

# **Chatfield Watershed**

## **Model Selection Technical Memorandum**

*prepared for*  
Chatfield Watershed Authority

*prepared by*  
Leonard Rice Engineers  
1221 Auraria Parkway  
Denver, Colorado 80204

*and*

Lynker Technologies  
5485 Conestoga Ct. Suite 220  
Boulder, Colorado 80301

September 15, 2015

TABLE OF CONTENTS

---

1.0	INTRODUCTION.....	1
1.1	Modeling Overview .....	1
1.2	Model Capabilities .....	2
2.0	MODEL SELECTION PROCESS .....	3
2.1	Initial Model Screening .....	3
2.2	Refined Model Screening .....	6
2.3	Model Selection Workshop.....	11
2.4	Final Model Analysis.....	11
3.0	CONCLUSIONS AND RECOMMENDATIONS.....	14
3.1	Model Selection Overview .....	14
3.2	Final Recommendation - HSPF.....	15
4.0	REFERENCES.....	16
	Appendix A.....	A-1

TABLE OF TABLES

---

Table 1:	Types of Models.....	2
Table 2:	Model Overview .....	3
Table 3:	Model Overview .....	7
Table 4:	Model Ranking Legend .....	7
Table 5:	Model Details .....	8
Table 6:	Watershed and Channel Functions.....	9
Table 7:	Water Quality and BMPs.....	10

TABLE OF FIGURES

---

Figure 1:	Chatfield Watershed with HUC-12 Subwatersheds .....	12
Figure 2:	Initial Model Selection.....	14
Figure 3:	Model Refinement.....	14
Figure 4:	Final Model Determination .....	15

## 1.0 INTRODUCTION

---

The Chatfield Watershed Authority (CWA) requires the development of a non-proprietary watershed model to help determine nutrient loading, particularly phosphorus, from the watershed to Chatfield Reservoir. Watershed models can be effective tools for investigating the complex nature of processes that impact surface and subsurface hydrology, sediment movement, and the transport and fate of organic and chemical constituents in watersheds. In the past 20 years, many models have been developed to simulate watershed-scale processes and the hydrologic impacts of different management scenarios. A watershed model can be used to achieve a better understanding of the impact of land use activities and different management practices on these hydrologic processes. Due to advances in GIS and the availability of spatial data, more and more semi-distributed models have been developed and tested. Selecting the 'best' model to simulate selected processes and management concerns of a specific watershed has thus become a challenge. To select an appropriate model for this project, the modeling team researched in detail a comprehensive array of watershed models in order to narrow down the possibilities and finally to recommend the best model for the project. This technical memorandum describes the model selection process and the recommendation to use the HSPF model.

### 1.1 Modeling Overview

Hydrologic models are commonly divided by their structural, spatial, and temporal framework as listed below. This project focused on deterministic, semi-distributed, continuous models for application to the Chatfield watershed.

**Model Structure:** deterministic versus stochastic

- **Deterministic models** use physically-based or empirically based equations as the structure of the model. These types of models are given an input to provide a single output.
- **Stochastic models** use random variables to provide an array (ensemble) of statistically reasonable results. The focus of stochastic models is to simulate the range of variability within a system.

**Spatial Model Types:** lumped versus distributed

- **Lumped models** use a single set of parameters for an entire model watershed.
- **Distributed models** divide the model domain (watershed) into evenly spaced grid cells, where each grid cell is individually parameterized
- **Semi-distributed models** form a compromise between the complexity of the lumped and distributed models. These models may be parameterized to the level of detail available to the modeler and then parameters are commonly averaged to a larger model scale.

**Simulation Types:** event versus continuous

- **Event-based models** are used to simulate a single event, which is usually a runoff (storm) event.
- **Continuous models** are used to simulate a long temporal domain. These models are typically run for two or more years at a daily or monthly time step.

This conceptual description of models can be complimented by a list of actual models and the types of questions they can answer. Some common types of water resources models include watershed models, in-stream water quality models, erosion models, and hydraulic models as shown in Table 1.

**Table 1: Types of Models**

Model Type	Examples	Purpose	Example Project Questions
<b>Watershed</b>	HSPF, SWAT	Simulate hydrologic and water quality processes within a watershed	-What are sources of loading within a watershed? -What are loading rates within a watershed?
<b>In-Stream Water Quality</b>	QUAL2K, QUAL2E	Simulate stream water quality.	-How does DO change throughout the day?
<b>Erosion</b>	ANSWERS, CREAMS, WEPP	Simulate erosion and transport of sediment within a watershed.	-What is the sediment load in a watershed?
<b>Hydraulic</b>	HEC-RAS	Simulate 1-d flow simulation and sediment transport.	-What is the scour at a bridge? -What is the stream power?

## 1.2 Model Capabilities

This project requires a model that meets the following objectives:

- Determine nutrient loading in Chatfield Watershed, with particular emphasis on phosphorus,
- Determine phosphorus inputs to Chatfield Reservoir, taking into consideration the fate and transport of phosphorus to Chatfield Reservoir, including rate of loading (flow proportional loading), and timing (seasonal and storm intensity variability),
- Prediction of pollutant load, trends in the concentrations, and assimilative capacity under potential management scenarios, relative to flow characteristics,
- Partitioning of phosphorus loads, as appropriate, between sub-basins for purposes of TMAL development, and
- Source identification by land-use and sub-basin, and where appropriate, specific activities which may be potential source problems.

These requirements focused the model selection efforts on **watershed models**.

## 2.0 MODEL SELECTION PROCESS

---

A two tier-process was used in the determination of an appropriate watershed model for this project: an initial screening process and a refined screening. The goal in the initial screening was to reduce ten potentially useful models to three models, which could then be analyzed in detail for the second phase of the model selection. The initial model screening is discussed in Section 2.1 and the refined model screening is discussed in Section 2.2. This information was presented to the CWA in a model selection workshop, which is discussed in Section 2.3. The model selection workshop helped develop additional questions regarding specific functionality of the final candidate models. These questions and their answers are provided in Appendix A, while an in-depth analysis of model features is discussed in Section 2.4.

### 2.1 Initial Model Screening

In the initial model screening a wide array of watershed models were considered and weighed on general model requirements. The models were categorized by complexity (high, medium, and low complexity) as well as whether they could simulate water quality processes. A brief summary and analysis of each model's potential to the Chatfield watershed project was conducted. This initial analysis reduced the models to HSPF, SWAT, and WARMF. The ten models initially analyzed are included in Table 2 and discussed in further detail below.

**Table 2: Model Overview**

Model	Model Complexity	Water Quality Model
AGNPS	Moderate	Yes
GWLF-E/Mapshed	Moderate	Yes
HEC-HMS	Moderate	No
HSPF	High	Yes
LSPC	High	Yes
N-SPECT	Low	Yes
PLOAD	Low	Yes
SWAT	Moderate	Yes
SWMM	Moderate	Yes
WARMF	Moderate	Yes

#### **AGNPS**

AGNPS is a good quality watershed model developed by the United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) originally for the purposes of event-based modeling of agricultural fields. As computing power and watershed modeling applications increased, the model was transitioned to a continuous simulation model. It is currently coupled with AnnAGNPS for use in pollutant load modeling, both of which are NRCS models. Although AGNPS simulates watershed processes well many of its features are unclear due to poor documentation, such as in-stream nutrient transformations, use of BMPs, and atmospheric deposition. Additionally, the model has been applied less frequently to TMDL-type projects than its competitor models, HSPF and SWAT. AGNPS was not considered for further evaluation due to the better fit of HSPF, SWAT, and WARMF. The model website can be found here: <http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042468>.

### ***GWLF-E/Mapshed***

The Generalized Watershed Loading Function (GWLF-E) model was developed at Penn State University and has seen acceptance by the United States Environmental Protection Agency (USEPA) due to its compatibility with the graphical user interface (GUI) and model framework BASINS. The model is more basic in its representation of a watershed than the HSPF and SWAT models and was therefore removed from the short-list of models. The model website can be found here: <http://www.mapshed.psu.edu/>.

**Basins** is the Better Assessment Science and Integrating point & Non-point Sources tool. It is designed to help collect the data necessary to run a watershed model. It has a GIS and GUI interface and can be used with HSPF, SWATT, SWMM, GWLF-E, and PLOAD. It can be found on the USEPA website here: <http://water.epa.gov/scitech/datait/models/basins/index.cfm>

### ***HEC-HMS***

This model was developed by the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) and was included in this review only for completeness. HEC-HMS is a commonly known lumped watershed model that is frequently used in engineering simulations. However, HEC-HMS does not simulate water quality and for this reason it was removed from the model selection. The model website can be found here: <http://www.hec.usace.army.mil/software/hec-hms/>.

### ***HSPF***

The Hydrologic Simulation Program – Fortran (HSPF) model was developed from the EPA Agricultural Runoff Management (ARM) model, the EPA Nonpoint Source Runoff (NPS) model, and the Hydrologic Simulation Program (HSP) (Aqua Terra, 2015). It is used for alternative scenario analysis of continuous long-term watershed simulation. HSPF can be run at time steps of minutes, hours or days and is commonly used in TMDL projects. This model was included in the short-list of watershed models for further review by the CWA. The model is currently hosted on the USEPA website as a part of the BASINS modeling framework here: <http://water.epa.gov/scitech/datait/models/basins/index.cfm>

### ***LSPC***

The Loading Simulation Program C++ (LSPC) model is a port of HSPF, which was written in FORTRAN, to a more current programming language C++. The model is for all intents and purposes a copy of the HSPF model; however there is some uncertainty on the conversion of water quality algorithms from HSPF to LSPC. This is discussed further in Appendix A, question 6. The HSPF model was chosen over the LSPC model since it has a more complete set of tools (including a BMP toolkit) and has the original model algorithms. LSPC has gained acceptance of the USEPA since it is hosted on its “Watershed Models” website which can be found hosted here: <http://www.epa.gov/athens/wwqtsc/html/lspc.html>.

### ***N-SPECT***

The nonpoint-source pollution and erosion comparison tool (N-SPECT) was developed by the National Oceanic and Atmospheric Administration (NOAA) for analyzing runoff nonpoint source pollutant loads. The model was built as a screening tool and can be used as an event-based model or annual model. The model has a spatial component and can be run using

Environmental Systems Research Institute (ESRI) ArcGIS software with the spatial analyst extension. Since N-SPECT is not a continuous model operated at a daily time step, it was removed from the final model selection. Additionally, the model does not allow the input of point source loads, which is important for accurate modeling of the Chatfield watershed. The model website can be found here: <http://coast.noaa.gov/digitalcoast/tools/opennspect/arcgis-versions>.

### ***PLOAD***

PLOAD is a simplified model used for the determination of annual pollutant nonpoint source loads. This model was removed from the final selection since it only produces output on an annual time step. The PLOAD model can be found hosted with the BASINS model here: <http://water.epa.gov/scitech/datait/models/basins/bsnsdocs.cfm>.

### ***SWMM***

Similar to HEC-HMS, the Stormwater Management Model (SWMM) was reviewed within the technical memorandum for completeness due to its widespread use. SWMM is a continuous simulation model that can be run at a daily or sub-daily time step but it can also be used to simulate single runoff events. However, its primary application is for urban watersheds, where planning for pipes and detention basins is needed to offset changes in runoff from urban development. Since the Chatfield watershed is dominated by national forest land, open space, and agricultural land, the SWMM model was not a good choice for the project. Models such as HSPF, SWAT, and WARMF incorporate topography, land use, and soils data to accurately represent the project watershed. The SWMM model can be found at the USEPA website here: <http://www2.epa.gov/water-research/storm-water-management-model-swmm>.

### ***SWAT***

The Soil and Water Assessment Tool was developed by J.G. Arnold at Texas A&M University with research support from the USDA Agricultural Research Service (ARS) to simulate pollutant yields from land management practices in ungaged watersheds. SWAT was developed from the SWRRB model (Simulator for Water Resources in Rural Basins), which was based on individual models including CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), and EPIC (Erosion-Productivity Impact Calculator). These models were developed by or in coordination with research teams from the USDA (Neitsch et al., 2011). The model enjoys worldwide use and continuous development especially in the academic community due to its open source code and annual user's conference. This model was included in the short-list of watershed models for further review by the CWA. The model website can be found here: <http://swat.tamu.edu/>.

### ***WARMF***

The Watershed Analysis Risk Management Framework (WARMF) was developed by Systech Water Resources, Inc. under the sponsorship of Electric Power Research Institute, Inc. (EPRI) (Goldstein, 2001). The model enjoys the support of Dr. Arturo A. Keller at the University of California, Santa Barbara who has provided input on the model performance and has prepared user manuals for the model. The model is unique in that it is geared toward stakeholder input and has a GIS application built into the model. It simulates land-based chemical processes proficiently as well as in-stream simulation of nutrients. However, it lacks the detailed model

output that HSPF and SWAT provide. This model was included in the short-list of watershed models for further review by the CWA. The model can be found hosted on the USEPA website here: <http://www.epa.gov/athens/wwqtsc/html/warmf.html>

## **2.2 Refined Model Screening**

The final candidate models HSPF, SWAT, and WARMF were analyzed using 14 different model capability categories. A model's functionality was ranked with a 3 for complete or best performance in this category, 2 for partial or moderate performance in a category and 1 for no support for the category or worst performance in the category. The models were ranked relative to one another since these were the final and best options for the project. For instance, in the category 'Used in TMDL Studies' HSPF and SWAT received 3's for full performance due to the wide acceptance within TMDL projects whereas WARMF received a 2 for moderate performance since it has not been used on as many TMDL projects. The model results are presented in Table 3, with a legend of the model scoring presented in Table 4.

The model ranking gave SWAT a score of 39, HSPF a score of 36, and WARMF a score of 30. While SWAT received the highest score, HSPF and SWAT both exceeded WARMF's ranking. The scoring of the final three candidate models is complemented with a detailed analysis of the major model components, which includes runoff calculation, watershed modeling routines, channel (in-stream) modeling routines, water quality constituents, and additional model features. The general model overview is shown in Table 5, the watershed and channel functions are shown in Table 6, and the water quality and BMPs functions are shown in Table 7.



**Table 3: Model Overview**

<b>Model Functionality</b>	<b>SWAT</b>	<b>HSPF</b>	<b>WARMF</b>
Spatial Component	●	●	◐
In-Stream Nutrient Transformations	◐	●	●
Sediment Transport	◐	●	●
Nutrient Output by Land Use	●	●	○
Used in TMDL Studies	●	●	◐
EPA BASINS Support	●	●	◐
Ease of Use	◐	○	●
Level of Documentation	●	◐	◐
GIS Application	●	●	●
Continuing Development	●	◐	◐
Anticipated Model Support & Updates	●	◐	○
Farming Practices	●	◐	◐
Implement BMPs	●	●	●
Auto-calibration	●	●	○
<b>Total Score</b>	<b>39</b>	<b>36</b>	<b>30</b>

**Table 4: Model Ranking Legend**

<b>Description</b>	<b>Symbol</b>	<b>Points</b>
Model performs well	●	3
Model performs in a limited manner	◐	2
Model performs poorly	○	1

**Table 5: Model Details**

<b>Model Functionality</b>	<b>SWAT</b>	<b>HSPF</b>	<b>WARMF</b>
<b>Model Details</b>			
<b>Model Development</b>	Texas A&M, USDA, open source	Aqua Terra Consultants, USEPA, USGS	Systech, EPRI, USEPA
<b>User Support</b>	Dedicated user groups, FAQs, workshops, conferences, website video training	PowerPoint training presentations, possible email list	Dedicated user group, training manual
<b>GIS Application</b>	ArcSWAT (ESRI), BASINS, MWSWAT (open source)	BASINS	WARMF
<b>Latest Release</b>	SWAT2012, revision 637, 5/18/2015	Version 12.4 pre-release April 2014	EPA version is v.6.1. WARMF 6.5 (5/18/2012) from Systech.
<b>Time Since Model Update</b>	3 months	1.3 years	3.3 years
<b>Overview</b>			
<b>Spatial Disaggregation</b>	Watershed, subwatersheds, HRUs	Watershed, subwatersheds, HRUs	Watershed, Land Catchment
<b>Homogenous Level (land use, soil, etc.)</b>	HRU	HRU	% of land catchment
<b>Runoff/Infiltration Method</b>	SCS Curve Number, Green-Ampt (requires sub-daily precipitation)	Storage based equations (non-linear reservoir)	Hydraulic conductivity
<b>Snow Modeling</b>	Yes	Yes	Yes
<b>Time Step</b>	Daily, sub-daily (requires use of Green-Ampt)	Daily, hourly	Daily
<b>Auto-calibration</b>	SWAT-CUP	PEST	No
<b>Features</b>			
<b>Weather Generator</b>	Yes	No	No
<b>Elevation Bands (for mountainous areas)</b>	Yes, up to 10 elevation bands within a subwatershed to account for orographic effects	Yes, ATEMP modifies using dry and wet lapse rates	Yes, one adjustment made within catchment to account for differences between weather station and land catchment
<b>Ponds and Reservoirs</b>	Yes, ponds are off-channel and reservoirs are on-channel	Yes, reservoirs are on-channel using FTABLES	Yes, reservoirs (CE-QUAL-W2)
<b>Point Source Loading</b>	Yes, daily, monthly, yearly, or average annual loading	Yes, add as time series	Yes, step function loading based on input file dates
<b>Septic Systems</b>	Yes, septic system module added in SWAT2009	Modeled as point sources or lumped to land use	Yes, by population density (standard, advanced, failing)

**Table 6: Watershed and Channel Functions**

Model Functionality	SWAT	HSPF	WARMF
<b>Watershed</b>			
<b>Sediment Erosion</b>	Modified USLE	USLE	Critical shear stress
<b>Evapotranspiration</b>	Penman-Monteith, Priestly-Taylor, Hargreaves method	Jeson, Hanson, Penman, Pan Evaporation	Hargreave's Method
<b>Confined Aquifer</b>	Yes, acts as model sink and allows pumping	Yes	No
<b>Atmospheric Deposition</b>	Nitrogen (dry and wet)	Nitrogen and phosphorus (dry and wet)	Nitrogen and phosphorus (dry and wet)
<b>Nutrient Transport in Watershed</b>	Soluble P in top 10 mm of soil. Organic and mineral P adsorbed to sediment	Phosphate in solution transported with water. Organic P and adsorbed phosphate are removed with sediment	Adsorbed and soluble movement
<b>Channel</b>			
<b>Flow Calculation</b>	Manning's Equation	Stage-discharge or Manning's Equation	Manning's Equation
<b>Flow Routing Methods</b>	Muskingum or variable storage	Kinematic wave of storage-routing method	Kinetic Wave
<b>Sediment Routing Methods</b>	Yes, simplified Bagnold model, Kodatie model, Molinas and Wu model, Yang sand and gravel model	Yes, SANDLD module simulates deposition, scour & transport. Uses Colby Method or Toffaleti's Method for sand	Yes, critical shear stress determines transport or deposition
<b>In-stream Nutrient Transformations</b>	Yes, QUAL2E component	Yes, RCHRES module	Yes
<b>Nutrient Transport</b>	Soluble inorganic P and Organic P. Adsorbed P transport is de-coupled from sediment transport	NH3 and PO4 adsorbed to sediment fractions	Dissolved and adsorbed, partitioned as a function of TSS

**Table 7: Water Quality and BMPs**

Model Functionality	SWAT	HSPF	WARMF
<b>Water Quality Parameters</b>			
<b>BOD</b>	○	●	●
<b>CBOD</b>	●	○	○
<b>DO</b>	●	●	●
<b>pH</b>	○	●	●
<b>Temperature</b>	●	●	●
<b>Sediment</b>	● Sand, silt, clay, small aggregates, large aggregates, gravel aggregates (if physically-based stream power used)	● Sand, silt, clay	● Sand, silt, clay
<b>Nutrients in Channel</b>			
<b>Orthophosphate (PO4) (Soluble P)</b>	●	●	●
<b>Organic (adsorbed) Phosphorus</b>	●	●	●
<b>Total Phosphorus</b>	●	●	●
<b>Organic (adsorbed) Nitrogen</b>	●	●	●
<b>Nitrite (NO2)</b>	●	●	●
<b>Nitrate (NO3)</b>	●	●	●
<b>Ammonium</b>	●	●	●
<b>Total Nitrogen</b>	●	●	●
<b>Algae</b>	○ Suspended algal biomass (phytoplankton)	● Phytoplankton, zooplankton, benthic algae (attached algae)	● Phytoplankton, periphyton
<b>Bacteria Modeling</b>	●	●	●
<b>Pesticide Modeling</b>	●	●	●
<b>Management Practices</b>			
<b>Fertilizer and Manure Applications</b>	● Yes, daily, monthly, automatic or continuous rates	● Yes, application interval specified in subroutine SPECL	○ Yes, applied via monthly loading rates
<b>Grazing operations</b>	●	○	○
<b>Tile drainage</b>	●	○	○
<b>Urban Areas/ Impervious Area</b>	●	●	●
<b>Irrigation Practices</b>	● Yes, manual and auto-application routines	● Yes, manual and auto-application routines	○ Yes, simplified routines
<b>BMPs</b>	● Yes, filter strips, detention pond, street sweeping, etc.	● Yes, filter strips, detention pond, street sweeping, etc.	● Yes, buffer strips, livestock fencing, detention ponds, street sweeping

### **2.3 Model Selection Workshop**

A meeting was held on August 8, 2015 between the CWA and the modeling team to review the available watershed models and help select the best model. A PowerPoint presentation reviewed much of the information from Section 2 of this technical memorandum. A thorough discussion during the meeting quickly turned to a decision between the HSPF and SWAT models. Although SWAT received the highest score according to Table 3, some members of the CWA were less concerned about the user-friendliness of the model (where SWAT surpassed HSPF) and were more concerned with the ability of the model to assess in-stream nutrients (where HSPF's model routines were superior to SWAT's model routines). Many questions were raised about how each model would handle adding BMPs and how they differed in their representation of in-stream nutrient and sediment processes. A list of questions was developed after the meeting that required further input from the modeling consultants. These questions and their respective answers are provided in Appendix A.

### **2.4 Final Model Analysis**

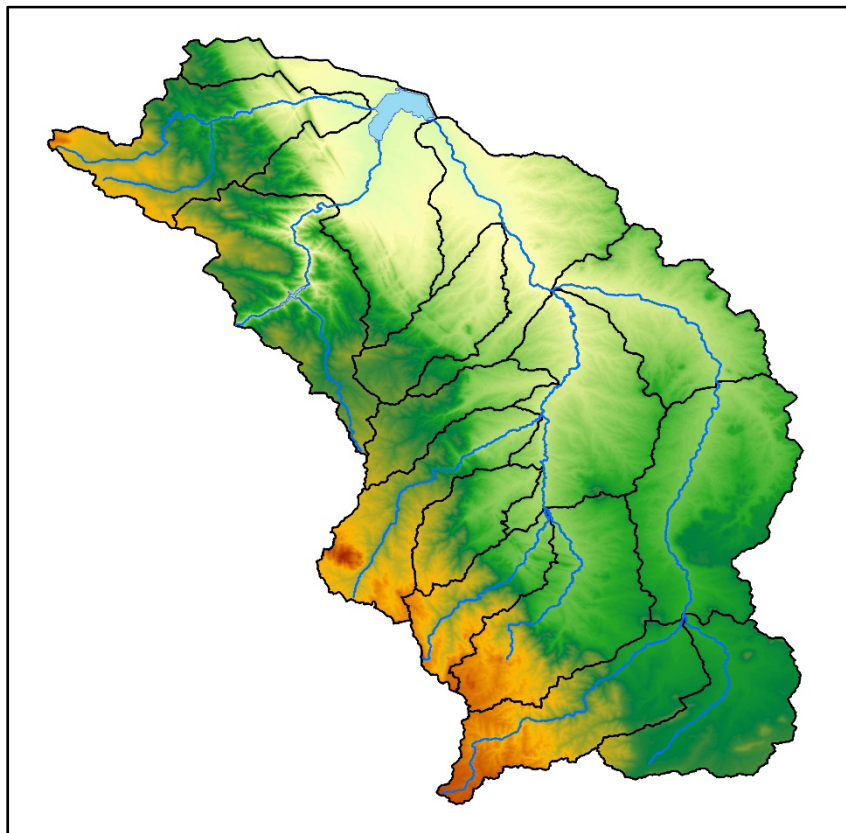
The refined model screening offered an in-depth look into each model's structure to highlight their strengths and weaknesses and further inform the model selection process. In many instances, the model structure for HSPF, SWAT, and WARMF (provided in Tables 5, 6, and 7), was identical or comparable in nature to one another. However, the differences between the models provided the most useful insight as to which model would best fit the needs of the CWA. For this reason the key model differences have been discussed in further detail, which include spatial representation, atmospheric deposition, nutrient transport within the channel, and fertilizer and irrigation practices.

#### ***Spatial Representation***

A watershed model represents the project watershed as one watershed, which can then be subdivided into many subwatersheds (or subbains). HSPF and SWAT further divide subwatersheds into hydrologic response units (HRUs), which are meant to be areas of homogenous (or nearly homogenous) land use and soil type. The output from HRUs are summed together and their total output is the output of the subwatershed. There is no routing from HRU to HRU, rather the routing occurs at the subwatershed scale. HSPF and SWAT both utilize HRUs to further refine the area within a subwatershed whereas WARMF allows only average values of land use and soil within a subwatershed. The consequence of these differences is that HSPF and SWAT can provide model output at the level of the HRU whereas WARMF cannot. This allows pollutant loading to be traced back to land use characteristics. Figure 1 shows the project watershed (Chatfield watershed) divided into subwatersheds using USGS 12-digit hydrologic units as an example.

#### ***Atmospheric Deposition***

HSPF and WARMF are able to model dry and wet atmospheric deposition of nitrogen and phosphorus whereas SWAT only models dry and wet atmospheric deposition of nitrogen. SWAT modelers have circumnavigated this issue by applying a monthly fertilizer application to simulate atmospheric deposition. Additionally, this issue is limited by the data available to use as model input. Atmospheric deposition data will likely be very coarse in nature and limited to average monthly or average annual rates/loads.



**Figure 1: Chatfield Watershed with HUC-12 Subwatersheds**

### ***Nutrient Transport within the Channel***

The models HSPF, SWAT, and WARMF are first and foremost watershed models, which means that they simulate hydrologic, sediment, and nutrient process within the land surface. This can be thought of as the **watershed module**. Each watershed module is connected by a **reach module** which simulates the river or in-stream processes. The reach modules transform the storm hydrograph, simulate erosion and deposition of sediment within the channel, and simulate water quality processes. HSPF and WARMF transport nutrients in the channel as a function of sediment and water quality processes, whereas SWAT's nutrient routine is decoupled from its sediment routine.

- HSPF has comprehensive modeling of in-stream processes. Simulated processes include benthic release of dissolved P, sorption and desorption of P to suspended sediment in the water column (which varies for different sediment size fractions), settling of suspended sediment, scouring of bed and bank sediment, uptake by phytoplankton or benthic algae and respiration and inorganic excretion by zooplankton (Aqua Terra Consultants, 2005).
- WARMF simulates dissolved and adsorbed phosphorus as a function of TSS using a partition coefficient ( $\alpha$ ). This is simplified compared to HSPF, but unlike SWAT it preserves a relationship between adsorbed phosphorus and the sediment transported in the channel. The adsorbed and dissolved fractions for nitrogen and other constituents are calculated in the same manner. The model simulates phytoplankton and periphyton

growth, uptake, and release, which is limited by ammonia, nitrate or both and total dissolved phosphorus (Goldstein, 2001).

- SWAT simulates sediment movement in the channel (reach) according to one modeling routine, while nutrient transport in the channel (reach) is simulated according to a linked QUAL2E model. Organic phosphorus can be converted to soluble inorganic phosphorus or settled with the sediment. It is a function of algal biomass, death rate of algae, rate constant for mineralization of organic phosphorus, initial concentrations, rate coefficient for settling, and flow travel time. The soluble inorganic phosphorus can change with algae uptake and diffusion from streambed sediments. It is a function of the rate constant for the mineralization of organic phosphorus, initial concentrations, sediment source rate for soluble phosphorus, depth of the channel, algal biomass, growth rate of algae, and the travel time in the reach (Neitsch et al., 2011).

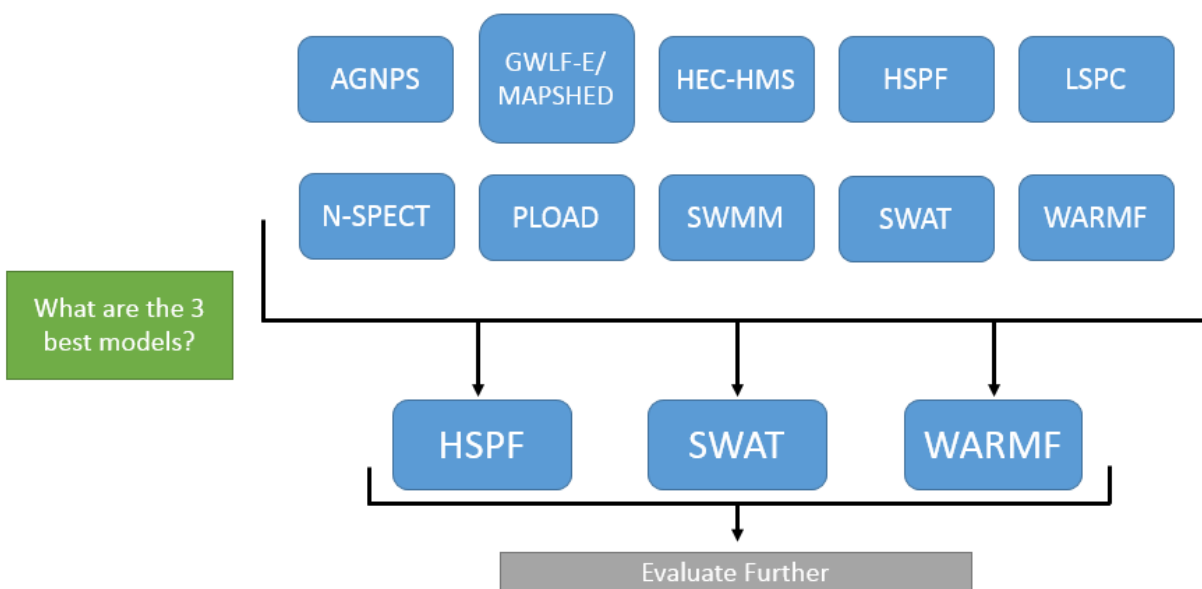
### ***Fertilizer and Irrigation Practices***

The HSPF and SWAT models allow the user a high level of customization as to how irrigation and fertilizer practices are simulated. WARMF allows only monthly fertilizer and manure applications, while SWAT allows daily, monthly or annual applications, and HSPF users can specify a fertilization routine. The irrigation practices in HSPF and SWAT can be dictated by auto-irrigation routines or manual amounts. The WARMF model allows for basin irrigation practices specified as a percentage of flow sources.

### 3.0 CONCLUSIONS AND RECOMMENDATIONS

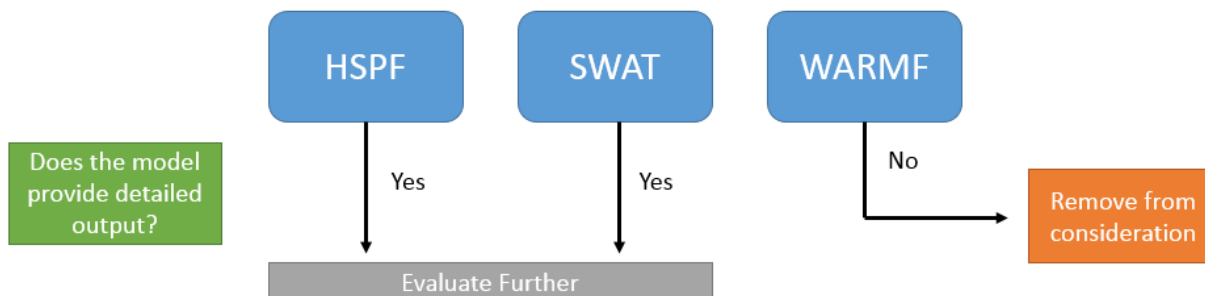
#### 3.1 Model Selection Overview

Ten watershed models were reviewed for modeling of the Chatfield watershed (AGNPS, GWLF-E/Mapshed, HEC-HMS, HSPF, LSPC, N-SPECT, PLOAD, SWMM, SWAT, and WARMF). This list was quickly reduced to the three best candidate models which were determined to be HSPF, SWAT, and WARMF (Figure 2).



**Figure 2: Initial Model Selection**

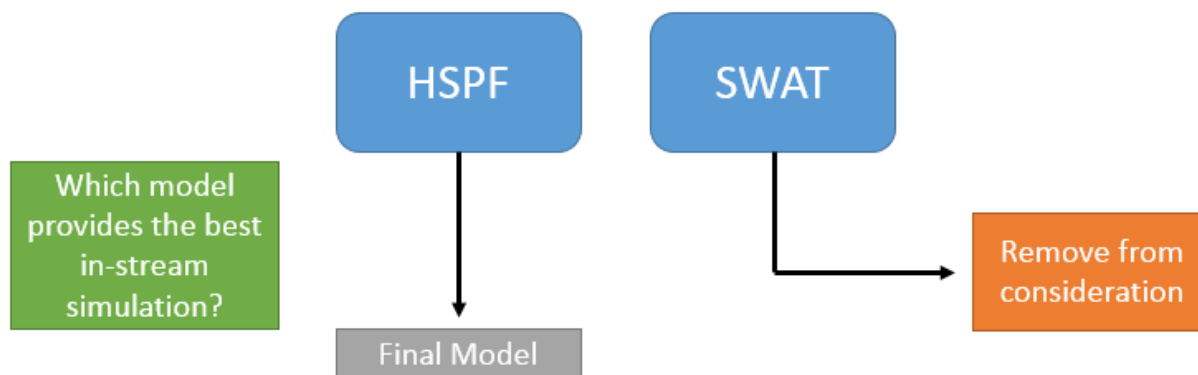
After careful review of the modeling documentation it was determined that the HSPF and SWAT models offered a level of increased functionality over the WARMF model. This was particularly clear when the final use of the model output was considered; the CWA needs to be able to analyze phosphorus output at a level of detail beyond the subwatershed. HSPF and SWAT provide model output that can be analyzed by subwatershed, HRU and ultimately traced to the land use types whereas WARMF does not (Figure 3).



**Figure 3: Model Refinement**



The final model selection between HSPF and SWAT was predominantly decided by the in-stream portion of the model (*reach module*) rather than the land-based portion of the model (*watershed module*). Although SWAT has an in-stream module, transport and transformation of nutrients is decoupled from the sediment transport module. The SWAT in-stream modeling structure is not as strong as the in-stream module with the HSPF model. The final model recommended for use in the Chatfield watershed project is HSPF (Figure 4).



**Figure 4: Final Model Determination**

### 3.2 Final Recommendation - HSPF

HSPF is a widely used watershed model that is commonly applied to TMDL related studies throughout the United States. The model is perhaps best known for its application to Chesapeake Bay water quality issues. HSPF was recommended to the CWA over other watershed models including SWAT and WARMF because it provides the most complete physical representation of a watershed. This includes simulation of land-based hydrologic processes (e.g., infiltration, runoff, sediment mobilization), land-based nutrient processes (e.g., plant uptake, fertilizer application, adsorption to sediment) as well as channel-based (in-stream) nutrient processes (e.g., advection with sediment, deposition, algae uptake).

The model has three main components, PERLND for pervious areas, IMPLND for impervious areas, and RCHRES for stream channels. Within the watershed (PERLND and IMPLND) and channel (RCHRES), HSPF proficiently models hydrologic and water quality processes. Nutrient constituents modeled within HSPF include total phosphorus and orthophosphorus as well as nitrate, nitrite, ammonium, and total nitrogen. HSPF properly accounts for soluble and sediment-bound nutrients transported across the land surface as well as dissolved and adsorbed fractions transported within the channel.

HSPF's modeling routines were determined to provide the CWA with the best potential model for quantifying nutrient loading within the watershed. The model will be built, calibrated, and validated to existing data collected as a part of this project; however, it will also be able to be updated as additional data are collected and best management practices (BMPs) are put into place. In the future, the model outputs can be linked to a reservoir model to determine nutrient processes within Chatfield Reservoir. HSPF will provide the CWA with a tool that will help answer important management questions within the Chatfield watershed now and in the future.

## 4.0 REFERENCES

---

- Aqua Terra Consultants, HSPF Version 12.2 User's Manual. Environmental Protection Agency (EPA), July 2005.
- Aqua Terra Consultants, HSPF Support, website accessed August 2015.  
<http://www.aquaterra.com/resources/hspfsupport/>).
- Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development1. JAWRA J. Am. Water Resour. Assoc. 34, 73–89. doi:10.1111/j.1752-1688.1998.tb05961.x
- Goldstein, R.A., 2001. Watershed Analysis Risk Management Framework (WARMF): Update One. A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation and Implementation.
- Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2011. Soil and Water Assessment Tool Theoretical Documentation Version 2009.

## Appendix A

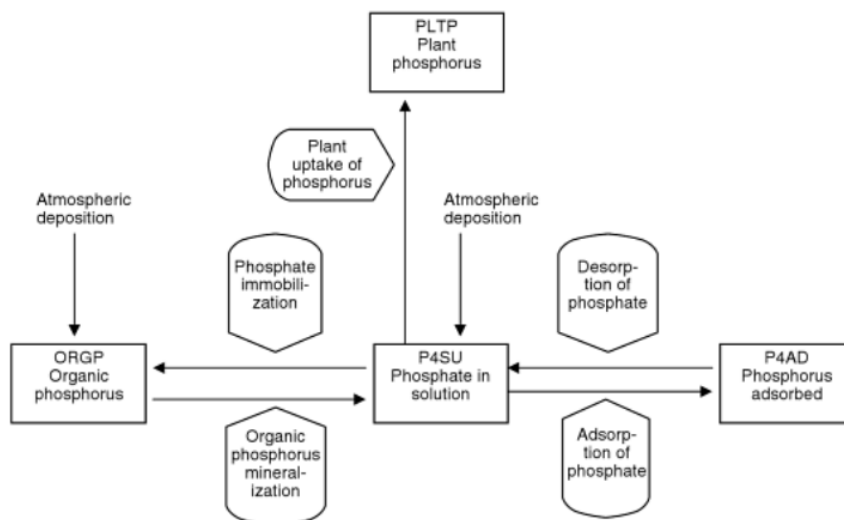
---

### Model Selection Follow-up Questions

Please type questions that you have regarding the functionality, data requirements, and selection criteria of the models being considered for the Chatfield Watershed Model project (SWAT/HSPF). Your questions and the supplemental information provided by our team will help the Modeling Subcommittee to reach a final model selection decision.

Note: The response to the questions posed by the CWA have been provided below in blue text.

1. Chris Carson, PCWRA - The only concern I had, which wasn't brought up, is in regards to Atmospheric Deposition of Phosphorus. The SWAT model only lists Nitrogen as where the other two handle both Nitrogen and Phosphorus. While Nitrogen is important Nutrient, the CWA is primarily concerned about Phosphorus and that component should be addressed wherever possible. While I don't know if atmospheric deposition of Phosphorus is of great impact in this region I do feel it should be a component of the model we decide upon if it is found to be at measurable levels and contributes to the watershed loadings.
  - a. Yes SWAT lacks this functionality and we would want to account for any phosphorus deposition based on locally/regionally measured values. SWAT model users have accounted for the phosphorus load from atmospheric deposition by adding a monthly fertilizer application to simulate this process.
  - b. Any atmospheric deposition data we are able to obtain will likely be very coarse in nature and limited to monthly or annual rates/loads.
  - c. HSPF users have also utilized this type of 'fix', i.e. adding Phosphorous through the special actions block where fertilizer or manure applications are described (the special actions block is a table of annual or monthly inputs), but also to the system directly as organic or adsorbed P through atmospheric deposition (see below).



**Flow diagram for P reactions** (from HSPF v.12 User's Manual)

2. Dan DeLaughter (per Julie Vlier, from meeting notes) - the model must be defensible when results are presented before the WQCC. This may come at the expense of diminished user friendliness (i.e. how easily non-model experts may update, calibrate and run simulations).

Ultimately, and regardless of what model is selected, the defensibility of the results of this project will be a function of how thoughtfully and rigorously the various steps in modeling have been conducted. As we discussed in the workshop, all watershed models have strengths and weaknesses, which means there is no perfect model for a specific project. The challenge is to ensure that for each modeling step we use the best available data and methods, and document these thoroughly so that the approach is transparent. There is now a broad literature for watershed modeling and we can use this to our advantage by researching and utilizing approaches that have been applied and accepted elsewhere by agencies such as EPA and USGS. By fully describing and defending various approaches we use, and then referencing the literature that we have drawn from, we will be able to provide CWA with the tools to defend any and all aspects of the model.

Both HSPF and SWAT have been widely used as watershed models and have implied EPA support through incorporation with the BASINS model framework. Both SWAT and HSPF can be thought of as having two modules: a **watershed module** (land processes) and a **reach module** (river processes). We believe the watershed output from both models is acceptable. Most current models ignore or poorly model in-stream processes. Only three of the models discussed in our workshop include in-stream processes: HSPF, SWAT, and WRMF. We identified HSPF as providing the most comprehensive modeling of in-stream processes with most relevance to this project, taking into consideration benthic release of dissolved P, sorption and desorption of P to suspended sediment in the water column (which varies for different sediment size fractions), settling of suspended sediment, scouring of bed and bank sediment, uptake by phytoplankton or benthic algae and respiration and inorganic excretion by zooplankton. Atmospheric

deposition is also considered. SWAT includes settling of organic P, benthic release of P, and uptake by algae but does not simulate interaction between dissolved P and suspended sediment.

We should seek the input from Joni at the State to ensure that she is agreeable to the model selection.

3. Dan DeLaughter (per Martha Hahn, from meeting notes) - phosphorus adsorption to sediments is an important process to simulate.
  - a. Agreed. This process is simulated by both models in the *watershed module*, but is simulated differently in the *reach module*. The reach module in SWAT transforms phosphorus without considering adhesion to sediment. HSPF transforms phosphorus according to sediment adhesion as well as water quality processes.
  
4. Dan DeLaughter (per Erica Keyser, from meeting notes) - Need to understand what happens when new versions are released. Will the model be portable to new versions?
  - a. This does not have a clear answer. The model structure will transfer (watershed, subwatersheds, HRUs) from one version to the next.
  - b. Model parameters from major model SWAT updates (SWAT2009 to SWAT2012) have changed so that they are not necessarily transferable. Our understanding is that SWAT revisions within version SWAT2012 will have little to no impact on the model. It is likely in the best interest of the CWA to continue using the same SWAT2012 version, but consider moving to the next major model version as needed (e.g., upgrade to SWAT2016 if revisions are acceptable).
  - c. HSPF does not have as many model updates and its core functions are largely considered “done”. Model upgrades/changes to HSPF will have an unknown effect on the model parameters. There is not a thorough amount of published research to determine how model changes impact its parameters. It is likely in the best interest of the CWA to continue using the same HSPF model version throughout the life of the project. As with SWAT, the CWA may want to consider a major model version upgrade (e.g. v12 to v13) if the model revisions were deemed necessary and acceptable.
  
5. Dan DeLaughter (per Erica Keyser, from meeting notes) - Would like more information regarding handling of BMPs. How will the CWA get in and tinker with BMP types and locations to evaluate results.
  - a. The specific methods will vary based on the model selection, but in both cases it will require changing model input files. This information will be provided in the model training documentation.
  - b. For example, in SWAT to add a dry pond or wetland to a given subbasin, the user provides the fractional area of the subbasin that the BMP receives (parameter PND\_FR and WET\_FR, respectively in input file .pnd).

- c. For example, in HSPF use the Best Management Practices Editor in WinHSPF to edit the Base.uci input file. Choose the reach the land use drains to, and then apply a BMP to a percentage of the desired land use.
  
6. Dan DeLaughter (per Erica Keyser, from meeting notes) - Why HSPF and not LSPC?
  - a. HSPF has BASINS for GUI support and has a BMP Web Toolkit for BMP creation. Per a conversation with John Butcher a modeler at Tetra Tech, LSPC is built off of an older version of HSPF (version 11 rather than 12) which lacks some model updates. Additionally some of the water quality routines have not been thoroughly tested to ensure their duplication of the HSPF routines.
  
7. Dan DeLaughter (per Tim Grotheer, from meeting notes) - Which model ties in best with a future lake model?
  - a. Either of the model outputs can be used to feed a reservoir model. It is a matter of formatting output text files from the watershed model to match the needs of the input text files for the reservoir model. This amount of effort should be the same regardless of the selected model.
  
8. Erica Keyser, Tetra Tech - If there is a future desire to perform cost-benefit analyses on implementation measures, can SWAT output be used in conjunction with SUSTAIN? LSPC output can be directly used as inputs for SUSTAIN. HSPF output can be used as SUSTAIN inputs with some post-configuration (script writing) to translate output into useable SUSTAIN data. Will SWAT output meet the time series needs for SUSTAIN input? SUSTAIN needs hourly input.
  - a. It seems that any model output can be used to feed SUSTAIN provided it is configured appropriately. SWAT can be run at an hourly time-step like HSPF.
  
9. Erica Keyser, Tetra Tech - With longevity of the model in mind, can both models be configured (or what are the limitations) to accommodate for future needs/changing conditions? [what is the LOE the Board can expect] In the same vein, if new pollutants of concern arise, what are the capacities/limitations of each model to adjust to changing needs? [Nutrients and TSS are the present concern]
  - a. The in-stream (**reach module**) in HSPF provides some opportunities in the future because its routines are more complex. A coarse in-stream calibration can be completed now using existing TSS data; however this may be further refined in the future with additional data. Without moving to a true in-stream model (e.g., QUAL2K), HSPF seems likely to provides more “room for growth” for CWA interests than SWAT.
  - b. HSPF and SWAT both provide capabilities for simulating dissolved oxygen and pesticides within the reach module. HSPF simulates pH while SWAT does not.

Note: Bill Szafranski, Lynker Technologies – I wanted to provide an update to the model detail tables. SWAT *does* provide sediment fractions within the channel using its updated physically-based model routines. An older model version (SWAT2005) did not have this feature. SWAT can currently simulate sand, silt, clay, small aggregates, large aggregates, and gravel aggregates in the channel.

Model Functionality	SWAT	HSPF	WARMF
<b>Water Quality Parameters</b>			
<b>Sediment</b>	<ul style="list-style-type: none"> <li>• Sand, silt, clay, small aggregates, large aggregates, gravel aggregates (if physically-based stream power is used)</li> </ul>	<ul style="list-style-type: none"> <li>• Sand, silt, clay</li> </ul>	<ul style="list-style-type: none"> <li>• Sand, silt, clay</li> </ul>