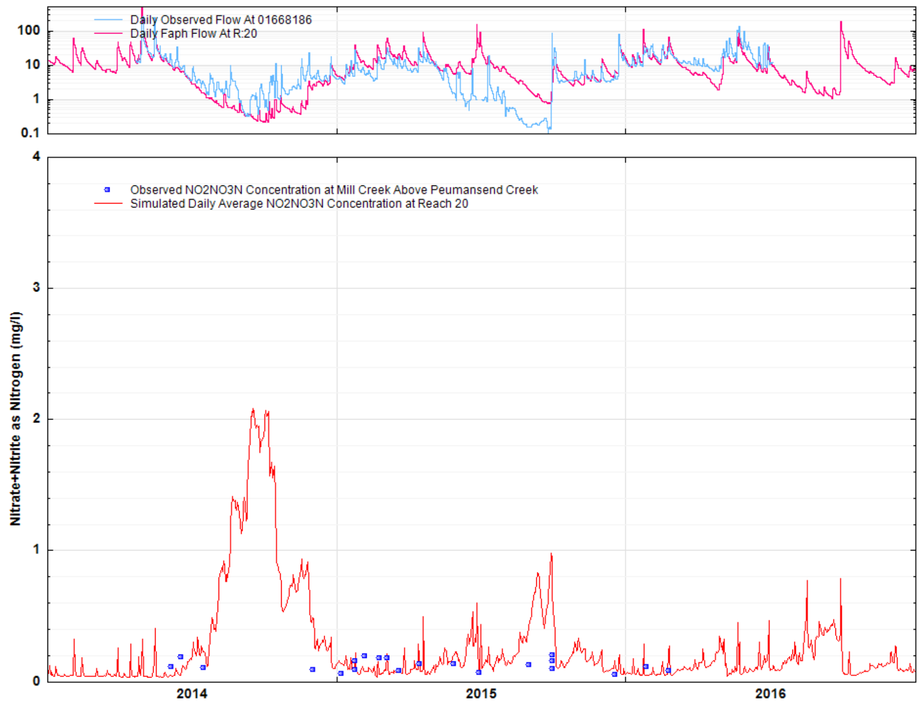
Additionally, a couple of extreme concentrations of TP in 2015 were not captured by the model for both calibration locations.

Table 3-8. Area-Weighted Loading Rate (Pounds/Acre/Year) of Nutrients of All the Land Uses in the Fort AP Hill Watershed Model Draining to Mill Creek Below Peumansend (Reach 45)

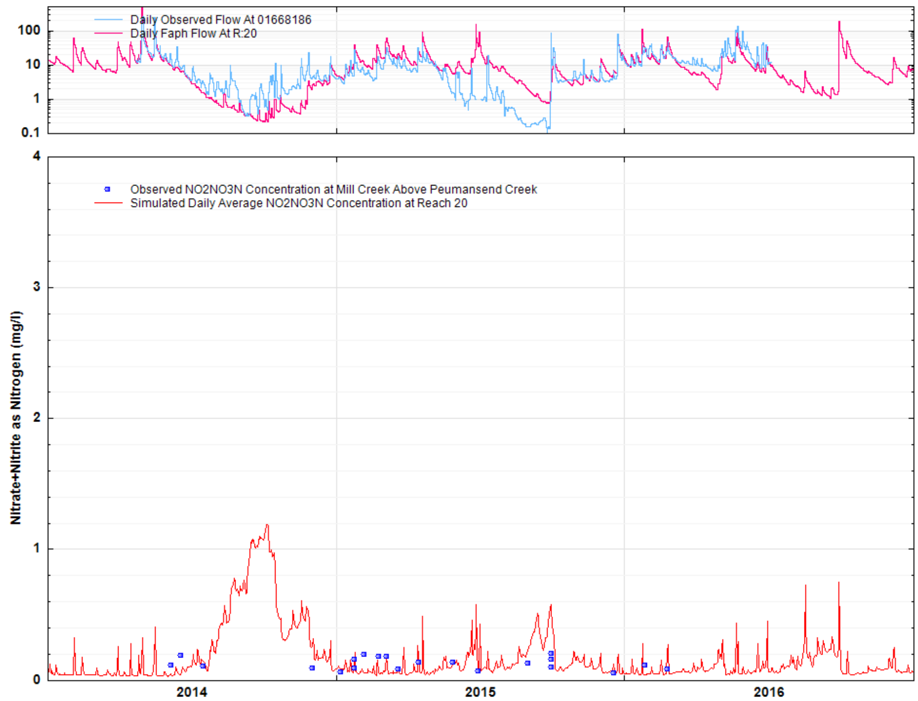
Land Use	Undisturbed Forest	Disturbed Forest	Paved Roads	Gravel Roads	Unpaved Roads	Ranges
Area (ac)	5,545.8	9,366.6	79.3	193.7	54.2	612.4
Sediment Loading Rate (tons/ac)	0.092	0.141	0.384	0.737	0.921	0.645
Ammonia Loading Rate (lbs/ac)	0.114	0.124	0.638	0.650	0.477	0.470
Nitrate Loading Rate (lbs/ac)	0.190	0.211	1.385	1.419	1.022	1.007
Total Nitrogen Loading Rate (lbs/ac)	1.852	2.147	3.855	3.963	3.632	3.448
Ortho P Loading Rate (lbs/ac)	0.025	0.028	0.027	0.027	0.031	0.030
Total P Loading Rate (lbs/ac)	0.176	0.199	0.205	0.205	0.230	0.218
Land Use	**Urban/Cantt. Low Int**	**Wetlands**	**Hay/ Cropland**	**Urban/ Cantt. Med/Hig**	**WtdAvg (Pervious Areas)**	**WtdAvg (Impervious Areas)**
Area (ac)	449.5	1,275.2	11.5	123.1	17,711.3	48.9
Sediment Loading Rate (tons/ac)	0.158	0.024	0.268	0.262	0.146	0.345
Ammonia Loading Rate (lbs/ac)	0.266	0.079	0.366	0.362	0.144	1.841
Nitrate Loading Rate (lbs/ac)	0.597	0.115	4.524	0.946	0.263	3.791
Total Nitrogen Loading Rate (lbs/ac)	2.623	1.124	6.743	3.071	2.078	6.697
Ortho P Loading Rate (lbs/ac)	0.030	0.016	0.030	0.028	0.026	0.695
Total P Loading Rate (lbs/ac)	0.213	0.113	0.213	0.205	0.187	0.811

3.3.9 Calibration Summary and Conclusions

The hydrology and water quality calibration results for the FAPH Watershed model show that the model replicated hydrology and water quality adequately, and it can be used as a tool for future watershed management. During some events, the model did a poor job in replicating the real-world conditions. The model can be further improved with long-term hydrology and water quality data. In addition to the observed data, the input forcing data, including meteorological point-source time series, could be further improved by focusing on individual events where simulated results do not match the observed data. The response of model during individual events also depend on hydraulic properties of the waterbodies. Detailed survey of these waterbodies will improve the model performance during these events.



(A)



(B)

Figure 3-14. Nitrate-Nitrite as Nitrogen Concentration in Mill Creek Above Peumansend Creek with (A) No Reduction in Point-Source Loading, and (B) 50 Percent Reduction in NO3-N Loading.

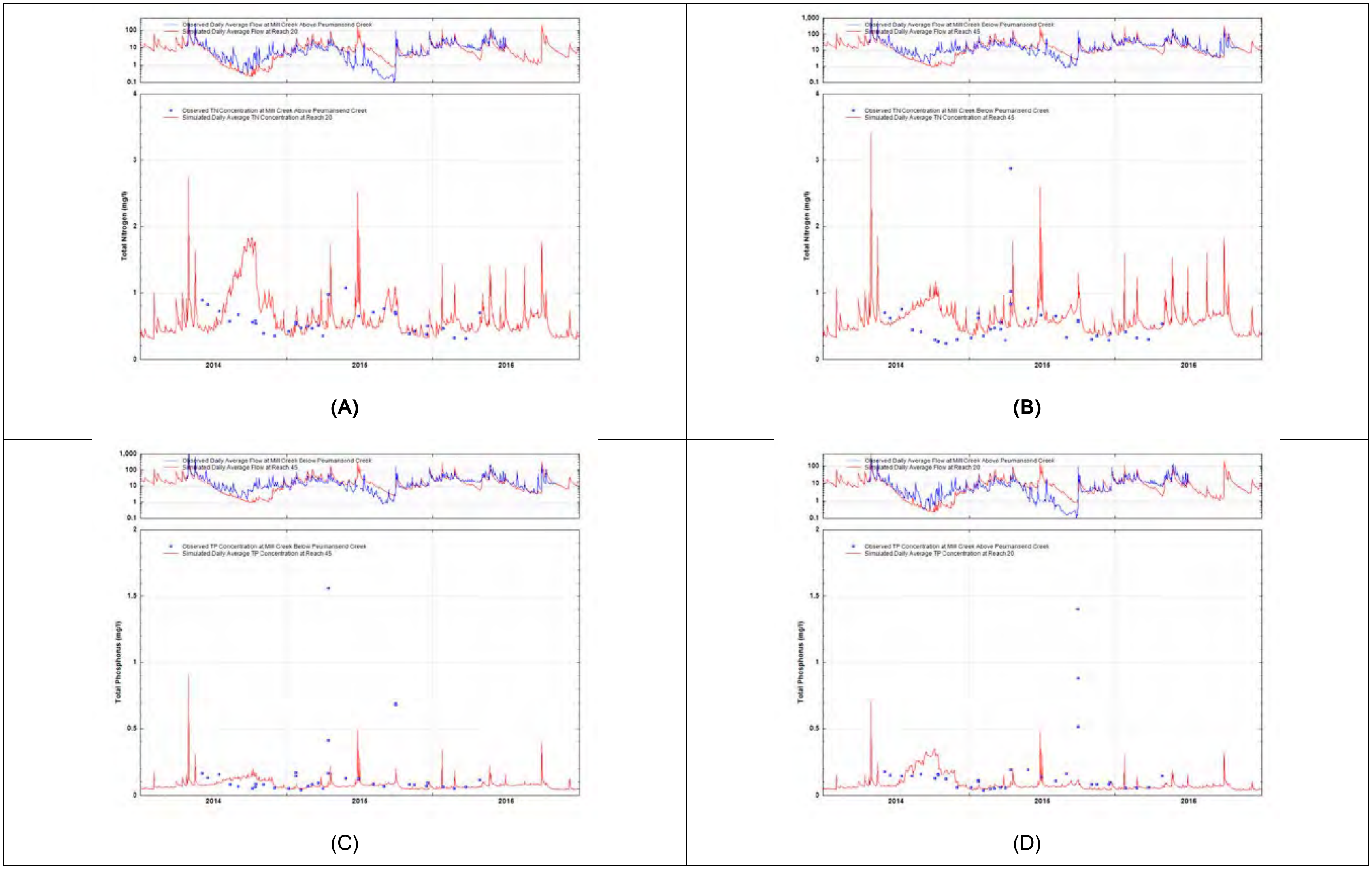


Figure 3-15. Observed and Simulated Total Nitrogen Concentration at (A) Mill Creek Above and, (B) Below Peumansend Creek. Observed and Simulated Total Phosphorus Concentration at (C) Mill Creek Above, and (D) Below Peumansend Creek.

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4.0 FORT AP HILL TASK 3: ASSESSMENT AND COMPARISON OF MODEL LOADING RATES

4.1 INTRODUCTION

The FAPH installation needs to meet TMDL requirements established by the USEPA CBP as defined by their Phase 5.3 Model, which is also based on the US EPA HSPF model. The NDCEE, operated by Concurrent Technologies Corporation (CTC), used the Phase 5.3 Chesapeake Bay Watershed Model, developed by the CBP along with several other partners, for the FAPH installations as part of a TMDL baseline assessment pilot study [NDCEE, 2011]. The NDCEE used Phase 5.3 Model to generate land use loads and loading rates in an effort to anticipate current condition loads to be established by the regulatory community. The NDCEE Phase 5.3 Model results were compared to the FAPH HSPF loading rates to assess consistency and/or differences between the two model applications to provide the basis for use of the FAPH results to meet the TMDL regulatory requirements for TSS, TN, and TP loadings.

4.2 METHODOLOGY FOR COMPARISON OF LOADING RATES

The land use aggregation scheme implemented by the NDCEE analysis resulted in four land use categories: Impervious Urban, Pervious Urban, Forest, and Agriculture and Other. To ensure a one-to-one comparison, to the extent possible, only relevant HSPF land uses were selected and the comparison to the Phase 5.3 Model is shown in Table 4-1. The land use loading rate comparison between the FAPH HSPF watershed model and the NDCEE Phase 5.3 Model is provided in Table 4-2, along with the FAPH/CBP ratios of the loading values.

Table 4-1. HSPF to NDCEE Phase 5.3 Model Land Use Linkage

FAPH HSPF Land Use	CBP Phase 5.3 Land Use
P_Hay/Cropland	Ag/Other
P_Undisturbed Forest	Forest
P_Wetland	
I_Urban/Cantt. Low Int	Impervious Urban
I_Urban/Cantt. Med/Hig	
P_Urban/Cantt. Low Int	Pervious Urban
P_Urban/Cantt. Med/Hig	

Table 4-2. Land Use Loading Rate Comparison Between FAPH and CBP Models

Land Use	HSPF Watershed Model			CBP Phase 5.3 Model			Ratio: HSPF/CBP Phase 5.3		
	TSS (lb/ac/yr)	TP (lb/ac/yr)	TN (lb/ac/yr)	TSS (lb/ac/yr)	TP (lb/ac/yr)	TN (lb/ac/yr)	TSS	TP	TN
Ag/Other	602	1.46	6.76	203	1.38	5.94	2.97	1.06	1.14
Forest	149	0.29	2.00	16	0.08	1.08	9.31	3.63	1.85
Impervious Urban	709	0.83	6.80	568	1.39	3.67	1.25	0.60	1.85
Pervious Urban	336	0.38	2.83	78	0.29	2.72	4.31	1.31	1.04

4.3 RESULTS DISCUSSION

Table 4-2 shows the FAPH HSPF model generally produces higher loading rates for all constituents and land uses except for Impervious Urban TP. Although there are some large discrepancies, both models follow similar trends on a relative basis (e.g., for TSS, Impervious Urban > Ag/Other > Pervious Urban > Forest). Also, the HSPF/CBP ratios of the loading rates are generally within a factor of 2, which is generally considered reasonable agreement for land use based loading rates. Exceptions to this are for the TSS loading rates and, as noted above, the TP loading rate for Impervious Urban. Some explanations and discussion of these differences are provided below.

- The scale of the two models is vastly different, with the FAPH model including 41 subwatersheds compared to 3 in the CBP Phase 5.3 Model for the FAPH watersheds.
- The Model land uses also differ with the FAPH including military-type land uses of trailing ranges, disturbed an undisturbed forest, paved roads, and 2 categories of urban land. In an attempt to provide a consistent comparison, we limited the loading rate comparison to the common land use categories in each model.
- The meteorological forcing data was also different; HSPF uses gridded NLDAS data compared to National Weather Service station data for the CBP Phase 5.3 Model.
- The simulation period for the FAPH HSPF model covers 2014–2016 compared to a much longer period of 1985–2005 for the Phase 5.3 Model.
- The CBP Phase 5.3 Model was not calibrated to any data points within the FAPH installation, whereas the FAPH HSPF model was specifically calibrated, although for a limited time period, to specific sites within the Installation, with data specifically collected for this purpose.

In summary, although there are differences between the loading rates for these two model applications, it is clear that the model results are mostly consistent and that the smaller-scale FAPH model is likely to be more representative of the actual FAPH Watershed behavior due to its scale of application and use of observed data collected on that watershed.

5.0 FORT AP HILL TASK 8: SMALL-SCALE STORMWATER RUNOFF ANALYSIS DEMONSTRATION

In conjunction with the ESTCP modeling of the FAPH watersheds, a small-scale application was developed to demonstrate how a comprehensive watershed model can be used to analyze stormwater runoff and provide information to aid BMP design and evaluate effectiveness at a local or subwatershed scale. The infiltration/detention pond at the auxiliary Ammunition Supply Point (ASP) located near 12274 Campbell Road was selected for the demonstration. The drainage area consists of a 0.67 acres of gravel parking lot and 0.89 acres of surrounding grassland for a total of 1.56 modified acres. The calibrated FAPH HSPF model and input time-series data were revised to represent and simulate runoff, storage volume, and outflow from the detention pond for 2-year, 10-year, and 100-year, 24-hour storm events, as part of the demonstration.

5.1 METHODS

A new subwatershed and corresponding reach were added to the existing FAPH HSPF model Users Control Input to represent the ASP drainage area, surface characteristics, and detention pond (Reach 805), respectively. The hydrologic characteristics that are associated with pervious and impervious Gravel Roads land uses were used to represent the gravel parking lot, and the impervious area was set using the surrounding subwatershed's (i.e., reach 800) percent impervious for Gravel Roads (5.3%). The hydrologic characteristics for Hay/Cropland HSPF land use were used to represent the grassland area as that was the closest category for turf/grass areas in the model.

A rating curve (discharge/volume/area as a function of depth/stage) was developed for the detention pond using the Post Construction Hydrology (Sheet ID CG698) and Dry Swale Details (Sheet ID CG501) designs [Mason and Hanger, 2015]. The final rating curve is shown in Table 5-1. The design sheets and following assumptions were made to calculate the surface area and volumes for each storage zone so that the total storage matched the 3840 cubic feet provided in the design:

1. Storage within the engineered soil
   a) Average dimensions of 130' × 8' × 21"
   b) Composite porosity of 25% [Freeze and Cherry, 1979]
2. Storage directly above soil to the bottom of the pipe drain with beehive grate inlet
   a) Average dimensions of 130' × 8' × 21"
3. Storage from bottom of beehive grate to top of beehive grate
   a) Assumed to be 5" over the average dimensions, from drawings
4. Storage above the beehive drain inlet to the base of the overflow weir
   a) Using the remaining available volume and the average dimensions of 130' × 20', a depth of 0.64 was calculated (Note: This seemed to be a small depth but no other info/ data was available.)
5. Volume and surface areas at incremental depths were calculated using linear interpolation and extrapolation

6. Compare simulated and observed instream concentrations at each of the calibration stations, and compare simulated and estimated loads where available
7. Analyze the results of comparisons in steps 2, 3, and 4 to determine appropriate instream and/or nonpoint parameter adjustments needed until model performance targets are achieved.

Table 5-1. Surface Area, Volume, and Flow for the ASP Detention Pond at Incremental Depths

Storage Zone	Depth (ft)	Area (sq ft)	Volume (cu-ft)	Flow (cfs)
Bottom of underdrain	0	0	0	0
	0.50	1040	130	0.0658
	1.00	1040	260	0.132
	1.50	1040	390	0.197
Top of soil	1.75	1040	455	0.230
	1.90	1391	543	0.250
	2.00	1625	601	0.263
Bottom of beehive grate	2.08	1820	650	0.274
	2.10	1832	701	0.310
	2.12	1847	761	0.389
	2.15	1869	852	0.553
Top of beehive grate	2.50	2129	1914	4.55
Start of weir	3.14	2600	3840	17.3
	3.20	2726	3916	18.6
	3.30	2830	4175	20.1
	3.50	3037	4692	23.6
	4.00	3553	5985	34.6
	5.00	4587	8570	63.2
	10.0	9754	21498	285
	20.0	20088	47353	984

The flow rate through the engineered soil to the perforated drain pipe was calculated using Darcy's Law [Freeze and Cherry, 1979] where flow is a function of hydraulic conductivity, head, cross-sectional area, and length of flow path. The area and flow path length were derived from the engineered soil dimensions, and the hydraulic conductivity was assumed to be 100 ft/day [Freeze and Cherry, 1979]. The flow rate into the catch pipe with beehive grate was calculated at each depth using either the sharp-crested weir or orifice flow equation [Gupta, 2008]. The limiting or lesser value from the two equations was set as the flow rate (orifice flow became limiting at 1.12 feet above the beehive grate weir). It was assumed that the effective flow length was 50% of the circumference due to the beehive grate. The energy equation was used to calculate the maximum flow rate through the 4-inch drain pipe at each depth assuming no head loss and laminar flow [Gupta, 2008]. It was determined that the flow rate into the pipe catchbasin was not limited by the drain pipe. **Also, we assumed the flow rate out of the vertical drainpipe (with the beehive grate) was also a 4-inch-diameter pipe at the same elevation as the lateral drains (Note that we had no information to confirm this outlet pipe but assumed it existed because that is normal practice for drains of this type.)** The flow rate out of the overflow weir was calculated using the broad-crested weir equation assuming the length of the spillway was 5 feet and did not change with depth.

Three 24-hour artificial storms were evaluated: (1) for a 2-year return period (3.5 inches), (2) a 10-year return period (5.5 inches), and (3) a 100-year return period (7.7 inches). The total volume for each of these storms was obtained from a separate analysis performed elsewhere at FAPH [Webb and Associates, 2016]. Each storm was distributed over the 24-hour period at 5-minute intervals following methods (e.g., SCS Storm type) provided in AQUA TERRA Consultants, [2009] and Donigian et al. [2011]. The storm events were introduced into the model's precipitation record (one at a time for each of the analyses) on 10/10/2016 after two significant precipitation events. The conditions at the end of the simulation on 10/9/2016 were used as initial boundary conditions for the simulation of the artificial storms, representing relatively full soil moisture conditions after the historic storms. Once the WDM was updated with the storms and the boundary conditions were set, the model was run on a 5-minute time-step to analyze the detention pond behavior.

5.2 RESULTS AND DISCUSSION

The three storm events were run in HSPF to evaluate the effectiveness of the ASP BMP. The main focus for this application was determining peak flow rate out of the ASP detention pond and the maximum storage required for each storm. The peak flow rates were 0.605, 1.58, and 2.52 cfs for the 2-year, 10-year, and 100-year storms, respectively. The required storage volumes were 868, 1126, and 1374 cu-ft for the 2-year, 10-year, and 100-year storms, respectively. The flow and storage volume results are also shown graphically in Figure 5-1.

Using only the developed rating and simulated storage volume data, it was determined that the existing detention pond can easily handle a 100-year, 24-hour storm event because the storage required (1374 cu-ft) never exceeded the storage provided based on the stated design volume (3840 cu-ft). We can also determine at what point and for how long flow into the pipe catch basin occurs because flow into the pipe occurs when the volume in the detention exceeds 650 cu-ft (obtained from the rating curve). Using the 2-year event as an example, flow into the pipe begins at 12:00 noon (total storage volume of 663 cu-ft) and ends at 13:25 pm (total storage volume of 642 cu-ft).

This application demonstrates how the existing watershed model can be used to analyze storm events at a small scale anywhere in the model domain. It can be used to determine pre-construction conditions, evaluate existing BMP effectiveness, and provide recommendations for future designs. It can also be used to run scenarios. For example, with the ASP application, the storm intensity and duration could be increased to determine what type of storm event would result in water overtopping the overflow weir.

Note that the behavior of the detention pond depends entirely upon the design specifications that we were able to extract from the design drawings, and the other assumptions noted above, because some of the needed details were not available in the drawings. **Before these results are used for any further analyses by the Installation, the assumptions should be confirmed by either on-site inspections or consultation with the design engineers.**

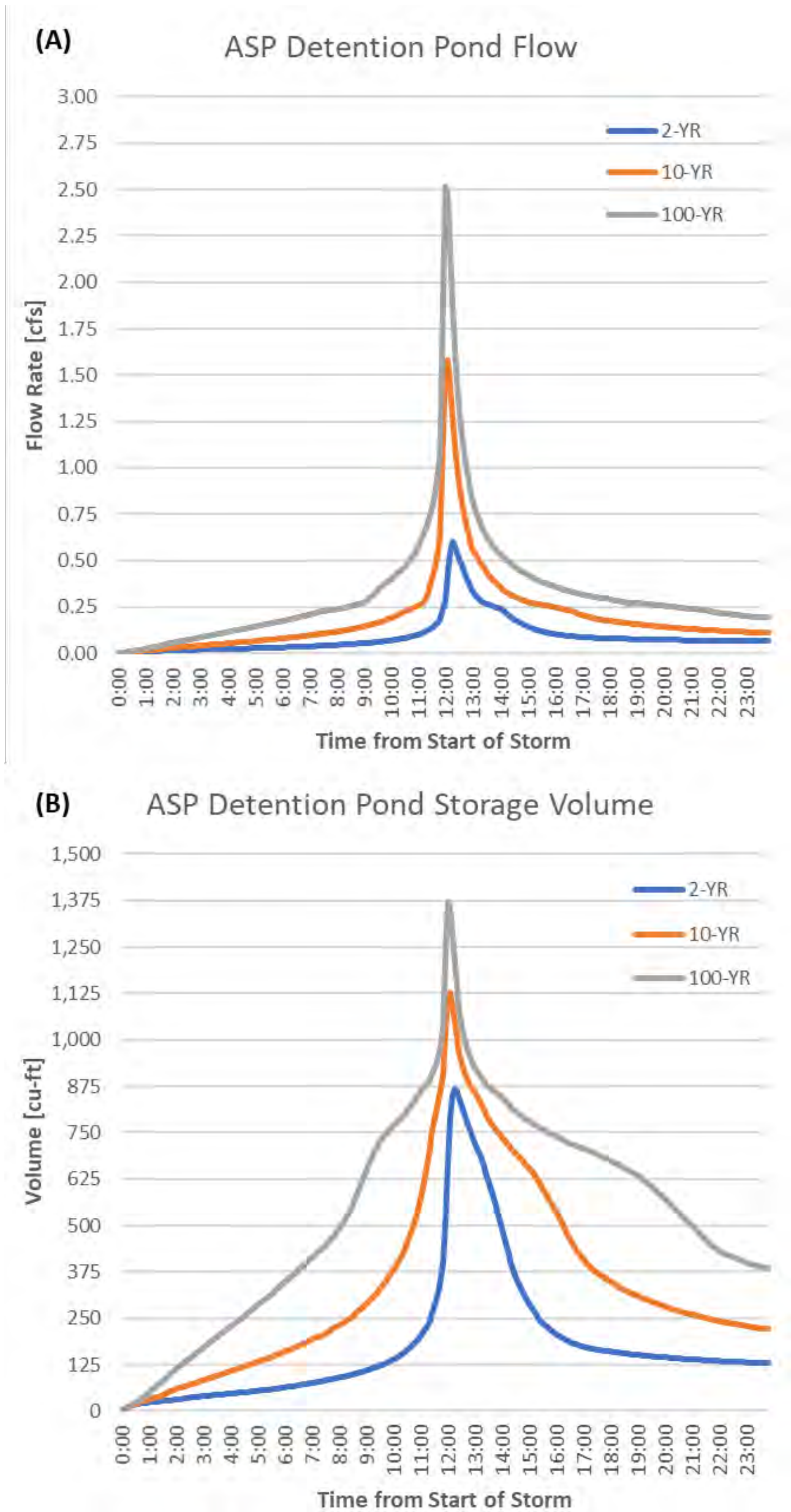

Figure 5-1. Flow Rate Out of the Detention Pond (A) and Storage Volume Within the Detention Pond (B) for Each Storm Simulation.

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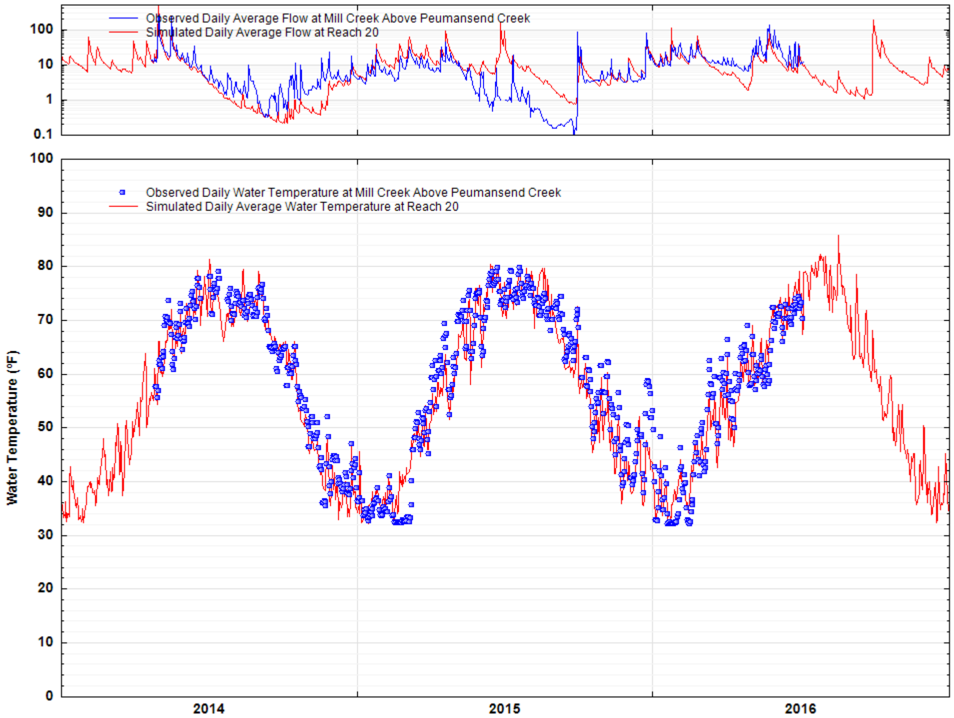
APPENDIX A: ADDITIONAL WATER QUALITY CALIBRATION RESULTS



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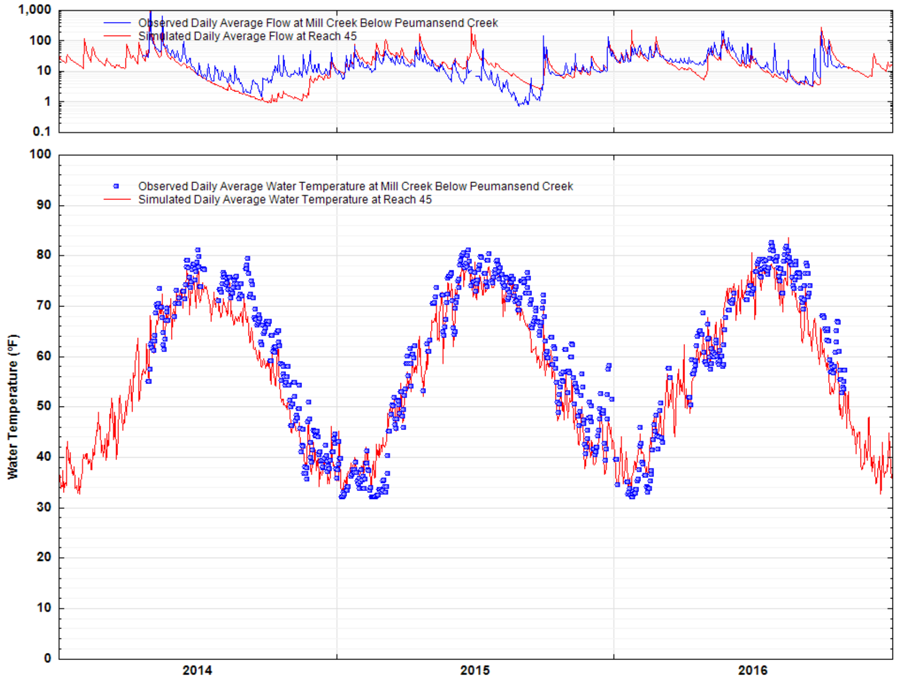
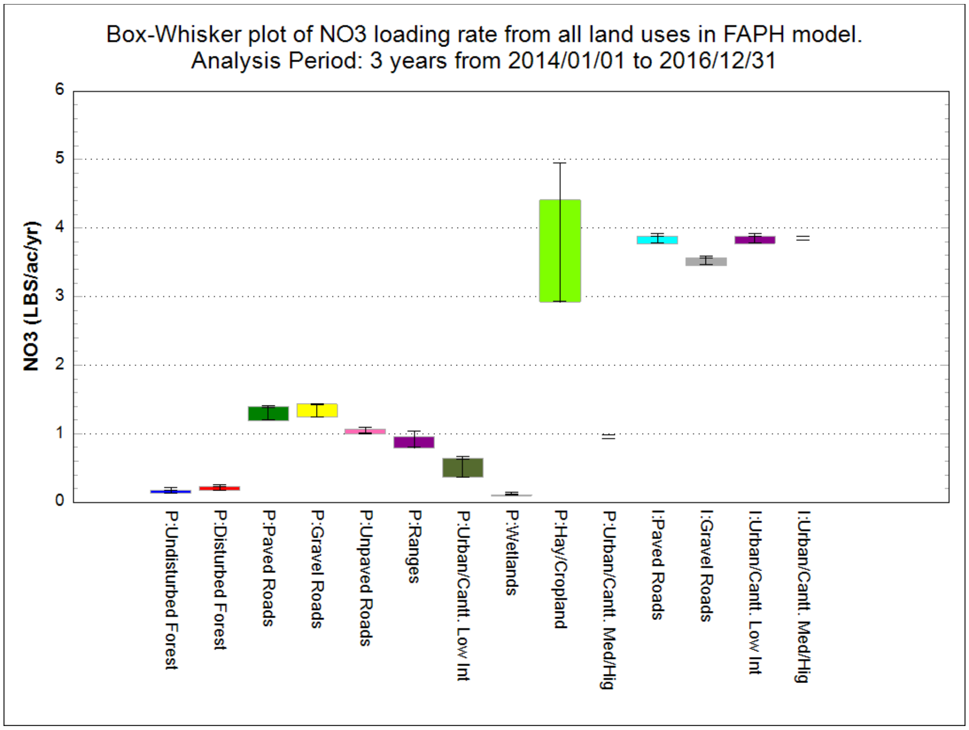


(B)

Figure A-1. Observed and Simulated Hourly Water Temperature (Degrees Fahrenheit) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.



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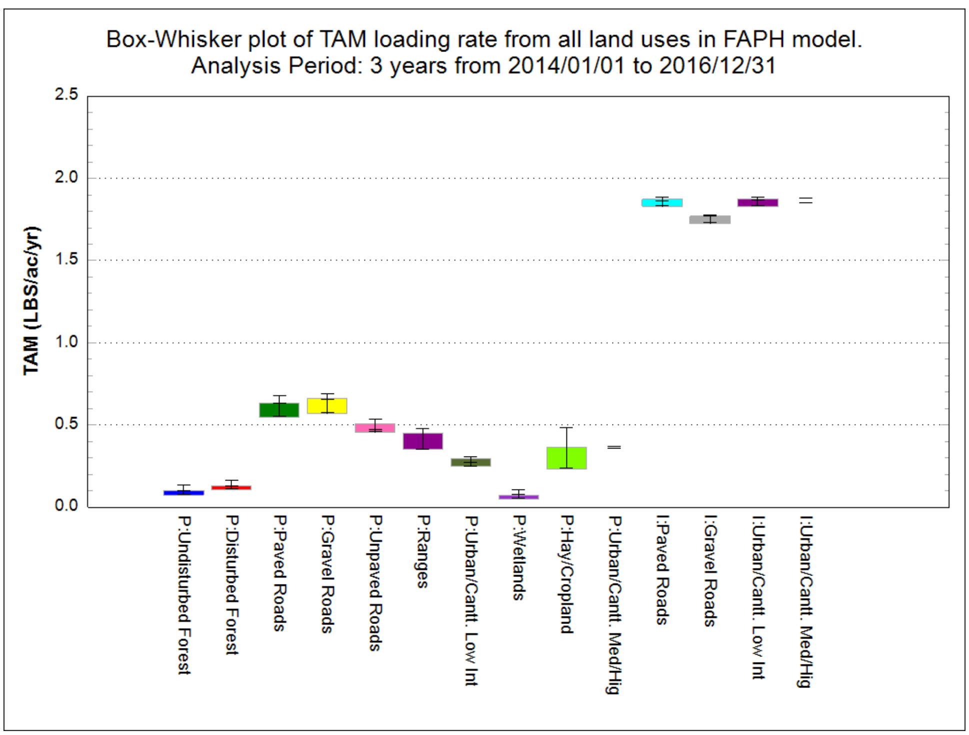


(B)

Figure A-2. Box-Whisker Plot of Loading Rates (Pounds/Acre/Year) of (A) Nitrate and (B) Total Ammonia From all the Land Uses in the FAPH Watershed.

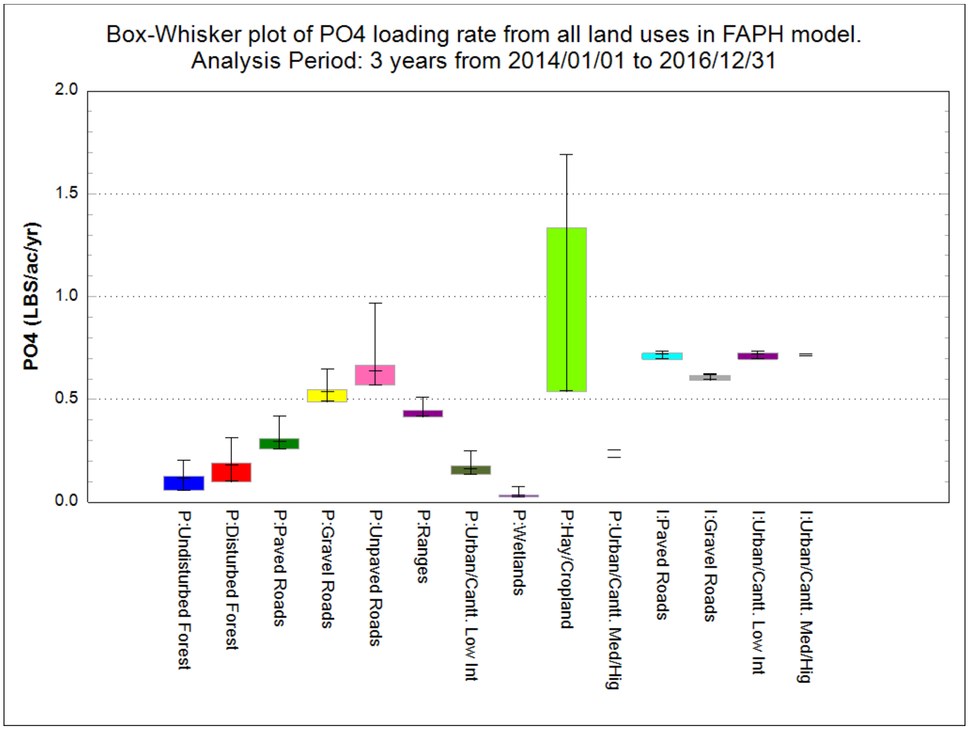
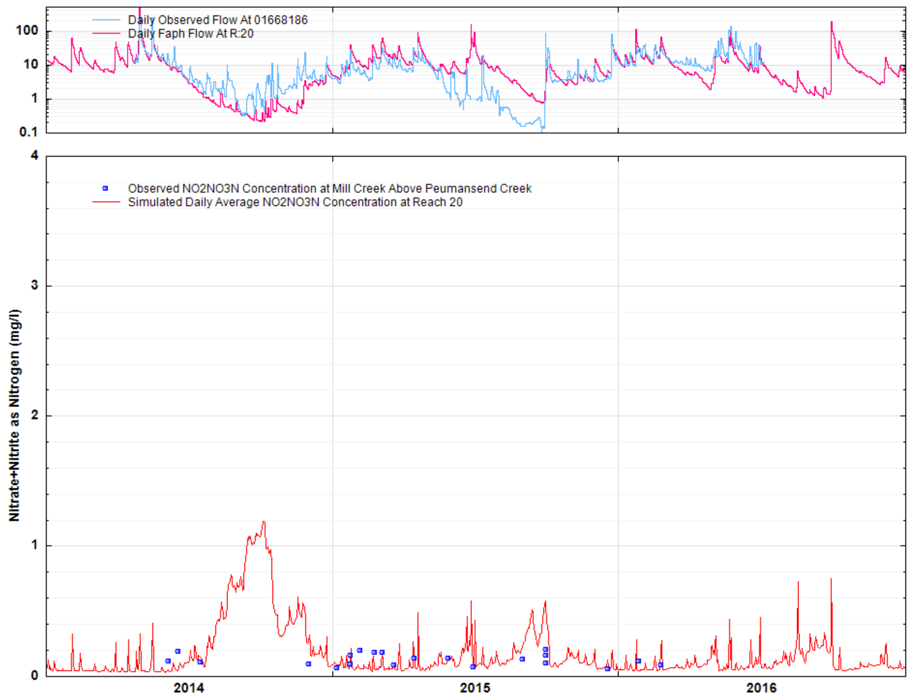


Figure A-3. Box-Whisker Plot of Loading Rates (Pounds/Acre/Year) of Orthophosphate From all the Land Uses in the FAPH Watershed.



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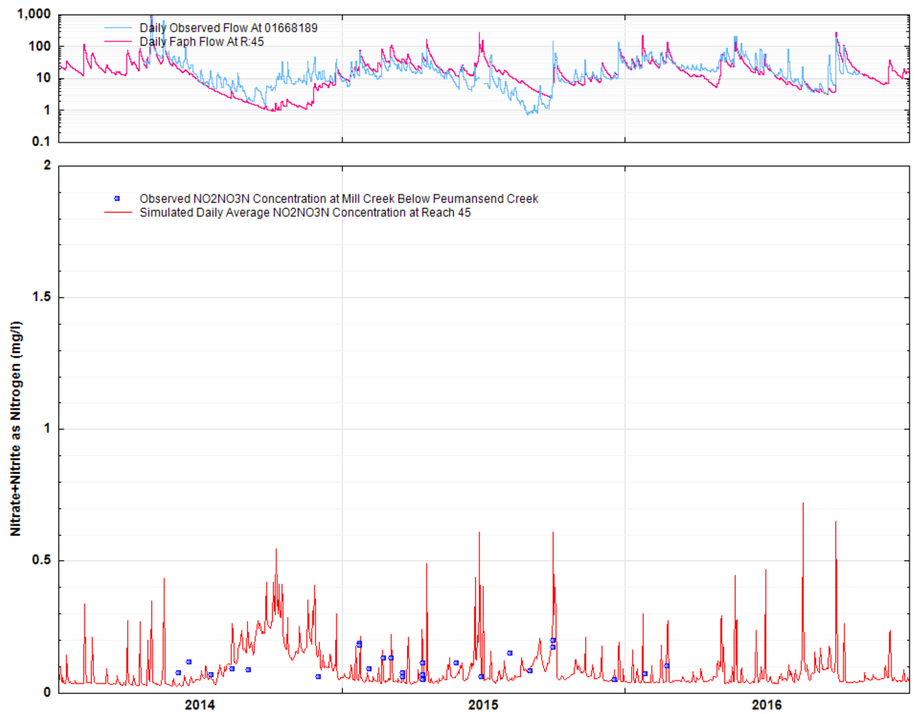
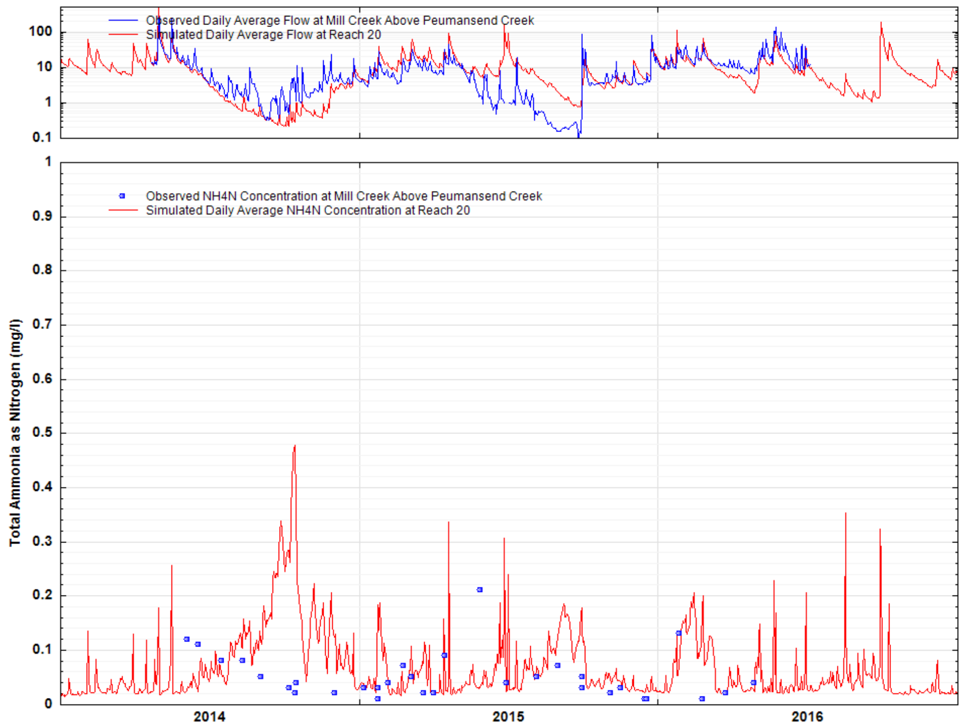


(B)

Figure A-4. Observed and Simulated Daily Average Nitrate-Nitrite as Nitrogen (Mg/L) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.



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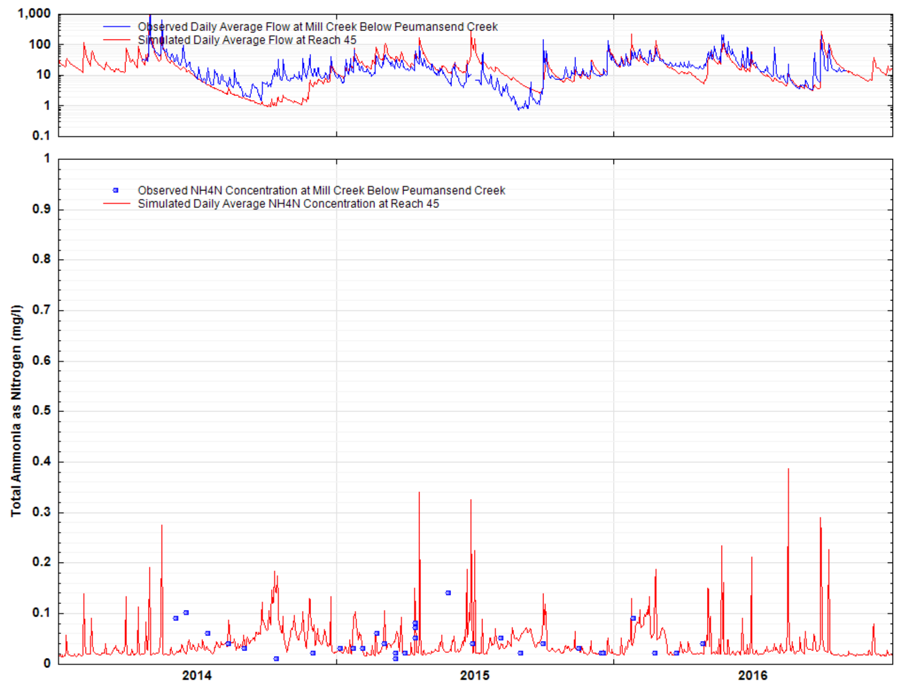
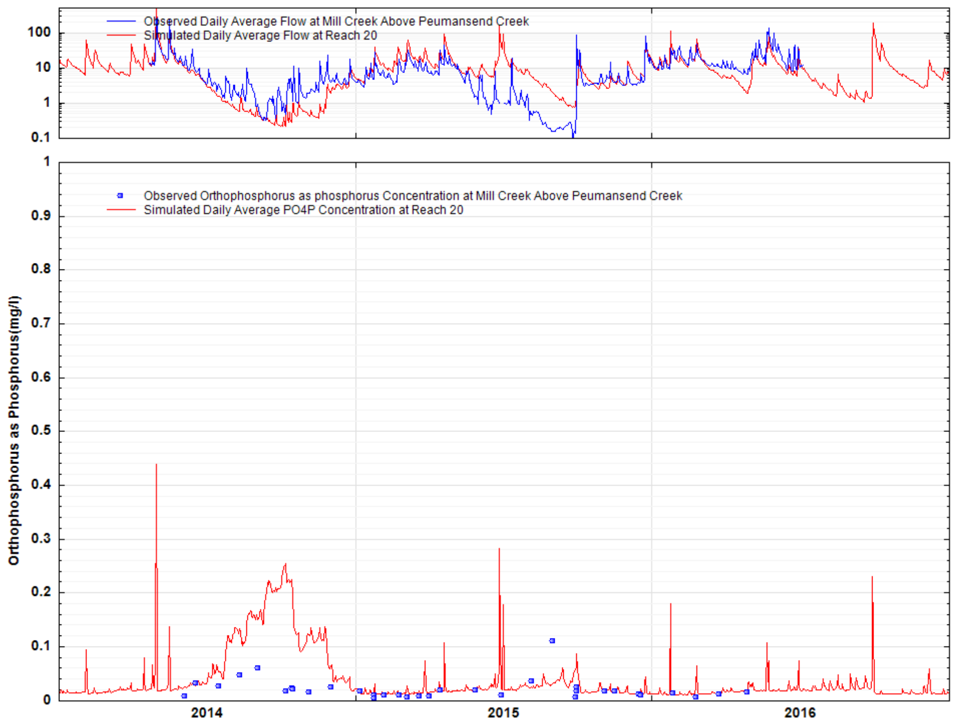


(B)

Figure A-5. Observed and Simulated Daily Average Total Ammonia as Nitrogen (Mg/L) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.



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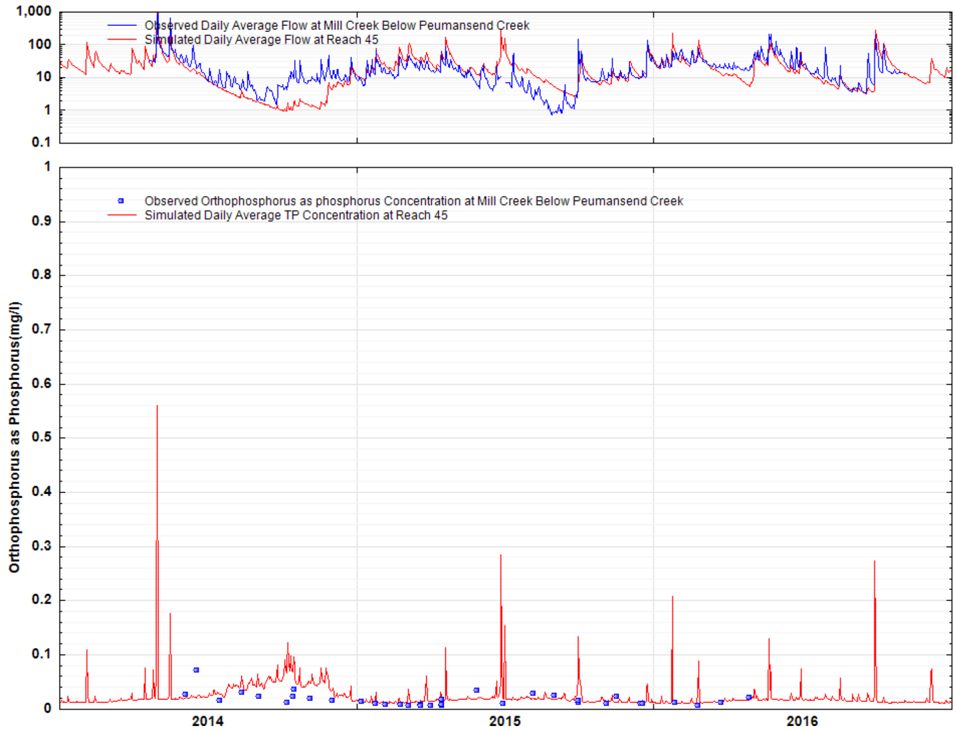

(B)

Figure A-6. Observed and Simulated Daily Average Orthophosphate as Phosphorus (Mg/L) at (A) Mill Creek Above Peumansend Creek, and (B) Mill Creek Below Peumansend Creek.