Optimization of Nonpoint Source Best Management Practices Selection through a Calibrated HSPF Modeling Approach

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ABSTRACT

JOSHUA HUNN: Optimization of Nonpoint Source Best Management Practices Selection through a Calibrated HSPF Modeling Approach
(Under the direction of Gregory W. Characklis)

Nonpoint source pollution is the leading cause of in-stream water quality impairments, with pathogens alone responsible for more than 40% of all such impairments in North Carolina. Without a concerted effort to assess and manage these overland pollutant sources from a comprehensive approach, there will continue to be minimal progress toward finally realizing the goals of the Clean Water Act. This work addresses nonpoint source pollution through the development of a fully calibrated and validated Hydrological Simulation Program-FORTRAN model for Northeast Creek Watershed, as well as the creation of a linear optimization model for microbial nonpoint source Best Management Practice (BMP) selection. Based upon optimized model results, there would need to be an investment in structural and non-structural BMPs of over $20,000,000 throughout the course of the next twenty years in order for Northeast Creek to meet in-stream regulatory requirements.

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Abbreviations

ac	: acre
ATEM	: air temperature
AWND	: average daily wind speed
BASINS	: Better Assessment Science Integrating Point and Nonpoint Sources
BIT	: Bacterial Indicator Tool
BMP	: best management practice
cfs	: cubic feet per second
CFU	: colony forming units
CLOU	: cloud cover
cm	: centimeter
CWA	: Clean Water Act
DCLO	: daily percent cloud cover
DEM	: digital elevation model
DEVT	: daily potential evapotranspiration
DEWP	: hourly dewpoint temperature
DPTP	: daily dewpoint temperature
EVAP	: potential evaporation
FC	: fecal coliform
HSPF	: Hydrological Simulation Program-FORTRAN
IMPLND	: impervious land segments
MOS	: margin of safety

NC	: North Carolina
NHD	: National Hydrography Dataset
NCDC	: National Climatic Data Center
NPDES	: National Pollutant Discharge Elimination System
PERLND	: pervious land segments
PEVT	: potential evapotranspiration
PQUAL	: HSPF module describing fecal coliform movement and storage
PREC	: precipitation
PSUN	: percent sun
PWAT	: HSPF module describing water flow and storage
RCHRES	: free-flowing reaches or mixed reservoir
RDU	: Raleigh-Durham Airport
SCONC	: State Climate Office of North Carolina
SOLR	: solar radiation
sq km	: square kilometer
TMAX	: maximum temperature
TMDL	: Total Maximum Daily Load
TMIN	: minimum temperature
USEPA	: United States Environmental Protection Agency
WIND	: wind speed
WWTP	: Wastewater Treatment Plant

Chapter I

Introduction

The passage of the landmark Clean Water Act (CWA) sought to ensure that all water bodies would be "fishable and swimmable" by requiring identification of, and remediation plans for, water bodies deemed physically, biologically or chemically impaired. However, thirty-five years later, more than 40% of assessed water bodies still do not comply with applicable water quality standards (USEPA 2007d). Substantial improvements in water quality have occurred through the control of point source discharges, primarily accomplished through the creation of the National Pollutant Discharge Elimination System (NPDES) program (USEPA 2007b). Effective point source controls have only shifted responsibility, however, as nonpoint sources are now the primary cause of surface water impairments (USEPA 1996), thereby necessitating greater understanding and action (USGAO 1990). Nonpoint sources (Figure 1) primarily include overland runoff from pervious and impervious land, failing septic systems, and, in the case of microbial contaminants, direct deposition by domesticated and wild animals (Standridge et al. 1979; O'Keefe et al. 2003; Im et al. 2004; Petersen et al. 2005). Better understanding of source contributions and control

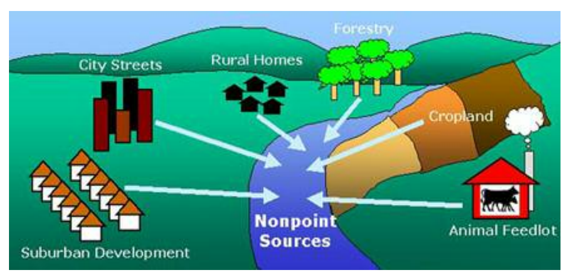

Figure 1: Schematic of possible nonpoint sources of pollution into a water body (NOAA 2006).

selection will be critically important to the development of effective water quality improvement strategies (Lehner et al. 1999).

1.1 Regulatory Background

Under the CWA, each state is tasked with identifying water bodies that do not meet federal or state mandated used-based water quality standards. For each impaired water body, the state must determine a pollutant-specific total maximum daily load (TMDL)[1] that the impaired water body can receive from all sources (both point and nonpoint) while maintaining regulatory compliance (USEPA 1972b). These impaired water bodies, placed on a state-generated 303(d) list (a number referencing the relevant section of the CWA), have been given priority status in terms of regulating point source discharges. When point source controls alone are insufficient to achieve compliance, consideration of nonpoint sources is required (USEPA 1972a). This latter provision of the CWA was largely ignored, however, until citizen groups brought lawsuits in the late 1990's pressuring the Environmental Protection Agency into action (USEPA 2007d). These suits were settled largely in favor of citizen groups, forcing the USEPA and individual states to accelerate the rate at which impaired waters were identified and brought into compliance.

1.2 Study Significance

Currently, more than 20,000 water body segments have been identified as impaired for at least one pollutant of concern (USEPA 2007d), such that nearly three-quarters of the population of the United States live within ten miles of an impaired water body. However, this number is likely far greater given that nationally only 19% of all

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[1] A TMDL includes not only the identification of acceptable source loadings, but also allocations of loading reductions among sources and a comprehensive plan to attain and continue to meet applicable water quality standards (see Birkeland 2001 for more detail).

river and streams have been assessed (SFWMD 2007). Of those water bodies that have been assessed, pathogens are the primary cause of more than 40% of North Carolina's and 13% of the United States' total in-stream impairments[2] (USEPA 2007a; USEPA 2007c), which underscores the importance of work addressing this issue. Unfortunately for the policy process, nonpoint source monitoring for a water body, particularly when microbially impaired, is generally cost-prohibitive, meaning that a comprehensive description of overland sources and their magnitudes is often impossible. Rather, many regulatory decisions are supported by water quality models which address this problem from a watershed scale. Given that most impaired water bodies have received minimal attention regarding the development of comprehensive plan to ensure and maintain regulatory compliance, this report offers a method for integrating the selection of microbial nonpoint source pollution controls into the TMDL policy framework using a representative watershed.

1.3 Effects of Nonpoint Source Pollution

Fecal coliforms are indicator organisms that serve as surrogates for human enteric pathogens such as Shigella, Salmonella, Giardia, and Cryptosporidium that are more difficult and costly to detect (Olivieri 1982; Bohn and Buckhouse 1985; Schueller 1999). Large-scale disease outbreaks attributable to these pathogens have occurred in public drinking water supplies, including those in Milwaukee (MacKenzie et al. 1994), Clark County, Nevada (Goldstein et al. 1996), and western Georgia (Hayes et al. 1989). Other studies have concluded that health risks also exist from recreational contact with

[2] In North Carolina, pathogenic impairments are by far the most common, accounting for nearly twice as many impairments as the second most common, which is due to unknown impairments. Nationally, pathogenic impairments are the second most common impairment, but are nearly identical in number to the leading cause, mercury.

biologically-impaired surface waters, particularly those that receive significant stormwater runoff (Pruss 1998; Haile et al. 1999; Curriero et al. 2001; Dwight et al. 2004; Stoner and Dorfman 2006).

Improvements made in surface water quality will alleviate the potential for illness from contact with impaired water bodies. Studies have shown that though the costs of managing and improving stormwater runoff can be high, the costs associated with post-treatment waterborne illnesses can potentially be much greater (Corso et al. 2003; Gaffield et al. 2003). This advocates for a preemptive approach to managing the public health effects associated with microbial contaminants in surface waters. In addition, from a development standpoint, research has shown that property values can actually increase for lots that are situated near certain stormwater controls, though this assumes that proper upkeep and maintenance is performed (Emmerling-DiNovo 1995; USEPA 1995).

1.4 Nonpoint Source Characterization

The loading of nonpoint source pollution to surface waters is highly variable, depending upon a number of factors that have been considered in the development and modification of comprehensive nonpoint pollution models (Loague et al. 1998).

1.4.1 Microbial Source Trends

In the case of bacterial contaminants (i.e. fecal coliforms), contaminant loadings to surface waters can increase dramatically as a result of rainfall events and resulting runoff (Stephenson and Street 1978; Edwards et al. 1997; Arienzo et al. 2001; Kistemann et al. 2002). This can be particularly true at the beginning of a storm event, when a "first-flush" of contaminants which have built up since the previous storm event are mobilized by runoff (Davis et al. 1977; Stutler et al. 1995). Bacterial concentrations also correlate well to land use patterns, with both agricultural and urban residential land cover typically having the highest bacterial loading rates (Francy et al. 2000; Arienzo et al. 2001; Tong and Chen 2002; Tufford and Marshall 2002; Kelsey et al. 2004; Mehaffey et al. 2005; Schoonover et al. 2005). Elevated contributions from urban areas have also been closely linked to increases in housing density and impervious land cover (Bannerman et al. 1993; Young and Thackston 1999; Mallin et al. 2000; Mallin et al. 2001). Principally, fecal coliform sources include direct deposition by wildlife, failing septic systems, and surcharging or failing sanitary sewers (Petersen 2005), though, because of the watershed-specific characteristics that determine fecal coliform loads, bacterial source tracking has been developed to better identify precise sources (Wiggins et al. 1999; Dombek et al. 2000; Burnes 2003). Finally, in-stream bacterial concentrations are also seen to vary seasonally, with summer months generally displaying higher levels (Van Donsel et al. 1967; Geldreich et al. 1968; Edwards et al. 1997).

1.4.2 Nonpoint Source Modeling

A collection of nonpoint source water quality models, each of which possess unique features and requirements (Borah and Bera 2003; Borah and Bera 2004), have been created to better represent physical conditions (Stutler et al. 1995; Saunders 1996; USEPA 2005a). As mentioned, extensive monitoring programs can be expensive and time-consuming, leading to the evolution of nonpoint source models to more realistically characterize pollutant sources and loadings, though a certain amount of uncertainty will be inherent in any attempt (Oreskes et al. 1994). Initially, characterization of physical processes was limited to quantifying overland flow (USDA 1986; Guo and Adams 1998). Pollutant loadings were then incorporated, being largely identified as either event mean concentrations as a function of physical parameters (Brezonik and Stadelmann 2002) or probabilistic models (Behera et al. 2006), though either was difficult to calibrate and validate. In an effort to increase confidence, computer-based nonpoint source pollution models have evolved to incorporate these loading characteristics with the capacity for the incorporation of localized physical parameters (Donigan Jr. and Huber 1991). Even though initial pollutant modeling efforts were targeted solely toward nitrogen, phosphorous, and sediment, further model efforts have included microbial constituents (Ferguson et al. 2003; Arnold and Fohrer 2005), though with no explicit consideration of bacteria-sediment interactions[3].

1.4.3 Model Selection

The Hydrological Simulation Program-FORTRAN (HSPF) code was selected to model this system and can be described in terms of several general characteristics:

- It is continuous, which allows for long-term trends to be modeled, rather than simply a single storm event;
- It is deterministic, such that an identical output will be achieved for every run completed with identical inputs;
- It is lumped parameter, which simplifies the model to allow localized parameters to be given the same value; and
- It is defined in terms of the watershed, which ensures hydrologically-consistent boundaries on the analysis (Center 2006).
- The HSPF code has been used in the development of several bacterial TMDLs (Yagow et al. 2001; Moyer and Hyer 2003; USEPA 2003; Benham et al. 2005; Benham et al. 2006), providing useful background for this modeling effort.

[3] Parallel work (Russo 2007) associated with this project is focused on incorporating bacterial-sediment interactions in the water column into modeling efforts, with the results used in coordination with this work to develop a comprehensive watershed restoration plan.

1.5 Nonpoint Source Pollution Controls

Nonpoint sources, due to their diffuse nature, are more difficult to control and are managed through a variety of best management practices (BMPs). A BMP can take one of two forms: (i) structural, meaning that controls are instituted to reduce pollutant loads after they have already been mobilized within the watershed through the use of hardware to alter flow paths, residence times, or infiltration capacity, or (ii) non-structural, which seek to prevent or reduce pollutant loads at the source without the use of any hardware (USEPA 1999). Examples of structural BMPs include wet or dry detention ponds, stormwater wetlands, buffer strips, grassed swales, and bioretention, while non-structural BMPs include redirected runoff, street sweeping, wildlife exclusion and educational programs (USEPA 2005b). This report suggests an approach to the selection of BMP control strategies for microbial contaminants using a linear programming framework that minimizes costs while ensuring regulatory compliance through integration with a fully calibrated and validated nonpoint source pollution model.

1.6 Study Location

Northeast Creek, which resides within a watershed located in the Piedmont region of North Carolina (Figure 2, with more detail in Appendix A), contains a 15.8-kilometer segment that is biologically impaired based on elevated fecal coliform (FC) concentrations (NCDWQ 2006). The watershed is approximately 123.5 sq. km. in area, spanning parts of Durham, Wake, and Chatham Counties, including drainage from parts of the cities of Durham and Cary, as well as Research Triangle Park. Though this watershed has historically been dominated by forest cover (as much as 80%), it is currently experiencing rapid urbanization, particularly in the upper reaches of the watershed, that has reduced this to around 50%. The water quality of this stream is a particular concern because it empties into Jordan Lake, a nutrient-sensitive water body that also serves as a drinking water source for the towns of Cary and Apex, as well as being home to a variety of recreational activities (USACE 1992).

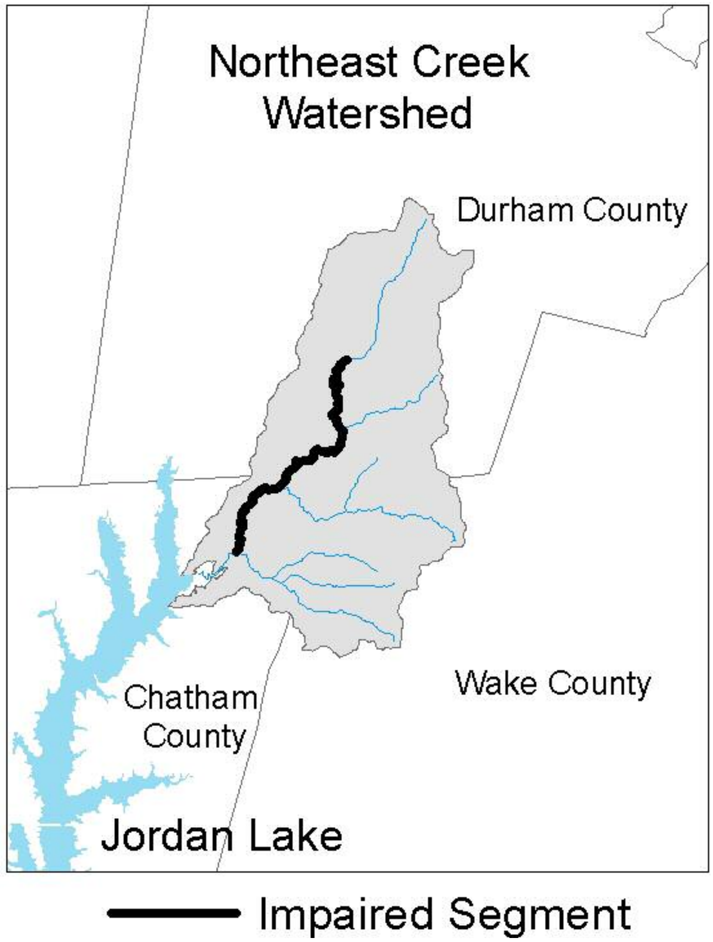


Figure 2: Spatial representation of Northeast Creek watershed.

Chapter II

Methods

HSPF requires user input of physical and chemical parameters to model watershed hydrology, suspended solids, and general quality constituents (in this case, fecal coliforms). The processes outlined below are used to develop, calibrate and validate an HSPF model integrating point and nonpoint source contributions. Model output will be used as input to a proposed optimization model for nonpoint source control selection to develop a least-cost strategy for achieving regulatory compliance.

2.1 Watershed Characterization

The HSPF model requires several inputs: (i) a watershed map file; (ii) a hydrographic reach file; (iii) assignation of land cover, and; (iv) regional climatic data. The first three inputs were developed using the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) modeling framework, which serves as a preprocessor for several nonpoint source models (USEPA 2001).

BASINS initially contains a national map displaying localized subbasins, from which data can be obtained. However, because Northeast Creek watershed does not comprise an entire subbasin, it was necessary to retrieve data for the complete Haw River Subbasin (USGS Code 0303002), which is located in the Upper Cape Fear River Basin (see Appendix A). Relevant data include the National Hydrography Dataset (NHD) and a Digital Elevation Model (DEM), which were used to determine watershed boundaries by identifying those water bodies and their corresponding overland flow planes which drain into Northeast Creek. Subwatersheds were automatically generated[4] corresponding to the major tributaries (Burdens Creek, Kit Creek, and Panther Creek) and their associated overland, interflow, and groundwater flow planes (Figure 3).

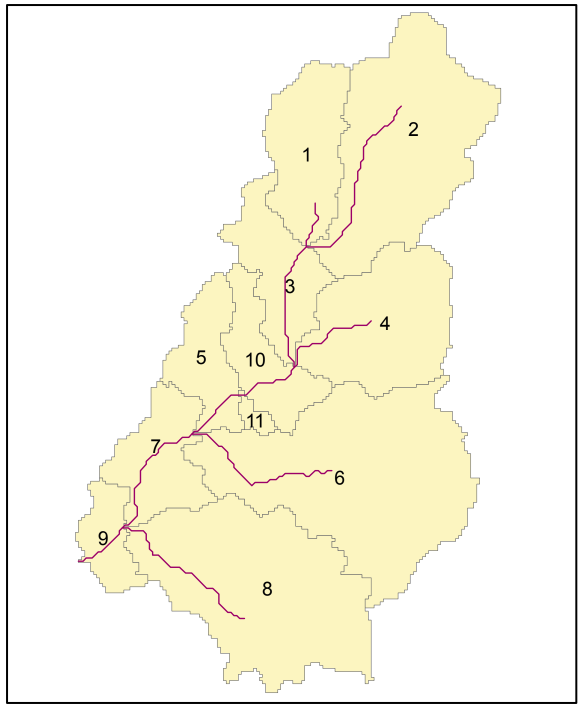


Figure 3: Northeast Creek subwatershed delineation with corresponding reach numbers.

While the DEM and NHD that were accessed through BASINS were sufficient for the scope of this project, the land cover dataset was outdated, and more recent data were acquired through the USGS[5] (2004). ArcGIS tools were then used to determine the amount of land cover that existed within each subwatershed (Appendix B).

2.2 Weather Data Preparation

A climatic dataset was developed for the watershed which primarily includes temperature and rainfall. For HSPF, all datasets are compiled and displayed in WDMUtil (Hummel et al. 2001), an external processor that will also organize outputted data. Following a procedure developed by the Virginia Tech Center for TMDL and Watershed Studies (Zeckoski 2006), most of the weather data was acquired from the National

[4] In addition to the automatic subwatershed delineation in BASINS, an additional outlet was manually added corresponding to the location of a USGS stream gage (at Reach 11) from which in-stream flow measurements were obtained. This also accounts for the reason that the reach numbering system would initially appear to be out of order.

[5] Land cover data was from the National Land Cover Dataset 2001 using Landsat-7 data purchased through the Multi-Resolution Land Characteristics consortium, with supporting work completed through the Southeast Gap Analysis Project.

Climatic Data Center (NCDC) from a station located in Durham, NC (NOAA 2005), with missing data supplemented by a weather station at Raleigh-Durham International Airport (RDU) and from the State Climate Office of North Carolina (see Appendix C for details).

2.3 HSPF Model Development

HSPF is fundamentally organized around the development of three modules: (i) pervious land segments (PERLND) that are subject to infiltration or overland runoff; (ii) impervious land segments (IMPLND) that are subject solely to overland runoff, and; (iii) free-flowing reaches or mixed reservoirs (RCHRES) that represent the stream segments (Bicknell 2001). These modules are primarily focused on the accumulation and transport of: (i) water; (ii) sediments, and; (iii) general quality constituents, such as fecal coliform, nitrogen, phosphorous, etc.

2.3.1 Pervious Land (PERLND) Theory Development

The flow of water (PWAT) in the PERLND module is built around several key processes (Figure 4), which all interact as part of the HSPF water balance. These processes are the primary driver of quality constituent movement. Overland runoff is described by:

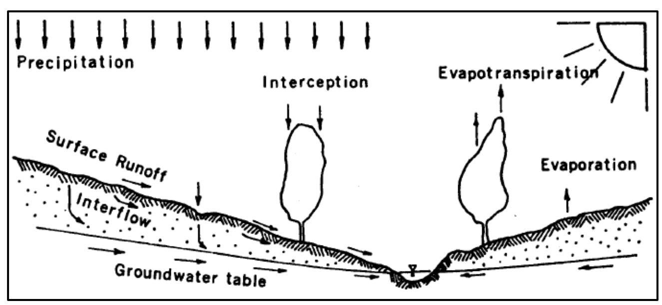


Figure 4: Representation of the hydrological flow process for the PERLND module in HSPF

$$2.54(SURO) = DELT60 * SRC * \left(1 + 0.6\left(\frac{SURSM}{SURSE}\right)^3\right)^{1.67} \text{, for SURSM < SURSE} \quad [1]$$

or

$$2.54(SURO) = DELT60 * SRC * \left(1.6 * 2.54(SURSM)\right)^{1.67} \text{, for SURSM > SURSE} \quad [2]$$

where:

SURO : surface outflow (cm/time step);

DELT60 : total time (hr/time step);

SRC : routing variable, based upon overland flow plane length and slope;

SURSM : mean surface detention storage over time step (cm);

SURSE : equilibrium surface detention storage over time step (cm).

The amount of water available for overland outflow is influenced by the fraction diverted to other processes, such as surface storage, interflow, and groundwater flow (developed more fully in Appendix D). Total overflow is primarily controlled through the adjustment of overland flow storage, as well as parameters associated with soil infiltration capacity.

The amount, as well as intensity, of rainfall and runoff that occurs is a critical component in determining the amount of sediment that is transported over the land surface. Sediment is mobilized through both washoff and scour, the sum of which represents the total sediment contribution to receiving waters during each time step. These two processes are described by:

$$WSSD = DETS * \frac{(SURO)}{(SURS + SURO)} \quad [3]$$

and

$$247.1054(SCRSD) = \frac{(SURO)}{(SURS + SURO)} * DELT60 * KGER * \left(\frac{2.54(SURS + SURO)}{DELT60} \right)^{JGER} \quad [4]$$

where:

WSSD : washoff of detached sediment (tons/sq km/time step);

DETS : detached sediment storage (tons/sq km);

SURO : surface overflow of water (cm/time step);

SURS : surface storage (cm);

SCRSD : scour of soil matrix (tons/sq km/time step);

KGER : coefficient for scour of the soil matrix;

JGER : exponent for scour of the soil matrix.

Total load estimates are most sensitive to the adjustment of the amount of detached storage that is available in each land segment.

Because fecal coliforms in runoff have been observed to exist in a sediment-associated, as well as a “free” (i.e. unattached), form (Characklis et al. 2005; Krometis et al. 2007), both water and sediment movement heavily influence the transport of fecal coliform in the quality constituent module (PQUAL). In PQUAL, overland mobilization and transport of fecal coliforms is considered as the sum of washed off and scoured sediment-associated FC, plus the contribution from direct overland flow of free-phase organisms. These processes are integral to determining the total general quality constituent load and are described by:

$$WASHQS = WSSD * POTFW \text{ ,} \quad [5]$$

$$SCRQS = SCRSD * POTFS \text{ , and} \quad [6]$$

$$SOQO = SQO * \left(1 - \exp\left(-SURO * WSFAC\right)\right) \quad [7]$$

where:

WASHQS : general quality constituent flux associated with sediment washoff (quantity/sq km/time step);

WSSD : washoff of detached sediment (tons/sq km/time step);

POTFW : washoff potency factor (quantity/ton);

SCRQS : general quality constituent flux associated with soil matrix scouring (quantity/sq km/time step);

SCRSD : scour of soil matrix (tons/sq km/time step);

POTFS : scour potency factor (quantity/ton);

SOQO : general quality constituent flux associated with washoff from land surface (quantity/sq km/time step);

SQO : storage of available quality constituent (quantity/sq km);

SURO : surface outflow of water (cm/time step);

WSFAC : susceptibility of quality constituent to washoff (1/cm).

2.3.2 Impervious Land (IMPLND) Theory Development

Similar to pervious surfaces, impervious overland flow is a function of surface storage and routing. For the accumulation and removal of water flowing over impervious surfaces, however, the water balance consists of only three subroutines: impervious retention, overland flow routing, and evaporation (see Appendix E for more detail).

In considering the removal of solids from impervious surfaces, only overland runoff is considered (as opposed to both washoff and scour):

$$SOSLD = SLDS * \left(\frac{SURO}{SURO + SURS} \right) \quad [8]$$

where:

SOSLD : washoff of solids (tons/sq km/time step);

SLDS : solids storage (tons/sq km);

SURO : surface outflow of water (cm/time step);

SURS : surface storage of water (cm).

While the primary transport mechanism is through surface runoff, daily dry weather removal by wind is also considered through the loss of a fraction of the total storage.

General quality constituents are modeled in much the same way as for the PERLND segments, as total washoff will account for direct washoff of both free-phase and sediment-associated constituents, such that:

$$SOQO = SQO * (1 - \exp(-SURO * WSFAC)) \quad [9]$$

where:

SOQO : washoff of quality constituent (quantity/sq km/time step);

SQO : surface storage of quality constituent (quantity/sq km);

SURO : surface outflow of water (cm/time step);

WSFAC : susceptibility of quality constituent to washoff (1/cm).

2.3.3 HSPF Parameter Development

The EPA has issued suggested soil and water accumulation and removal default parameters for both the PERLND and IMPLND modules, as well as suggestions for parameter adjustment given local conditions (USEPA 2000b; USEPA 2006a).

As quality constituent parameters are entirely watershed-specific, the Bacterial Indicator Tool (USEPA 2000a), an external program, was used to determine land cover- and subwatershed-specific monthly quality constituent accumulation rates and total storage limits (see Appendix F). This tool requires user input of land cover areas by subwatershed, as well as livestock and wildlife population densities and a breakdown of urban land into commercial, residential, and transportation usages. Though this tool only explicitly calculates bacterial inputs for urban, forest, cropland, and pasture land covers, the recommended wildlife population densities and animal fecal coliform production rates were used to create corresponding outputs for the rangeland, barren, and wetland land covers.

A full summary of all input PERLND and IMPLND parameters for the hydrology, solids, and quality constituent modules can be found in Appendix G, with a complete model code found in Appendix H.

2.4 Parameter Calibration

Observed data describing in-stream flow and FC concentrations were necessary to calibrate and validate the model by adjusting PERLND and IMPLND parameters related to each of the associated processes.

2.4.1 Data Inventory

For adjustments made regarding the accumulation and removal of water, flow data from the USGS stream gage (gage ID 0209741955 on Northeast Creek at SR1100 near Genlee (USGS 2007)) were used to compare with modeled flow. Per HSPF requirements, daily mean stream flow values were obtained for the period of January 1, 2001- September 30, 2006 (the most recent data available), with every day having a recorded value. Weekly grab sample FC concentrations (Appendix I) were recorded at three locations (one upstream and two downstream) between the years of 2001-2002 by the Triangle Wastewater Treatment Plant (WWTP)[6] as part of their NPDES monitoring program, with supplemental data for this period available from USEPA STORET (USEPA 2006b). However, there were several incidences of "soft" data, for example, measurements that were only indicated as being greater than a certain threshold. In those instances, these soft data points were removed from the dataset before analysis. Because sufficient data points were only available for this two year window, calibration of FC parameters was completed for data corresponding to January 1, 2001 – December 31, 2001 for both a downstream (Reach 5) and an upstream reach (Reach 3), with validation completed at both sites for the period January 1, 2002 – December 31, 2002.

2.4.2. Hydrology Calibration

Modeled in-stream flow was compared with observed conditions by using an external hydrology calibration program, HSPEXP (Lumb et al. 1994). Based upon literature examining the sensitivity of hydrological parameters in HSPF (Al-Abed and Whiteley 2002), PERLND parameters related to upper and lower zone nominal storage

[6] The Triangle Wastewater Treatment Plant is the only active point source discharger into Northeast Creek or any of its tributaries. Therefore, the collection of point source inputs for this model only included average daily effluent flow and fecal coliform concentrations from the treatment plant.

and infiltration capacity were refined, as were the initial storages for both the PERLND and IMPLND processes. Since the greatest concern for microbial concentrations is generally during the summer months and periods of high flow following storm events, calibration, though performed continuously for the entire period of available data, focused upon ensuring that summer storm event modeled volumes were as close as possible to observed volumes over those same storm events. Ultimately, a difference of less than 5% was present between total modeled and observed summer storm event volumes over the period January 1, 2001- December 31, 2005 (Figure 5 shows a representative subset of this period), as well as a total volume difference of less than 15% throughout the entire model simulation period[7].

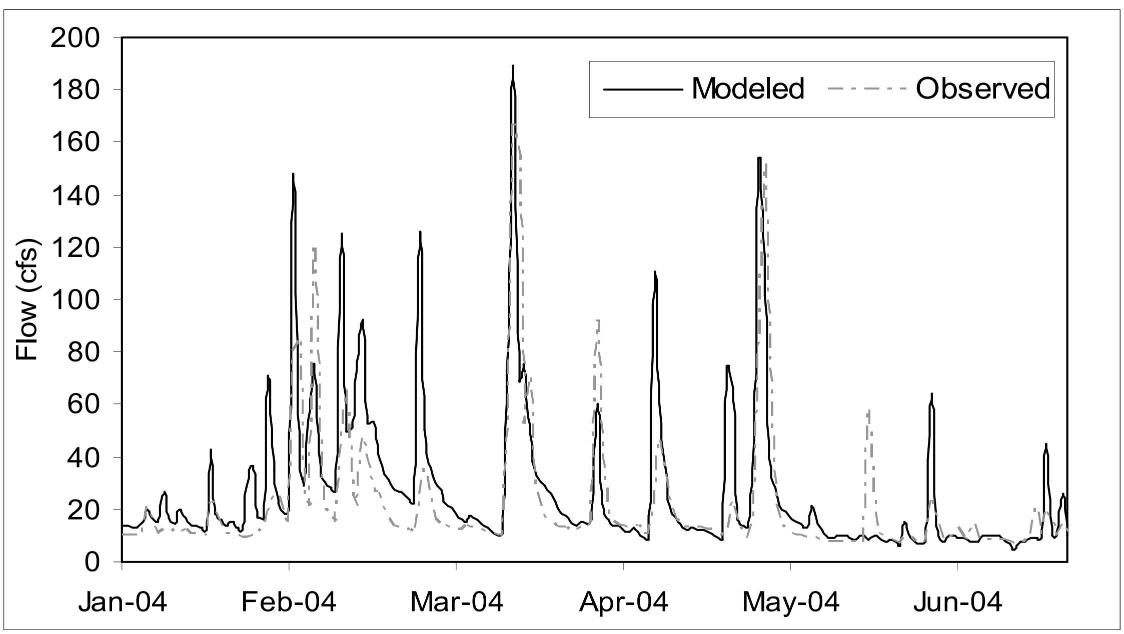
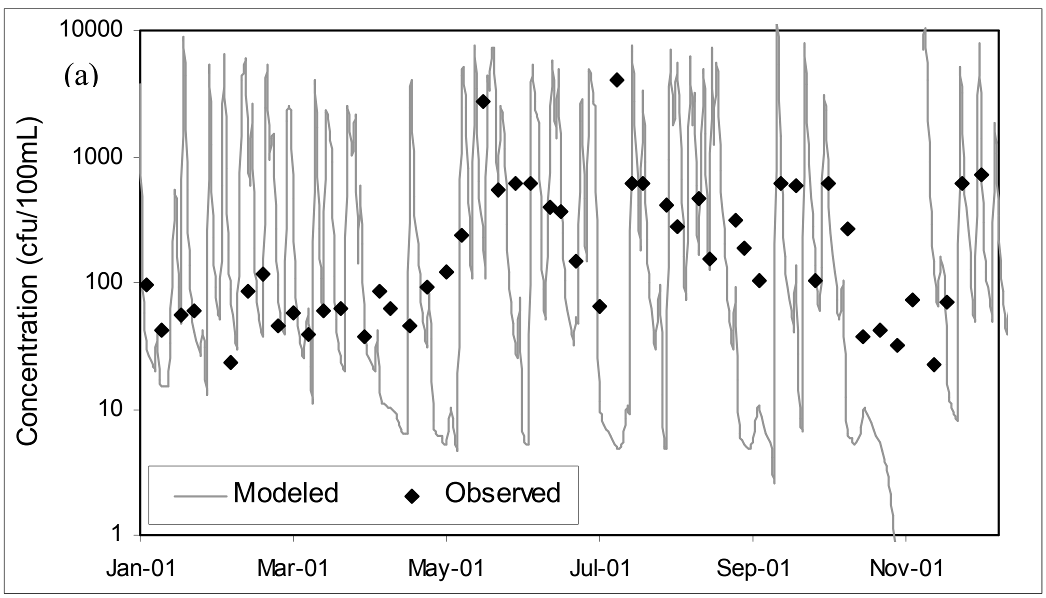


Figure 5: Modeled flow at Reach 11 vs. observed USGS gauge flow data.

[7] The hydrology within HSPF should be able to calibrated fairly precisely given sufficient data. However, there were several incidences, particularly at periods of low flow, when in-stream flow values less than the amount of effluent being released upstream of the USGS gage. This discrepancy accounts for the higher errors for the total simulation period, but storm volume error should be more precise.

2.4.3 Fecal Coliform Calibration

In terms of adjusting parameters affecting in-stream FC concentrations, previous studies suggested that the greatest sensitivity was found in PERLND parameters (Paul et al. 2004). However, because of the increasing urbanization that is occurring in Northeast Creek watershed, IMPLND parameters routinely yielded greater effects upon in-stream FC concentrations. Therefore IMPLND parameters associated with overland storage, as well as the minimum overland flow to remove 90% of built-up FC organisms and the maximum FC storage potential, were adjusted to calibrate modeled in-stream FC concentrations for Reaches 3 and 5 with observed FC data from January 1, 2001 - December 31, 2001 (Figure 6a-b).



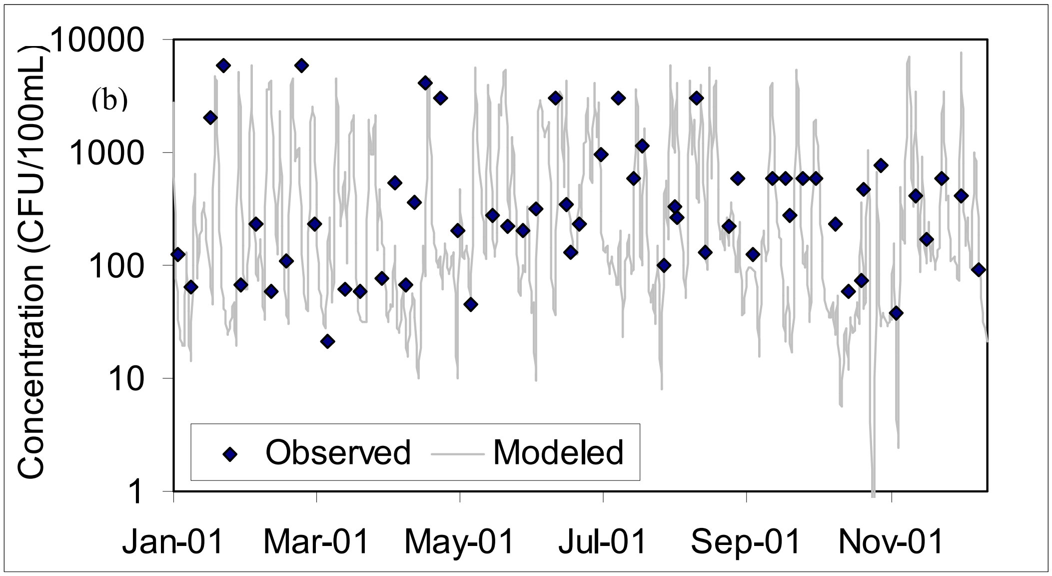


Figure 6: Comparison of Modeled vs. Observed in-stream FC concentrations for (a) Reach 3 and (b) Reach 5 during calibration.

For a policy context that is primarily concerned with the identification and adjustment of bacterial concentrations, it is acceptable to make recommendations based upon order of magnitude estimations (Dorner et al. 2006). Therefore, quantification of error between observed and modeled data took the form of determining the percentage of modeled data points that fell within one order of magnitude of the observed value[8]. For Reach 5, 88% of modeled values (51 out of 58) fell within one order of magnitude of observed data, and, for Reach 3, 84% of values (42 out of 50) met this criterion (Appendix J). Further examination revealed a nonparametric Spearman's rank correlation coefficient of 0.49 for Reach 5 and 0.52 for Reach 3, with a significance of greater than 0.001 for observed and modeled dataset.

[8] Because HSPF outputs on a daily time step, and observed grab samples can be taken at any point in that day, error estimation was completed based upon a three-day best estimate that would allow points to be more accurately compared (Russo 2007).

2.5 BMP Analysis Framework

Though the science of bacterial source characterization and quantification has been the subject of increasing study (Whitlock et al. 2002; Burnes 2003; Jamieson 2004; Weiss et al. 2006), as yet there has been no broad agreement on a standardized method to identify a source control strategy that will most efficiently meet regulatory requirements. To that end, a linear programming framework is suggested such that an objective function, which is equal to the total costs associated with a BMP implementation plan, is minimized while ensuring that in-stream FC concentrations are reduced to compliant levels. This cost minimization will take the following form:

$$Z = \sum C_i (X_{jk}, F_{ijk}) + M_i (X_{jk}, F_{ijk}) + O_i (A_i) \qquad [10]$$

subject to:

$$R = \sum Y_i * (X_{jk} * F_{ijk}) * Q_k \geq R_{compliance} \qquad [11]$$

where:

C_i : Capital cost of construction of BMP *i* ($);

M_i : Present value cost for 20-year maintenance of BMP i ($);

O_i : Opportunity cost[9] associated with area of BMP i ($/acre);

X_{jk} : Area of land cover *k* in subwatershed *j* (acre);

F_{ijk} : Fraction of land cover *k* in subwatershed *j* contributing to BMP *i*;

A_{ij} : Surface area required for BMP *i* in subwatershed *j* (acre);

---

[9] In this analysis, opportunity costs only account for the cost of land that would be surrendered for a structural BMP, meaning that any loss of economic benefits that could have been gained through that land parcel were not included.

R : Watershed reduction in FC loading, in colony forming units (CFU);

Y_i : Efficiency of BMP *i* (FC fraction removal);

Q_{jk} : Yearly FC loading for land cover *k* in subwatershed *j* (CFU/acre).

For this set-up, X_{jk} (Appendix B), Q_{jk} (Appendix M), Y_i (Table 1, synthesis of Appendix K), and C_i, M_i and O_i (Wossink and Hunt 2003; USEPA 2005) are all known. $R_{compliance}$ is calculated from HSPF as a measure of the difference between in-stream FC quantities at baseline and regulatory-compliant conditions. F_{ijk} is the only unknown parameter in this model and is allowed to vary such that runoff from one particular land segment is not intercepted by multiple treatment controls in what is known as a "treatment train." Though it is technically feasible that such a system could be used, the effects of such systems on removal efficiencies are not clearly understood and are therefore not considered in this analysis, but could be necessary should the present suggested model prove unable to ensure sufficient reductions (VADCR 2004).

The outlined approach assumes that a monolithic structural BMP will be able to drain all of a specific land cover type within a subwatershed at just one location. This is neither a feasible nor a cost-effective approach to stormwater management. However, this set-up can be adjusted to allow for typical BMP sizes to be considered (NCDENR 2005). The total required BMP area (based upon overland drainage areas) can be allocated to a collection of typically-sized BMPs. Costs corresponding to a typically-sized BMP can then be used in place of the original exponential functions (Table 1). Ultimately, this model will output the optimal BMP allocation displaying which BMP(s) to choose, which land cover(s) or subwatershed(s) to target, and the total land area required to meet the necessary reductions. However, it is the responsibility of the watershed planner to ensure that these individual BMPs will be located in a spatially optimal manner (Zhen et al. 2004; Perez-Pedini et al. 2005).

Though not incorporated into this linear programming framework, non-structural BMPs were also considered in this analysis, and, at least for this representative watershed, were necessary for ensuring regulatory compliance without requiring extraordinary costs. The incorporation of non-structural BMPs has the effect of reducing pollutant loading to the structural BMPs, thereby increasing their efficiency and extending their service life. Research has shown that educational initiatives, including television and radio spots, flyers and brochures, and public signage, can have an effect upon human behavior, as well as garner public support for other control initiatives (Dietz et al. 2004), though television ads have been shown to have the greatest capacity to reach the public (Schueler 2000). Another non-structural BMP, street sweeping can have a significant impact on FC loads from impervious urban surfaces (Zariello et al. 2002), reducing the total load along streets by as much as 50% when performed routinely, particularly when sweeping occurs during extended dry periods so as to minimize the effects from the first-flush phenomenon.

i	BMP Type	Efficiency[1]	Size	Cost ($)		Allowable Land Uses
				Capital	Maintenance	
1	Stormwater Wetland	90%	$SA=0.020X^2$	$C=3{,}852X^{0.484}$	$C=4{,}502X^{0.153}$	All Urban
2	Wet Retention Pond	65%	$SA=0.015X^2$	$C=13{,}909X^{0.672}$	$C=9{,}202X^{0.269}$	All Urban, Cropland, Pasture
3	Buffer/Filter Strips	85%	$SA=0.110X^3$	C=13,000(.11X)	C=20(320X)	Cropland, Forest, Wetlands, Barren, Pasture, Rangeland
4	Bioretention	80%	$SA=0.025X^2$	$C=2{,}861X^{0.438}$	$C=3{,}437X^{0.152}$	All Urban, Cropland, Pasture
	Street Sweeping	50%[4]		C=200,000	C=20/curb mile	Impervious Urban
	Education	15%[5]			C=650000	All

1 Synthesis of structural BMP efficiency review from Appendix K
2 Wossink and Hunt 2003
3 USEPA 2005
4 Zariello et al. 2002
5 Dietz 2004

Table 1: Summary of BMP characteristics that were used in the optimization analysis (full compilation of sources found in Appendix K).

Chapter III

Results

A strategy for selecting a least-cost mitigation strategy for microbially-impaired water bodies has been suggested that could be incorporated into the existing TMDL policy framework. HSPF allows these optimized source control strategies to be verified by modeling the watershed under suggested conditions. If properly implemented, these reduction strategies will be an important first step in removing Northeast Creek, or other water bodies to which this framework is applied, from the list of impaired water bodies, though great responsibility will lie with those who have been tasked with implementation and upkeep of a proposed integrated pollution control system.

3.1 Model Validation

Output from the HSPF model was used to verify that results were consistent with previous work showing that overland FC contributions increase with both rainfall and temperature (Figure 7). Examinations of overland contributions reveal that the highest aggregate monthly loads occurring during those months with the largest aggregate rainfall. There are also implicit indications that temperature is correlated with FC loading as larger amounts are generally observed in the warmer months, though this trend is much less explicit that that with rainfall.

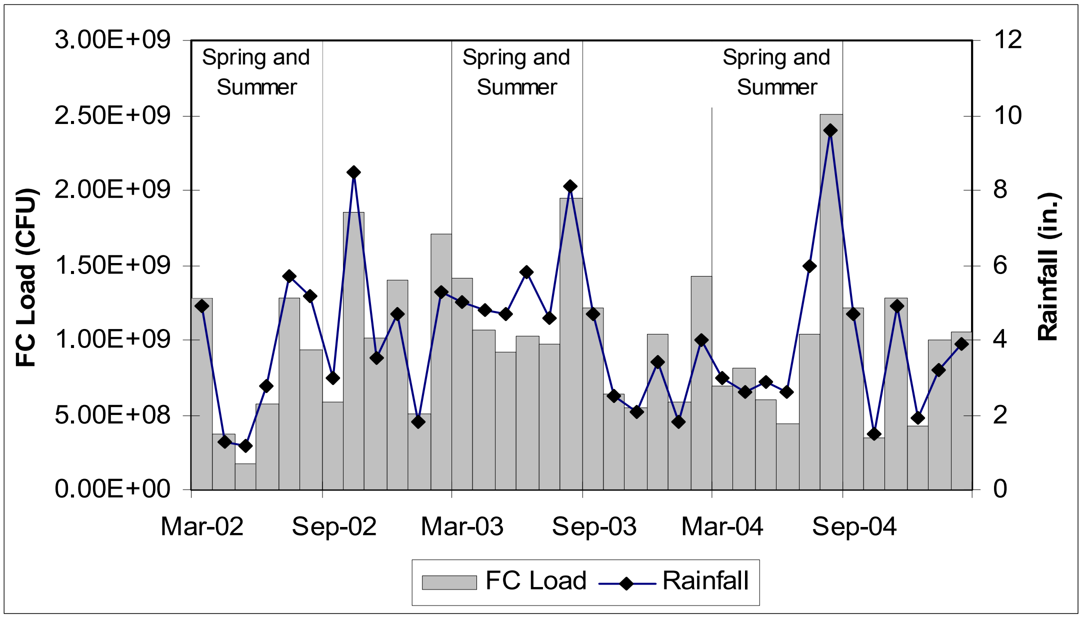
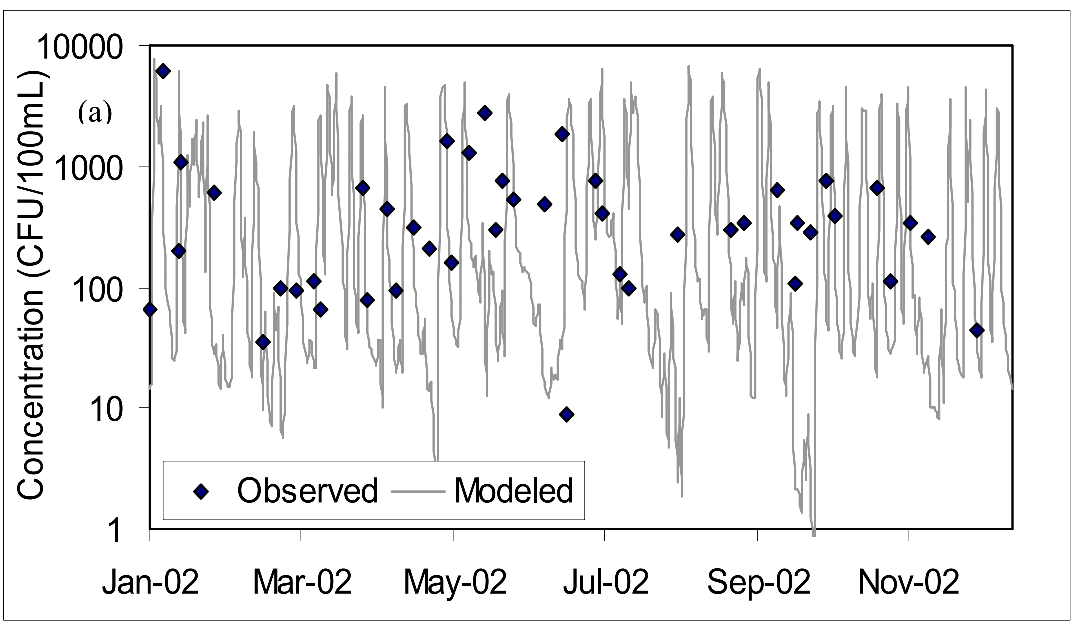


Figure 7: Cumulative monthly rainfall and modeled FC contributions from Subwatershed 1.

Validation of the calibrated model was completed using in-stream FC measurements from January 1,2002- December 31, 2002 (Figure 8a-b).



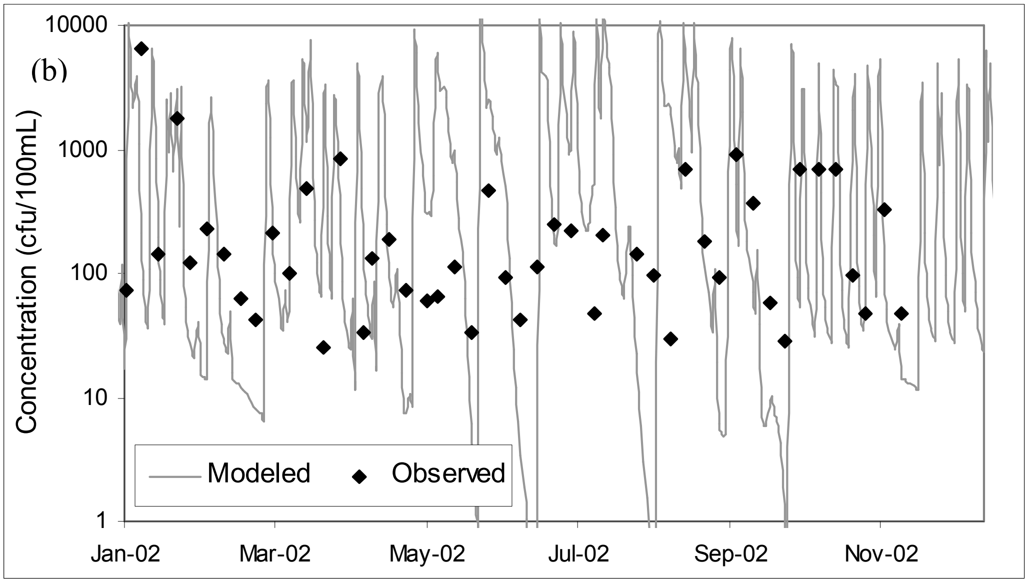


Figure 8: Comparison of Modeled vs. Observed in-stream FC concentrations for (a) Reach 5 and (b) Reach 3 during validation.

Again, as order of magnitude estimations are sufficient in modeling exercises, quantification of error between observed and modeled data took the form of determining the percentage of modeled data points that fell within one order of magnitude of the observed value. For Reach 5, 82% of modeled values (36 out of 44) fell within one order of magnitude of observed data, and, for Reach 3, 90% of values (43 out of 47) met this criterion (Appendix J). Further examination revealed a Spearman's rank correlation coefficient of 0.42 for Reach 5 and 0.63 for Reach 3, which equates to a significance of slightly less than 0.001 between modeled and observed data for Reach 5 and greater than 0.001 for Reach 3.

3.2 Regulatory Violation Validation

According to North Carolina regulations, FC concentrations in surface freshwaters shall not exceed a 5-consecutive sample geometric mean concentration of 200 CFU/100mL, nor exceed 400 CFU/100mL in more than 20% of grab samples

(NCDENR 2004). Consistent with its impaired designation, model results confirm that Northeast Creek regularly violates this standard (Figure 9). For Reach 3, which is directly upstream of the WTWTP, more than 40% of all in-stream geometric mean concentrations and 29% of all daily samples violate North Carolina state standards for the period of January, 2005-June, 2006[10]. For the same period, approximately 30% of geometric mean concentrations and 23% of all daily samples were in violation for reaches below the WWTP, indicating that WWTP effluent generally dilutes in-stream FC concentrations (see Table 2 for further explanation).

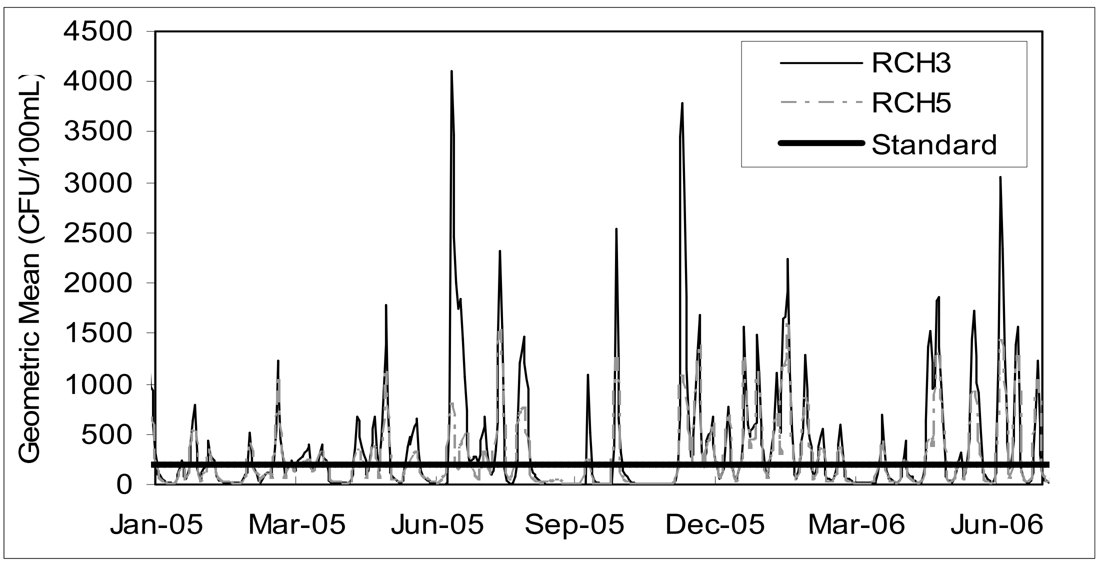


Figure 9: Modeled in-stream 5-day running geometric mean concentration at locations above (Reach 3) and below (Reach 5) the Triangle Wastewater Treatment Plant.

[10] While the model was calibrated for data available in 2001 and 2002, policy suggestions were made for the period of January 1, 2005 – June 30, 2006 due to the installation of additional treatment processes at the WWTP that were fully on-line at the beginning of 2005.

	Dry Weather			Wet Weather[11]		
	MIN	MEAN	MAX	MIN	MEAN	MAX
RCH3	0	486	9781	0	3372	9261
RCH5	1	309	6840	1	2701	7291
WWTP	1	13	905	1	11	116
	Concentrations in CFU/100mL					

Table 2: Summary of in-stream and effluent FC concentrations for the period of January 1, 2005 - June 30, 2006.

As shown, average modeled in-stream FC concentrations under wet weather conditions are nearly an order of magnitude larger, further confirming the importance of storm events for FC transport. Reach 3 is prone to higher in-stream FC concentrations due to the presence of significant amounts of impervious surfaces in the upper reaches of the watershed. Due to comparitively much lower mean FC concentrations in the WWTP effluent, mean in-stream FC concentrations below the WWTP will generally be lower due to dilution.

3.3 Source Loading Identification

Similar to results from previous work (Garcia-Armisen and Servais 2007), modeled results indicate that impervious surfaces in urbanized watersheds routinely yield the vast majority of in-stream FC loading when wastewater discharge is regulated by advanced treatment processes, though this relationship will not hold for watersheds dominated by agricultural land cover. Point source FC contributions from the WWTP, however, are still greater than pervious surface contributions (Figure 10, with more detail in Appendix L).

[11] In this case, wet weather is defined as any day in which the total precipitation is greater than 0.2 inches, which accounts for 15% of days between January 1, 2005 – June 30, 2006.

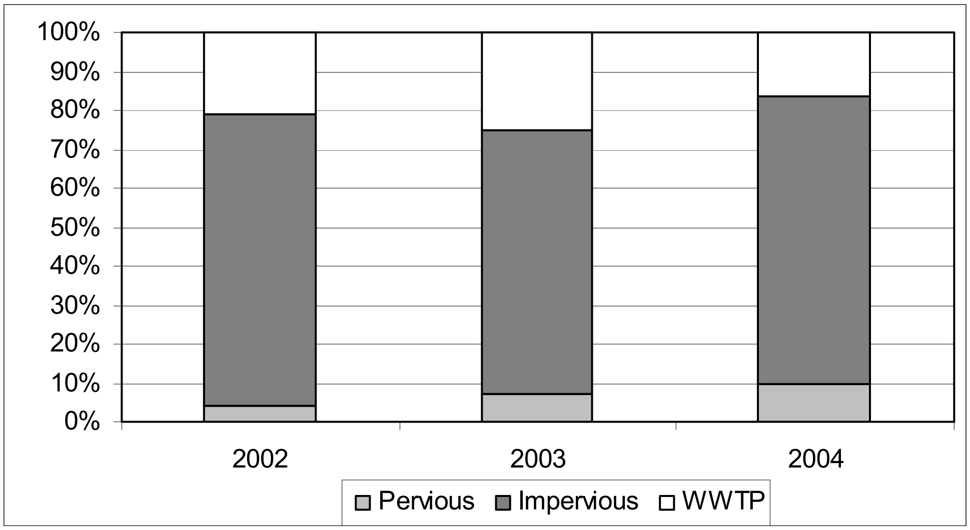


Figure 10: Relative fractions of sources of in-stream fecal coliform loading.

Given that there are currently very few nonpoint source controls in place in the watershed[12], these results indicate that reductions from impervious land segments will be critical in reducing in-stream concentrations to meet regulatory requirements. This also suggests that controls will be most effective when placed in subwatersheds having the greatest amount of impervious surfaces, particularly for those reaches that do not experience the effects of dilution from WWTP effluent.

3.4 Nonpoint Source Controls

The choice and placement of BMPs is at the heart of an effective watershed restoration plan. Though many new development projects are required to include BMPs to counteract the negative effects of land use changes, this does not address the adverse effects associated with pre-existing development. Therefore, the selection of BMPs in this analysis will be made under the assumption that any future net increases in FC

[12] According to correspondence from the City of Durham (2007), only the overland runoff from about 40 acres of pervious and impervious urban areas is subject to nonpoint source controls. This value is likely somewhat greater currently, though, given that the City of Durham has passed an ordinance requiring the use of nonpoint source controls for new projects.

loading associated with land use changes will be addressed accordingly (such as is suggested in Randolph(2004)), allowing this work to be concerned solely with addressing present conditions.

3.4.1 Source Control Examination

Initially, a mixture of nonpoint source BMPs were introduced into the HSPF model was altered to see if necessary reductions in in-stream FC concentrations could be achieved solely through the implementation of either structural or non-structural nonpoint source controls. Maximum coverage of structural nonpoint source controls took the form of stormwater wetlands for urban drainage and buffer strips for all other permeable land cover runoff[13]. Non-structural controls took the form of educational initiatives, increased street sweeping, and wildlife exclusion (to prevent direct deposits from wildlife). However, model output indicated that sufficient reductions could not be achieved along the entire impaired stream length through the implementation of either structural or non-structural nonpoint source controls alone (Figure 11a-b).

[13] Stormwater wetlands were chosen for all urban runoff and buffer strips were chosen for all other permeable land covers due to their having the greatest removal capabilities for the associated land cover types.

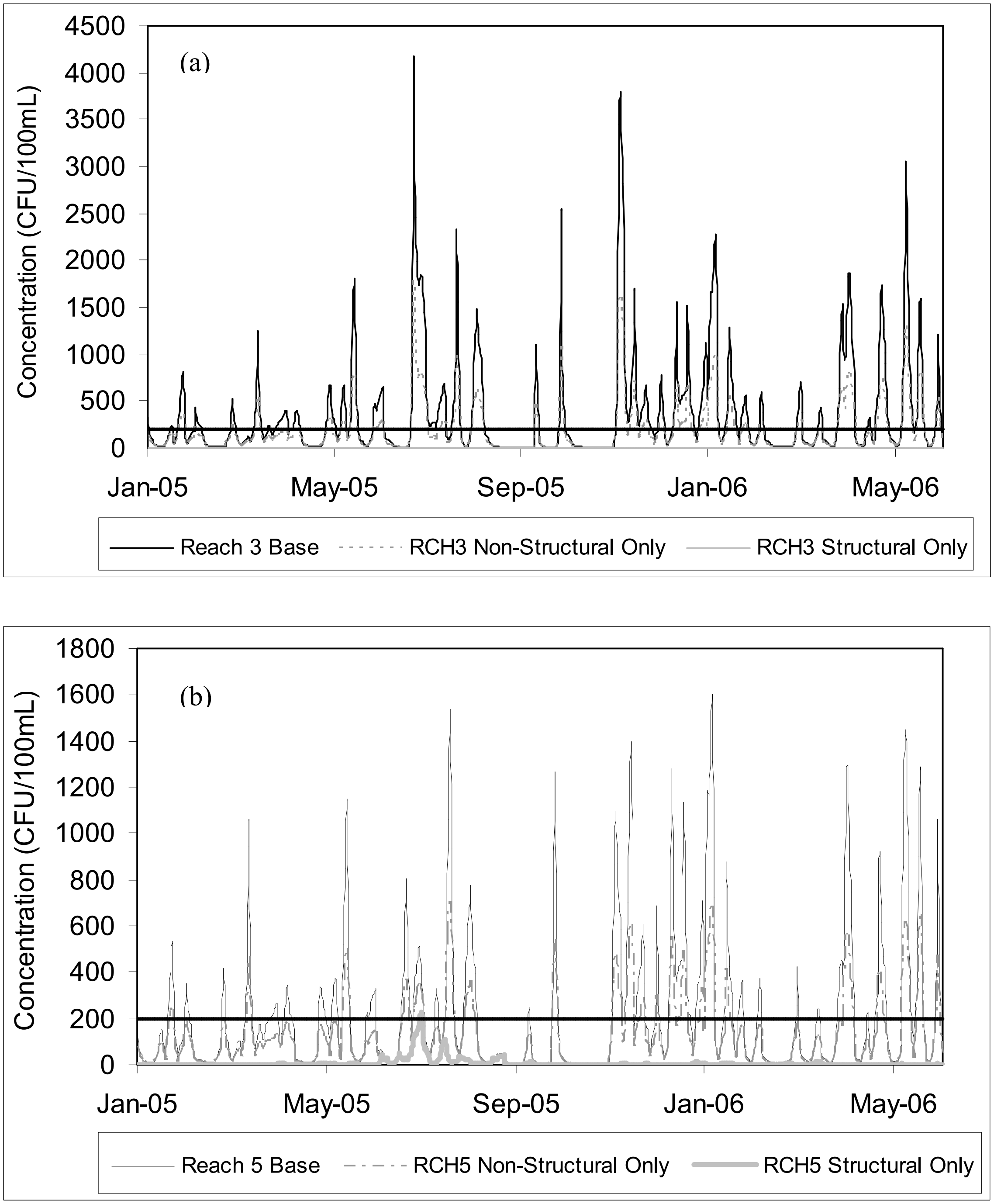


Figure 11: Comparison of source reduction control strategies with baseline conditions for locations (a) above and (b) below the WWTP.

It is important to note that it was feasible to achieve in-stream regulatory compliance for Reach 3 through the introduction of structural nonpoint source controls alone, though this was not possible in Reach 5, indicating that the WWTP effluent concentrations at this instance were sufficient to violate in-stream standards in the absence of any other FC loading within the watershed. Therefore, it is imperative for the WWTP to able to ensure that an additional 1-log removal of the peak effluent loads over the period of January 1, 2005-June 30, 2006 can occur.

3.4.2 BMP Optimization Results

Before the linear optimization model was run using What's Best (Lindo 2006), additional point source controls (representing the assurance of an additional 1-log removal of peak effluent concentrations) and new non-structural nonpoint source controls (representing education initiatives and street sweeping[14]) were introduced into the model. Then, it was possible to determine the lowest cost alternative to address the balance of excess overland FC loadings through a mix of structural BMPs. A summary of the least cost strategy is presented (Table 3, with full details in Appendix N). This scenario minimizes the costs that would be garnered from capital, 20-year maintenance, and land purchase costs.

All Urban		
	Stormwater Wetlands Coverage	Total Cost
Sub 1	51.3%	$671,245
Sub 2	100%	$2,554,782
Sub 3	100%	$1,544,464
Sub 4	100%	$1,640,847
Sub 5	100%	$830,079
Sub 6	19.6%	$218,551
Sub 7	100%	$163,661
Sub 8	100%	$606,605
Sub 9	-	-
Sub 10	100%	$843,030
Sub 11	0%	$0
		$18,149,800

Table 3: Lowest cost strategy of urban land coverage in each subwatershed whose runoff must be intercepted by stormwater wetlands.

The suggested control strategies were then introduced to the calibrated and validated HSPF model to verify that modeled 5-day running geometric mean concentrations do not exceed the state-mandated threshold at any point over the study time period, including the addition of a margin of safety (MOS)

[14] Note that, though wildlife exclusion was initially considered as a potential non-structural BMP, this was not included in the final analysis given concerns over whether this could effectively be implemented, as well as the desire to preserve the natural habitats that exist.

(USEPA 2007d) corresponding to 10% of the standard (Figure 12). This MOS works to ensure that storm events (which are the primary cause of regulatory non-compliance from nonpoint source pollution) larger than those examined would not adversely affect the water body to a point in which it would be out of compliance.

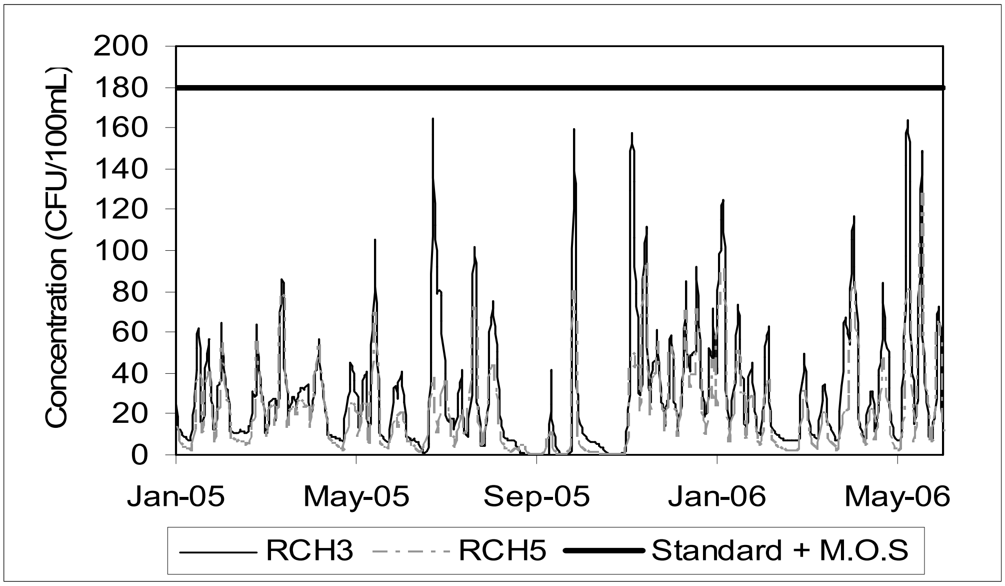


Figure 12: Modeled in-stream running 5-day geometric mean FC concentrations following implementation of least cost BMP allocation scenario.

3.4.3 BMP Costs

As seen, the 20-year costs of structural BMPs alone would be nearly $18,200,000 in present value terms (Table 4). 20-year educational initiative costs of $650,000 are based on the spending budgeted by the North Carolina Clean Water Education Partnership for similar purposes (Bruce 2006). With the inclusion of street sweeper costs of slightly more than $3,000,000, the total value of

Education	$0.65 M
Street Sweeping	
Capital	$0.68 M
O&M	$2.37 M
Structural BMPs	
Capital	$5.13 M
O&M	$5.31 M
Opportunity	$7.71 M
Total	$21.85 M

Table 4: Summary of costs associated with management practices for the control of FC in Northeast Creek watershed

structural and non-structural BMPs rises to around $21,850,000.

In order to cover the costs of the proposed management strategy, each resident (including future residents based upon current population growth trends) would need to contribute $57/year toward the construction and maintenance of this system of BMPs (Appendix O). These costs are substantial, and some point of reference regarding the value that local residents might place on water quality should provide a useful basis for comparison. Though residents in Northeast Creek watershed have not been directly surveyed to determine their willingness to pay for water quality improvements, research in the nearby Catawba River basin of western North Carolina has shown that residents were willing to pay $139/year for five years toward water quality protection, to ensure that the Catawba remains acceptable as both a drinking water source and recreational water body (Eisen-Hecht and Kramer 2002; Kramer and Eisen-Hecht 2002).

Though further efforts will clearly be needed to determine the allocation of fiscal responsibility, understanding the necessary commitment provides a point of reference for the entire project. These results indicate that the necessary reductions can be achieved through a combination of pollutant source controls, but will require constant reassessment vis a vis new projects that lead to net increases in watershed FC loadings. This method of nonpoint source controls selection could develop into an effective tool in the TMDL policy framework, particularly as regards the development of a comprehensive watershed restoration plan.

Chapter IV

Final Remarks

Due to the large number (both nationally and in North Carolina) of microbially impaired water bodies, it is crucial that more concentrated efforts are made to address this issue. This work has done so within the framework of developing a watershed restoration plan for one such impaired water body, Northeast Creek, which is in a representative area of the Piedmont region of North Carolina. This process included the development and calibration of a nonpoint source pollution model focused on fecal coliforms, as well as a strategy to identify a least-cost mitigation strategy to ensure regulatory compliance.

HSPF model calibration was completed using available physical and biological data, with validation yielding greater than 80% of modeled values within an acceptable range of observed data. Ensuring model validation was necessary before utilizing the BMP optimization model. Results from this analysis reveal that the suggested mitigation strategy will have a 20-year present value cost of a little over $20,000,000. This investment will yield dramatic improvements in water quality, allowing Northeast Creek to be declassified as an impaired water body, thereby diminishing the threat to public and environmental health. However, it is the responsibility of public officials and other interested parties to ensure implementation of source controls by developing a means of financing these new initiatives. Were this burden placed entirely on the watershed's residents, it would be necessary for every resident over the next twenty years to pay $57 per year toward the cost of this mitigation plan. This strategy has suggested both structural and non-structural initiatives to ensure regulatory compliance. However, the potential benefits of these controls are contingent upon the incorporation of nonpoint source controls when land use changes cause a net increase in overland microbial loads.

The recommendations that have been presented in this report represent the findings from the usage of the best available technology for watershed modeling that exists at the moment. As with any modeling application, however, there are shortcomings that do exist, such as the lack of sufficient data to perform continuous fecal coliform calibration and validation, the lack of specificity regarding overland fecal coliform loadings, and uncertainties with regard to sanitary sewer and septic system failure rates, all of which lead to rather large error bounds on the magnitude of overland contributions. In addition, there exist large uncertainties on actual versus theoretical fecal coliform removal capability from the selected best management practices. Given these conditions, therefore, it is important to interpret model results with caution given that these results are an accurate representation of the underlying model. Further efforts to improve this work would revolve around better identification of overland sources and their magnitudes, as well as more refined estimations of fecal coliform removal from structural and non-structural best management practices.

The process of watershed assessment, restoration, and management cannot exist within only one sphere of influence, but must be considered in terms of its scientific, environmental, political, and economic characteristics. This project is meant to address the issue of the need for the development of a standardized method for selecting nonpoint source controls within the TMDL policy framework.

Appendix A

Spatial Representation of Northeast Creek Watershed

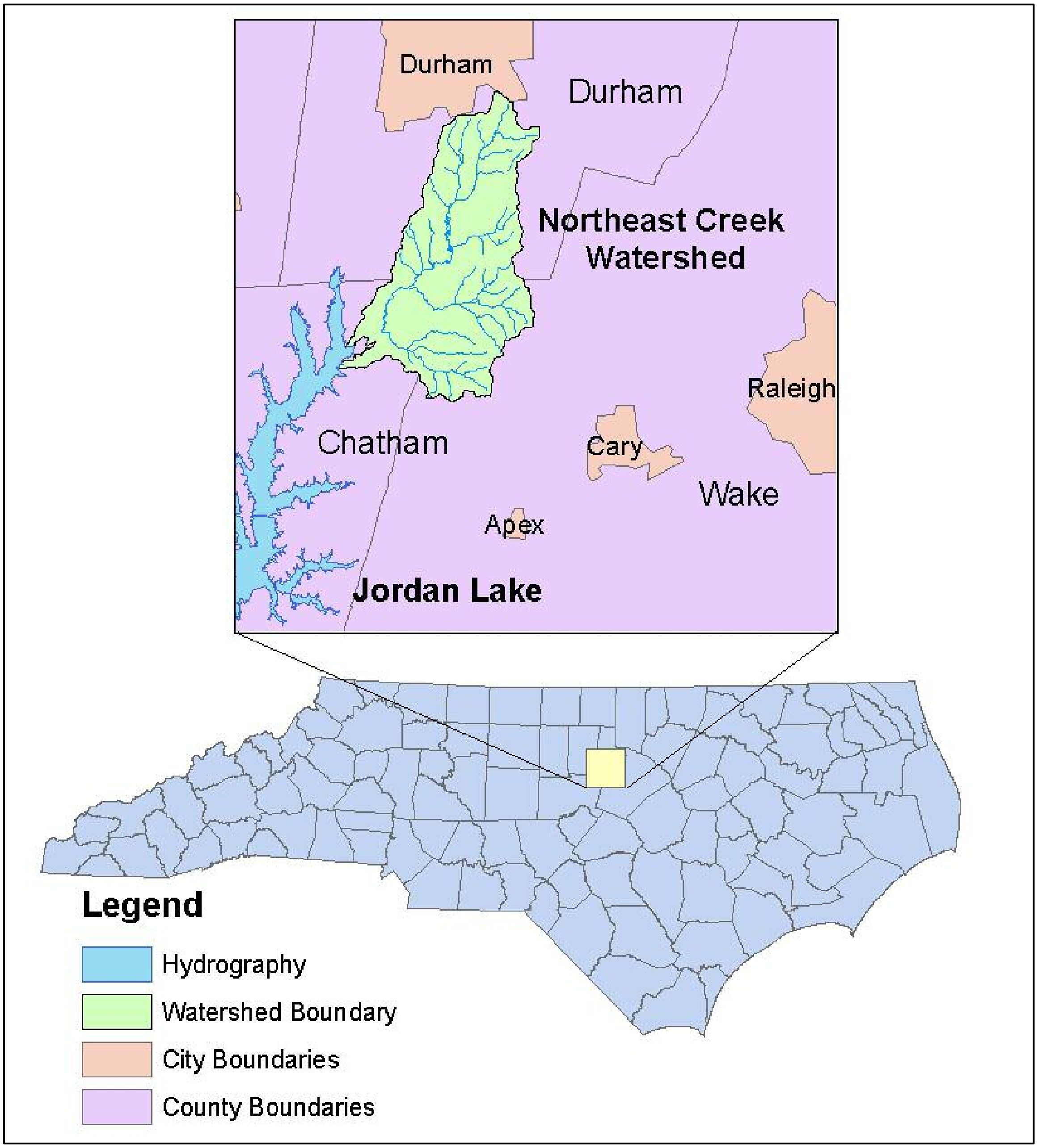


Figure A.1: Placement of Northeast Creek watershed within the Piedmont region of North Carolina.

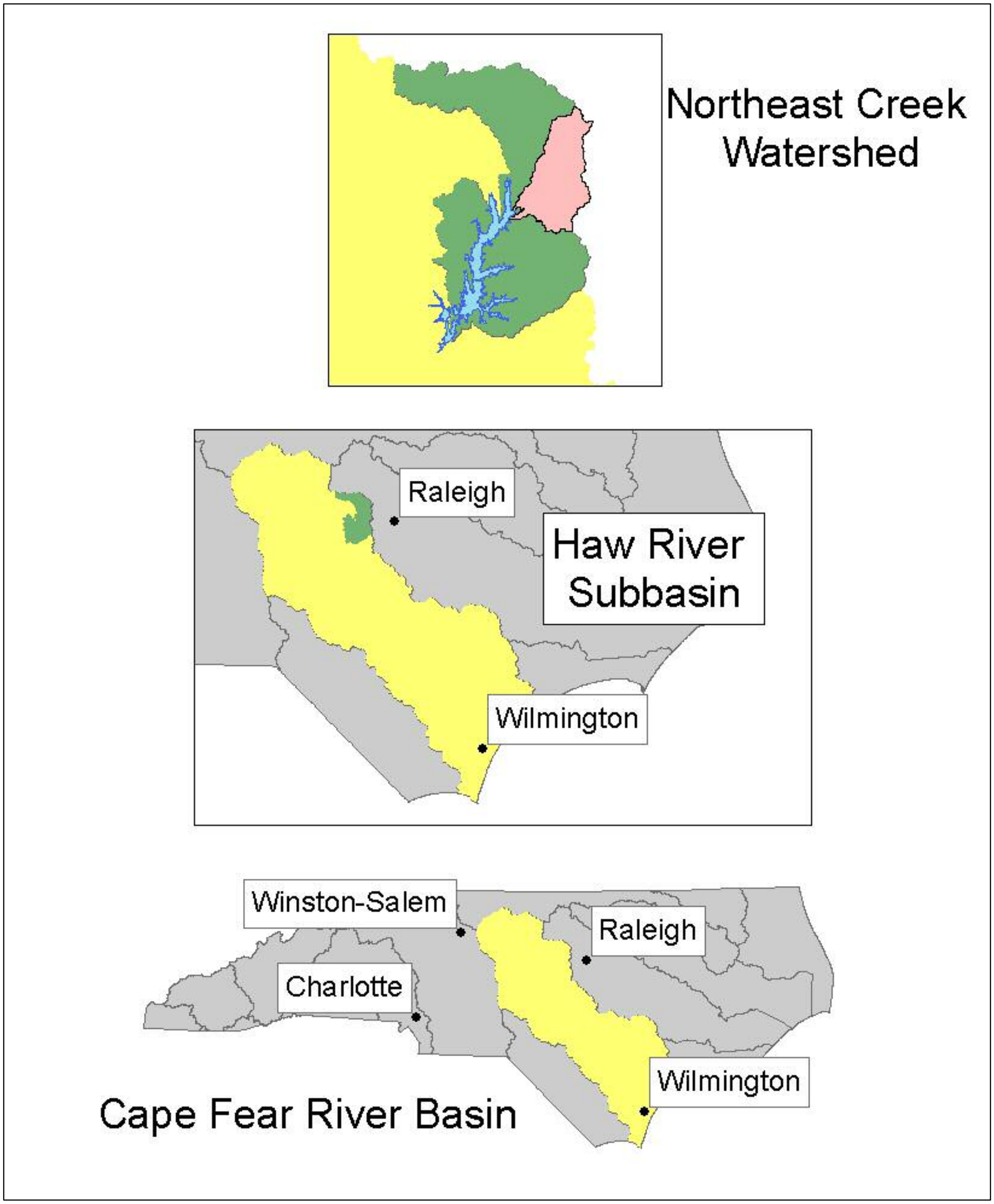


Figure A.2: Placement of Northeast Creek watershed within the Haw River Subbasin and the Cape Fear River Basin.

Appendix B

BASINS subwatershed land use distribution (acres)

	Pervious							Impervious
	Urban	Cropland	Forest	Wetland	Barren	Pasture	Rangeland	Urban
Subwatershed 1	556	22	807	87	22	65	65	556
Subwatershed 2	1085	52	2221	258	52	310	103	1085
Subwatershed 3	656	18	108	288	-	54	36	656
Subwatershed 4	697	65	1329	227	32	130	65	697
Subwatershed 5	353	-	423	197	-	28	56	353
Subwatershed 6	475	203	4270	668	203	271	203	475
Subwatershed 7	70	52	1095	313	17	52	70	70
Subwatershed 8	258	172	3836	401	-	458	344	258
Subwatershed 9	-	18	622	178	-	45	27	-
Subwatershed 10	358	29	387	172	14	14	100	358
Subwatershed 11	3	3	113	8	-	19	11	3
	Percentage of Total Watershed Area							
	14.8%	2.1%	49.8%	9.2%	1.1%	4.7%	3.5%	14.8%

Table B.1: Allocation of land use by subwatershed.

Appendix C

Weather Data Preparation

Weather Data was prepared according to the method established by Zeckoski (2006) at the Virginia Tech Center for TMDL and Watershed Studies.

C.1 Weather Data Requirements

A weather data file for providing the weather data inputs into the HSPF Model was created for the period January 1997 through September 2006 using WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi/hr), total daily solar radiation (Langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Durham, North Carolina, which was located within the Haw River watershed. Hourly precipitation values were obtained from the State Climate Office of North Carolina (SCONC) from four stations (Figure C.1). The raw data required varying amounts of preprocessing within WDMUtil to obtain the following hourly values: precipitation (PREC) (in), air temperature (ATEM) (°F), dew point temperature (DEWP) (°F), solar radiation (SOLR) (Langleys), wind speed (WIND) (mi/hr), potential evapotranspiration (PEVT) (in), potential evaporation (EVAP) (in), and cloud cover (CLOU) (tenths, range 0-10). The final WDM file contains these hourly datasets.

C.2 Raw Data Processing

Weather data were obtained from the NCDC's weather stations in Durham, NC (312515, Lat./Long. 36°03'N/78°58'W, elevation 400 ft) and at the Raleigh-Durham Airport, Wake County, NC (317069, Lat./Long. 35°52'N/78°47'W, elevation 416 ft).

Hourly precipitation data were obtained from the SCONC's weather stations at Chapel Hill-Williams Airport (Lat./Long. 35°93'N/79°07'W, elevation 512 ft), Raleigh-Durham Airport (Lat./Long. 35°52'N/78°47'W, elevation 435 ft), Reedy Creek Field Laboratory (Lat./Long. 35°81'N/78°74'W, elevation 420 ft), and Lake Wheeler Rd. Field Lab (Lat./Long. 35°73'N/78°68'W, elevation 382 ft). The majority of the NCDC data was available since 1980, but the hourly precipitation data was not recorded until the beginning of 1997, thereby setting the starting point for modeling period. Substitutions for missing data are described below. The procedures used to process the raw data to obtain finished data required for input to HSPF are also described in the following sections.

- <u>Hourly Precipitation</u>

  Hourly precipitation (HPCP) data were downloaded from SCONC's web site for four locations over the entire period of record. Given the proximity of the station to the actual watershed boundaries, the Raleigh-Durham Airport (RDU) station was chosen as the base dataset. Of the possible hourly values in this period, only 2% of values were missing. The RDU record was patched with values corresponding to an average of the remaining stations. The resulting file was imported into WDMUtil and given the constituent label "PREC."

- <u>Temperature</u>

  Separate daily maximum temperature (TMAX), daily minimum temperature (TMIN), and daily dew point temperature (DPTP) files were downloaded from the NCDC website for the Durham, NC location. These data had units of tenths of degrees Fahrenheit and were divided by a factor of 10 prior to use in the WDM file. The *disaggregate temperature* function in WDMUtil was used to create an hourly average temperature file (ATEM). The *disaggregate dewpoint temperature* function in WDMUtil was used to create an hourly dewpoint temperature file (DEWP).

- <u>Average Daily Wind Speed</u>

  Average daily wind speed (AWND) was downloaded from the NCDC website from the Durham, NC location. The units of the data were tenths of miles per hour; therefore, the timseries was divided by a factor of 10 prior to use in the WDM file. The *compute wind travel* function in WDMUtil was used to calculate the total wind travel in miles/day. Then the *disaggregate wind travel* function in WDMUtil was used to calculate the hourly wind speed throughout the day (WIND) using the distribution coefficients shown in Table C.1.

Hour	12	1	2	3	4	5	6	7	8	9	10	11
AM	0.035	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.035	0.037	0.041	0.046
PM	0.05	0.053	0.054	0.058	0.057	0.056	0.05	0.043	0.04	0.038	0.036	0.036

Table C.1: hourly distribution coefficients for wind speed.

- <u>Cloud cover and solar radiation</u>

  In the absence of daily cloud cover, percent sun (PSUN) can be used to estimate DCLO. DCLO is used by WDMUtil to estimate hourly cloud cover in tenths (CLOU) as well as solar radiation (SOLR) in Langleys. PSUN was not available at the Durham, NC station, but it was available at the RDU location. However, this data was not available for the period of record specifically. It is noted that the model is rather insensitive to the parameters derived from PSUN; therefore, to bridge the gap of missing data, values from January 1997-September 2006 were filled in by copying the values from January 1985-September 1994.

The *compute percent cloud cover* function in WDMUtil was used to calculate the daily percent cloud cover in tenths (DCLO) from PSUN. Because there is not a *disaggregate percent cloud cover* function available, the *disaggregate wind travel* function was used with hourly distribution coefficients all set to 1 to calculate the hourly percent cloud cover in tenths (CLOU).

The *compute solar radiation* function in WDMUtil was used to calculate the daily solar radiation in Langleys (DSOL) from DCLO and the RDU station latitude (35°52'N). The *disaggregate solar radiation* function was then used to calculate the hourly solar radiation (SOLR).

- <u>Evaporation/Evapotranspiration</u>

  Two types of evaporation/evapotranspiration are required for input to HSPF: potential evaporation from a reach or reservoir surface (EVAP), represented as Penman pan evaporation; and potential evapotranspiration (PEVT), represented as Hamon potential evapotranspiration.

  The *compute Penman pan evaporation* function in WDMUtil was used to calculate daily Penman pan evaporation (DEVP) from TMIN, TMAX, DPTP, TWND, and DSOL. Then the *disaggregate evapotranspiration* function was used to calculate EVAP from DEVP.

The *compute Hamon PET* function in WDMUtil was used to calculate daily potential evapotranspiration (DEVT) from TMIN, TMAX, the RDU station latitude (35°52'N), and monthly coefficients all equal to 0.005. Then the *disaggregate evapotranspiration* function was used to calculate PEVT from DEVT.

C.3 Summary of weather data preparation

The weather data were prepared for input to HSPF as described in the previous section. A summary of the NCDC input parameters, WDMUtil functions used, and final HSPF parameters are presented in Table C.2.

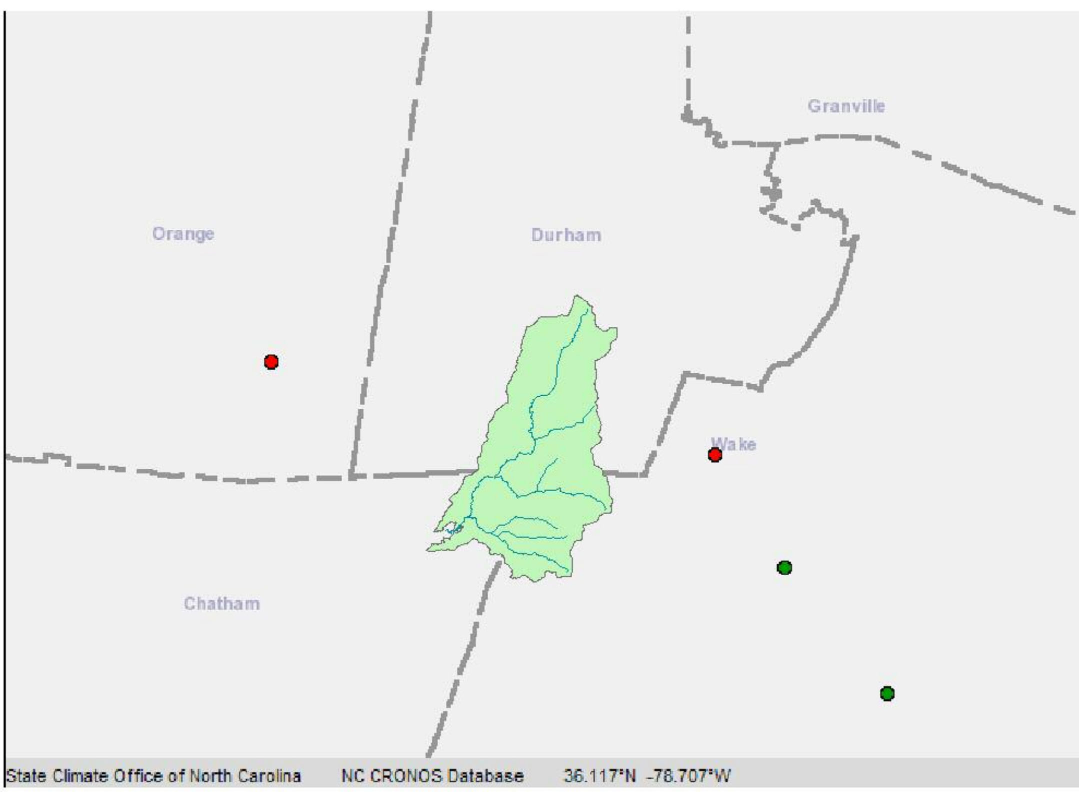


Figure C.1: Spatial locations of four data sources for hourly precipitation as retrieved from the State Climate Office of North Carolina.

NCDC Input Parameters	Intermediate Input	WDMUtil Functions	Intermediate Output	Final HSPF Parameter
HPCP	--	None	--	PREC
TMAX, TMIN	--	Disaggregate temperature	--	ATEM
DPTP	--	Disaggregate dewpoint temperature	--	DEWP
PSUN	--	Compute percent cloud cover	DCLO	--
	DCLO	Disaggregate wind travel[1]	--	CLOU
	DCLO	Compute solar radiation	DSOL	--
	DSOL	Disaggregate solar radiation	--	SOLR
AWND	--	Compute wind travel	TWND	--
	TWND	Disaggregate wind travel	--	WIND
TMAX, TMIN, DPTP	TWND, DSOL	Compute Penman pan evaporation	DEVP	--
	DEVP	Disaggregate evapotranspiration	--	EVAP
TMAX, TMIN	--	Compute Hamon PET	DEVT	--
	DEVT	Disaggregate evapotranspiration	--	PEVT

[1]all hourly coefficients set to 1

Table C.2: Summary of weather input parameters and processing in WDMUtil required for HSPF modeling.

Appendix D

HSPF PERLND Module Processes

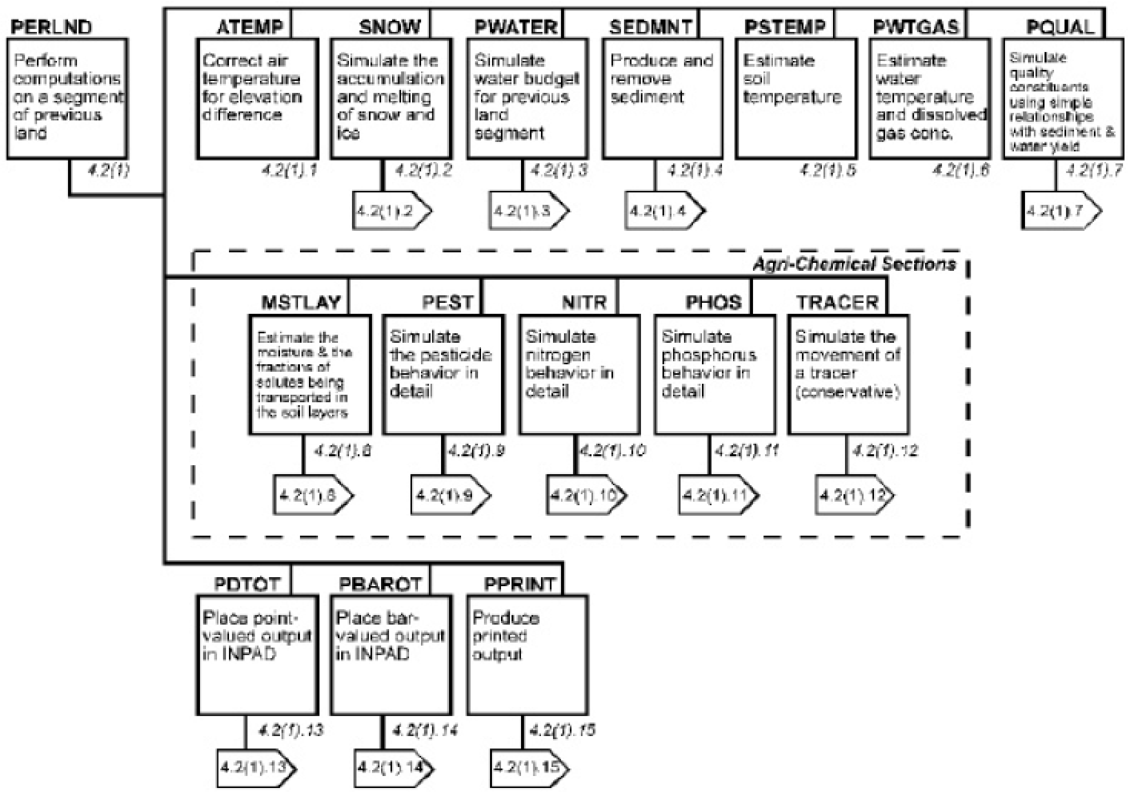


Figure D.1: Structural representation of the PERLND module within HSPF.

For this project, the PWATER, SEDMNT, and PQUAL sections will be developed fully, with model development background being explored more fully below. Further reference can be found in the HSPF User's Manual (Bicknell 2001).

D.1 PERLND PWAT Development

PWAT is dominated by several key processes: overland flow, surface interception, evaporation and evapotranspiration of flow, interflow, and groundwater flow. These processes are interrelated (Figure D.2a-D.2b), and will be explored more fully below.

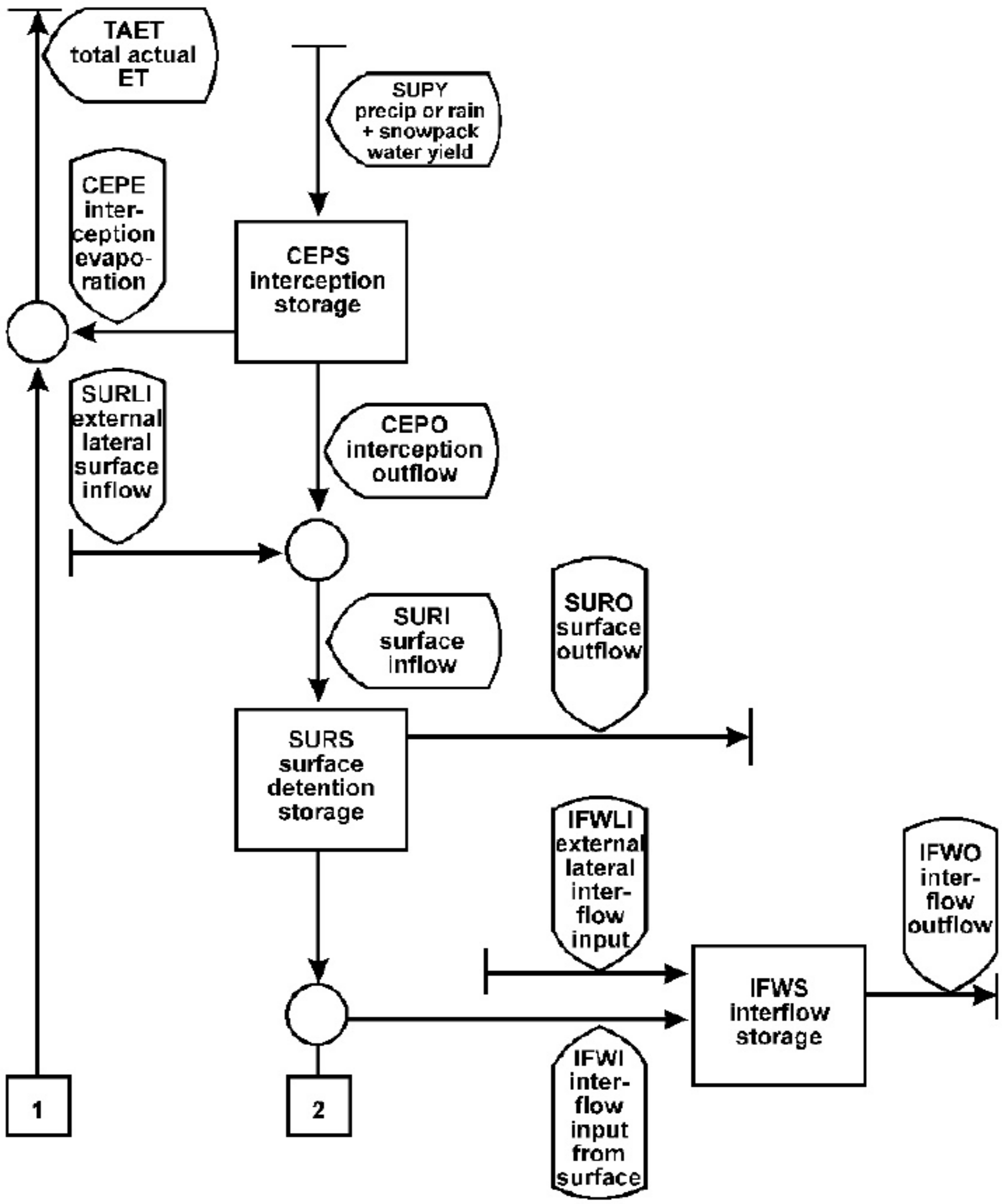


Figure D.2a: Flow diagram of water movement and storage as modeled in the PWAT section of the PERLND module in HSPF.

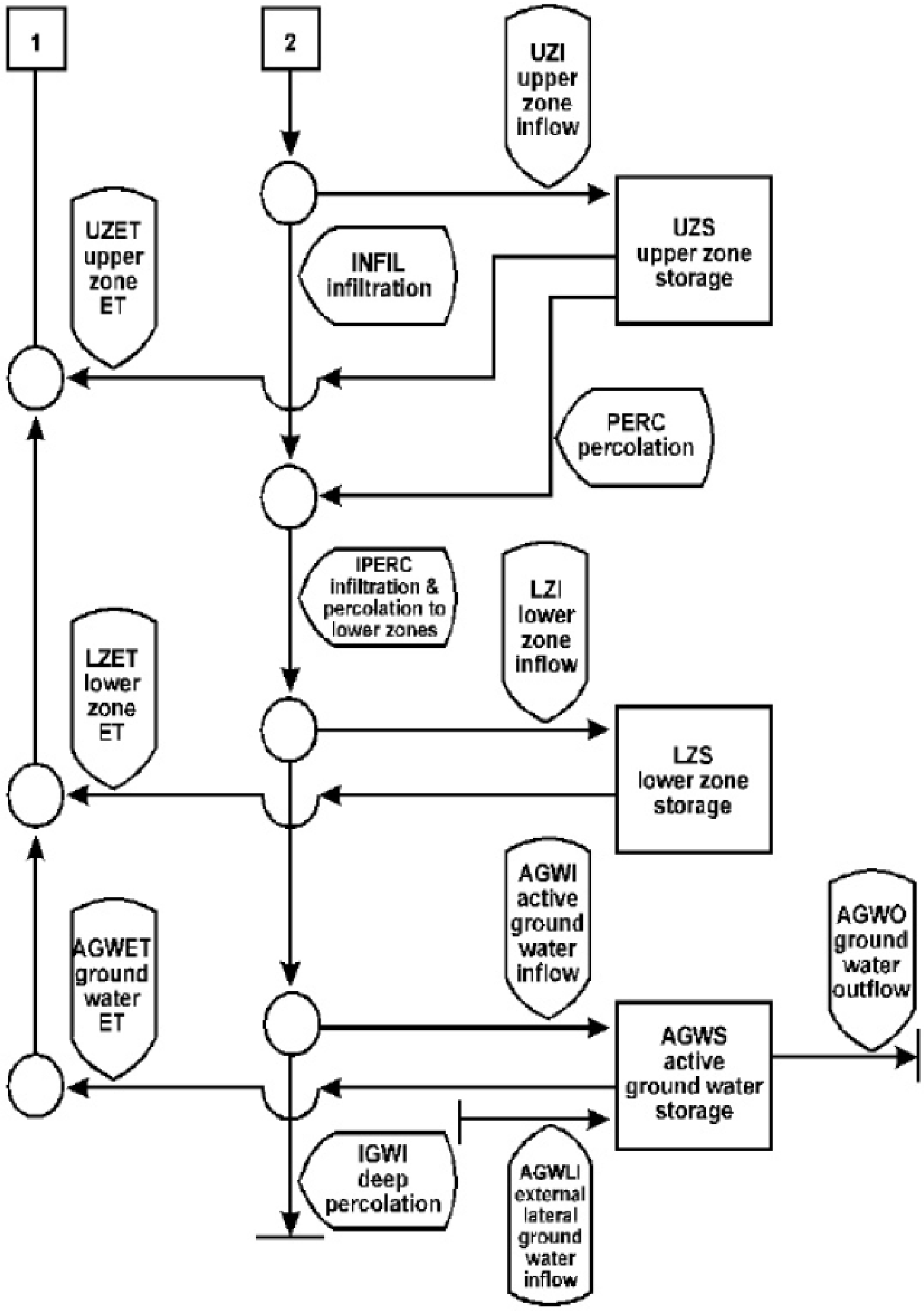


Figure D.2b: Flow diagram of water movement and storage as modeled in the PWAT section of the PERLND module in HSPF.

As illustrated in the previous figures, a balance exists for water interacting with any pervious land segment. This balance can be described by the following:

$$\sum PREC = Runoff + Interflow + GroundwaterFlow + Interception + ET\ ,$$

the parameters for which will be described below.

D.1.1 Infiltration Capacity

Infiltration is important in determining the maximum amount of rainfall that can realistically be absorbed into the soil for a given rainfall event, thereby also providing information as to the runoff. The infiltration capacity of the soil is described by the following equation:

$$IBAR = \left(\frac{INFILT}{\left(\frac{LZS}{LZSN} \right)^{INFEXP}} \right)$$

where:

IBAR = mean infiltration capacity (in/interval)

INFILT = infiltration parameter (in/interval)

LZS = lower zone storage (inches)

LZSN = lower zone nominal storage parameter (inches)

INFEXP = infiltration exponent parameter

D.1.2 Interflow Discharge

Interflow discharge is important when considering that certain runoff events will experience lags due to temporary incorporation into interflow storage. The discharge due to interflow is described by the following equation:

$$IFWO = (IFWK1 * INFLO) + (IFWK2 * IFWS))$$

where

$$IFWK1 = 1.0 - \left(\frac{IFWK2}{KIFW}\right),$$

$$IFWK2 = 1.0 - \exp(-KIFW), and$$

$$KIFW = -\ln(IRC) * \frac{DELT60}{24}$$

where:

IFWO = interflow outflow (in/interval)

INFLO = inflow into interflow storage (in/interval)

IFWS = interflow storage at start of interval (inches)

IRC = interflow recession parameter (1/day)

DELT60 = number of hours per interval

D.1.3 Percolation into Upper Zone Storage

This process describes the amount of water that percolates into upper zone groundwater storage from interflow and is thereby removed from the potential interflow evapotranspiration amount, and is described by the following equation:

$$PERC = 0.1 * INFILT * UZSN * (UZRAT - LZRAT)^3$$

where:

PERC = percolation from the upper zone (in/interval)

INFILT = infiltration parameter

UZSN = upper zone nominal storage parameter (inches)

UZRAT = ratio of upper zone storage to UZSN

LZRAT = ratio of lower zone storage to LZSN

D.1.4 Lower Zone Infiltration

Once water has reached the upper groundwater zone, it either flows laterally through this upper zone or percolates into lower zone groundwater storage. The equation to account for the fraction of water entering lower zone storage is described by the following:

$$LZFRAC = 1.0 - LZRAT * \left(\frac{1}{(1 + INDX)} \right)^{INDX}$$

where

$$INDX = 1.5 * |LZRAT - 1.0| + 1.0$$

where:

LZFRAC = fraction of infiltration plus percolation that enters lower zone storage

LZRAT = ratio of LZS/LZSN

D.1.5 Groundwater Outflow

Once the percolated water has reached the groundwater, it can either flow laterally through the groundwater storage or can be lost into the deep aquifer. The equation to describe the outflow of active groundwater, which will be critically in the development of in-stream base flow during dry weather, is described by the following:

$$AGWO = KGW * (1 + KVARY * GWVS) * AGWS)$$

where:

AGWO = active groundwater outflow (in/interval)

KGW = groundwater outflow recession parameter (1/interval)

KVARY = parameter to account for nonlinearity between active groundwater storage and outflow (1/inches)

GWVS = index to groundwater slope (inches)

AGWS = active groundwater storage at start of interval (inches)

D.1.6 Evapotranspiration Potential

The final element of the water balance for a pervious land segment is contained in the evapotranspiration parameter. Evapotranspiration will be routed through a series of subroutines until the potential has been reached, which are as follows:

- Active groundwater outflow (in-stream base flow)
- Overland interception storage
- Upper zone groundwater storage
- Active groundwater storage
- Lower zone groundwater storage

At any point along this pathway, should be potential evapotranspiration be reached, this parameter will be satisfied.

D.2 PERLND Sediment Development

The accumulation and removal of sediment on permeable land segments are a function of several key parameters (Figure D.3).

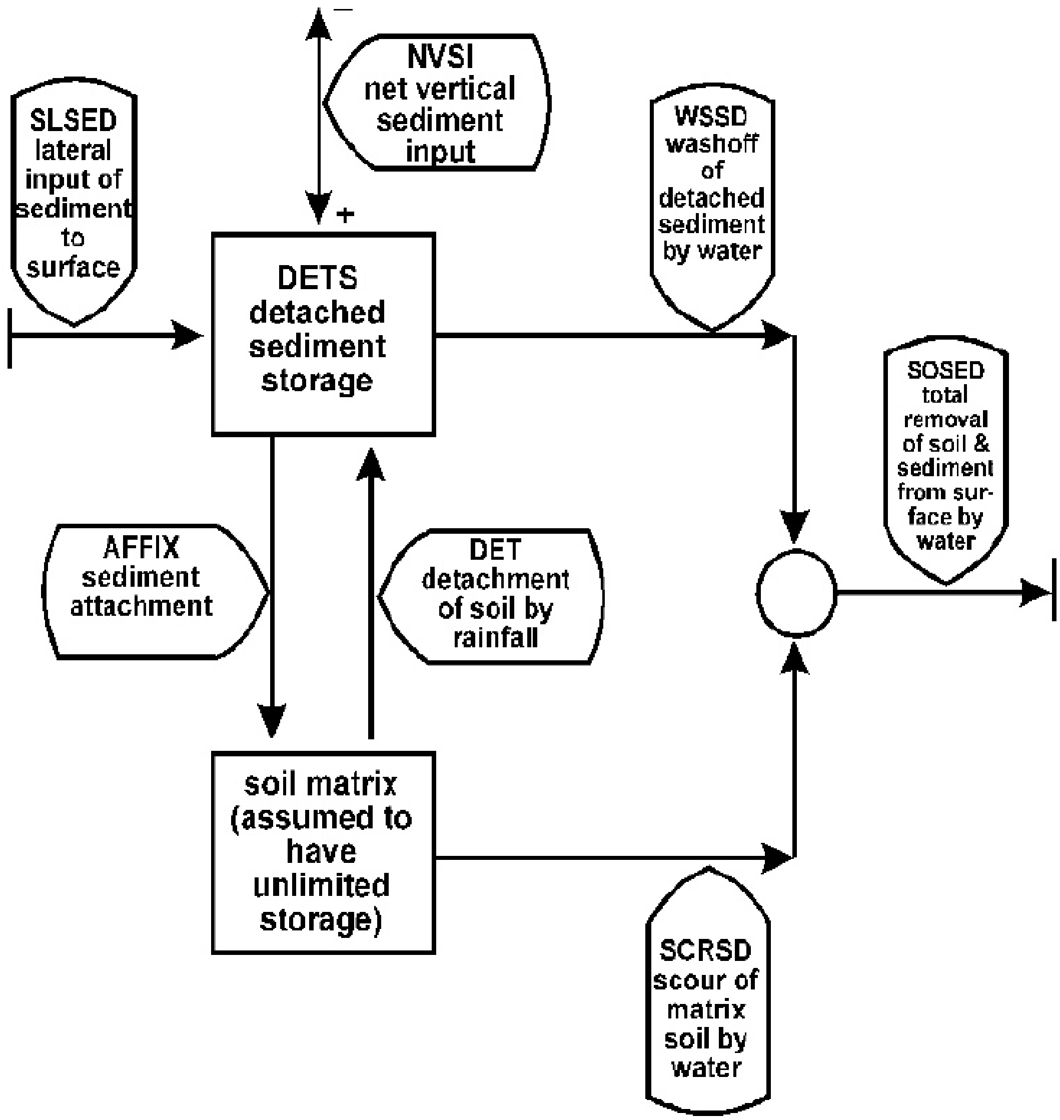


Figure D.3: Flow diagram for sediment processes in the HSPF PERLND module.

D.3 PERLND Quality Constituent Development

The accumulation and removal of quality constituent from a permeable land segment is a function of several key parameters (Figure D.4). This quality constituent is removed from a permeable land segment through the washoff and scouring of the soil matrix, as well as overland flow.

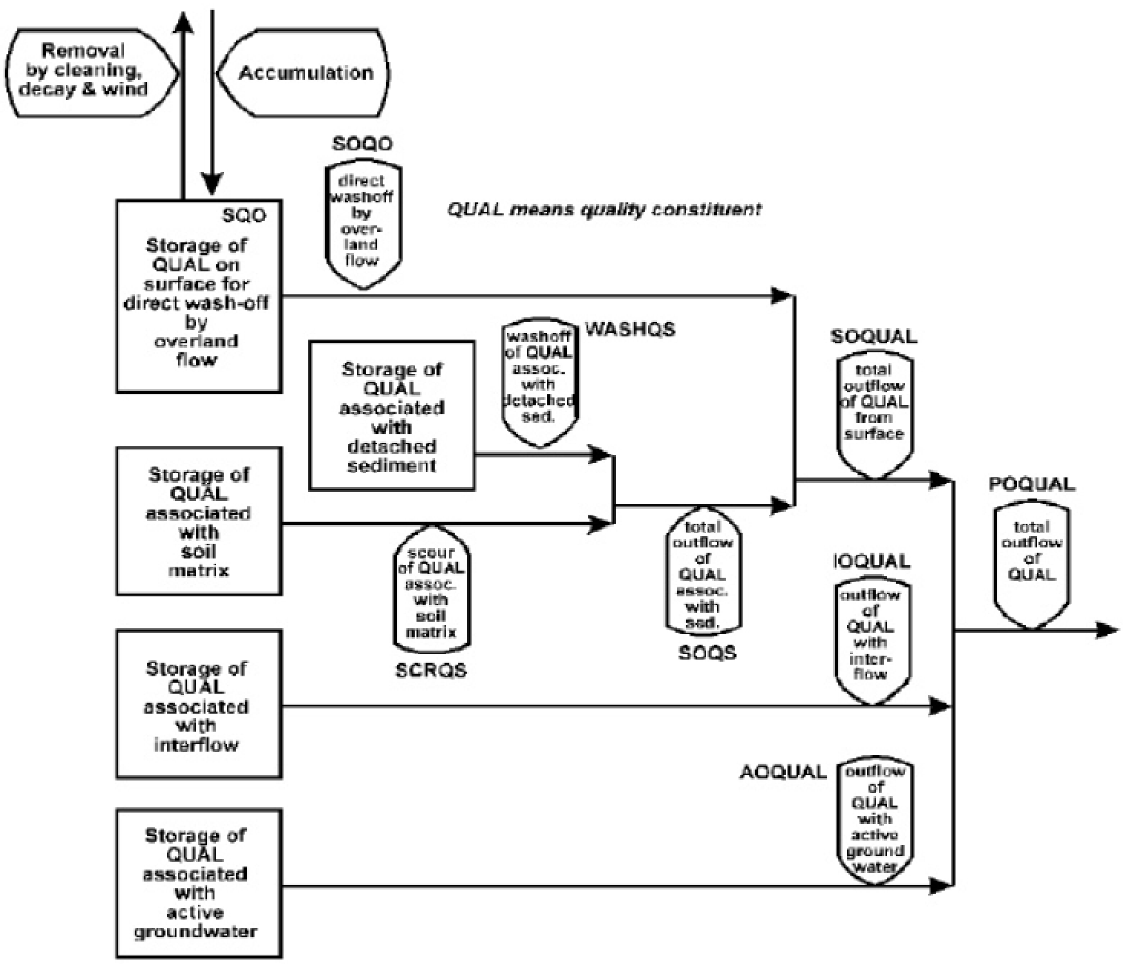


Figure D.4: Flow diagram for quality constituent processes in the HSPF PERLND module.

Appendix E

HSPF IMPLND Module Processes

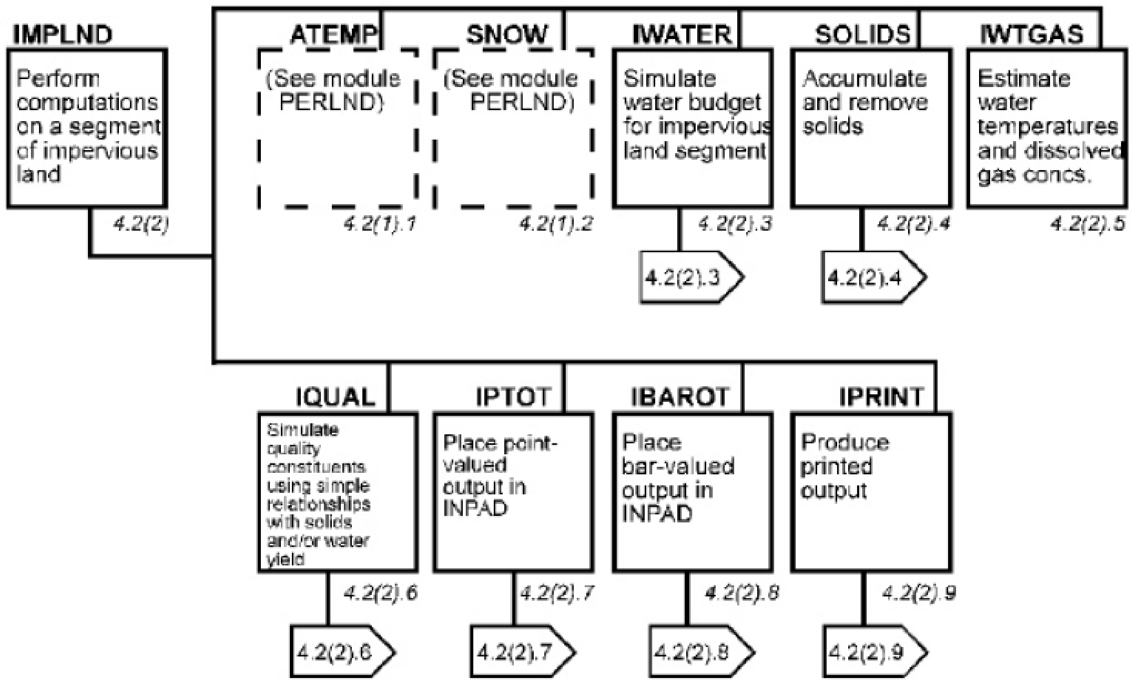


Figure E.1: Structural chart for the IMPLND module of HSPF.

For this project, primary attention will be focused upon the development of modules corresponding to the accumulation and removal of water, solids, and quality constituents. Further theory development can be found in the HSPF User's Manual (Bicknell 2001).

E.1 IMPLND IWATER Module

The accumulation and removal of water (Figure E.2) in the IMPLND module is determined based upon the amount of surface storage that exists on impervious surfaces, which influences the amount of water available for evaporation and surface runoff.

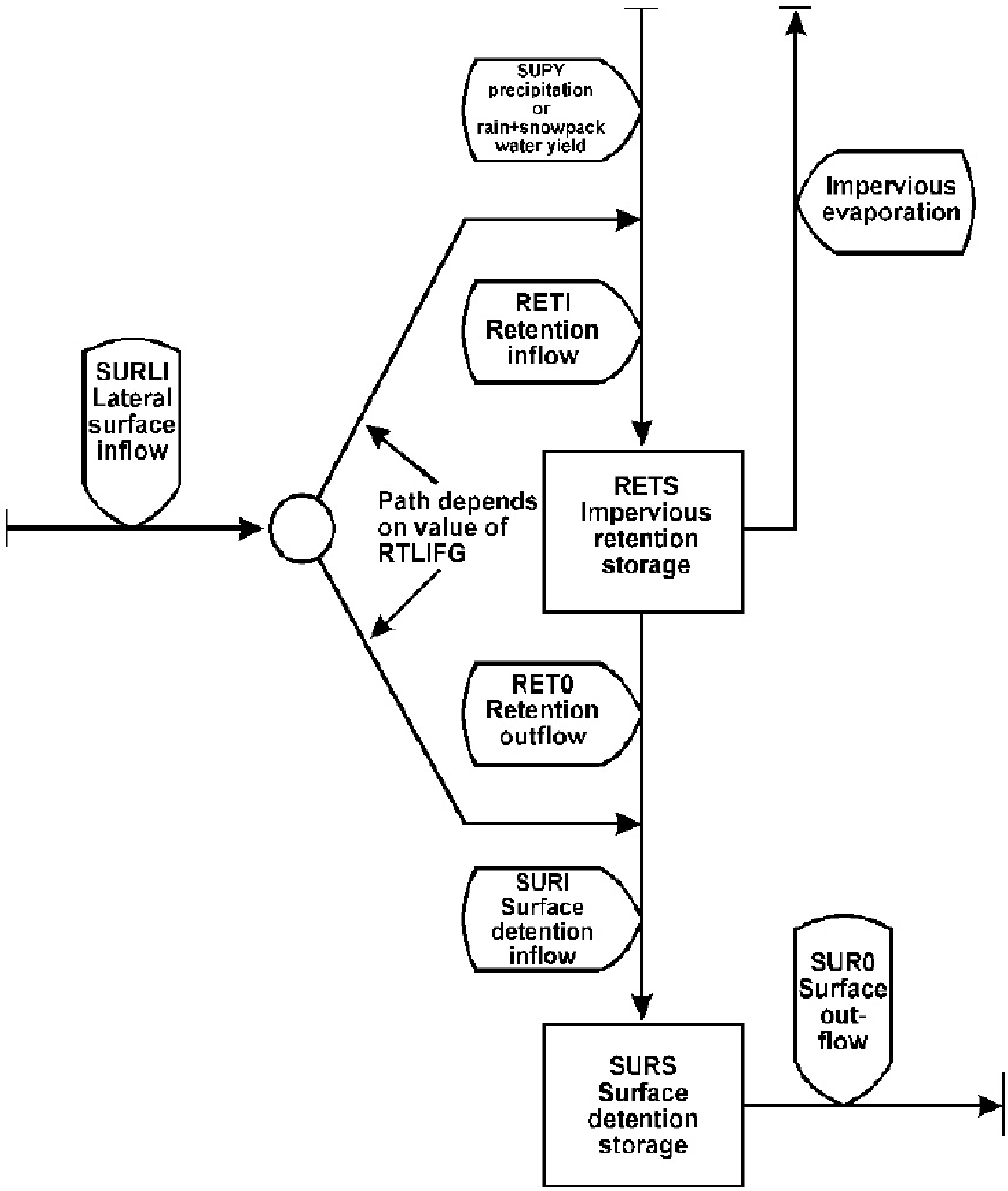


Figure E.2: Flow model for the hydrological processes associated with the IMPLND module in HSPF.

E.2 IMPLND SOLIDS Development

IMPLND solids (Figure E.3) are a function of the total solids storage available in the impervious land segment, from which solids are washed off by overland flow or removed through other processes.

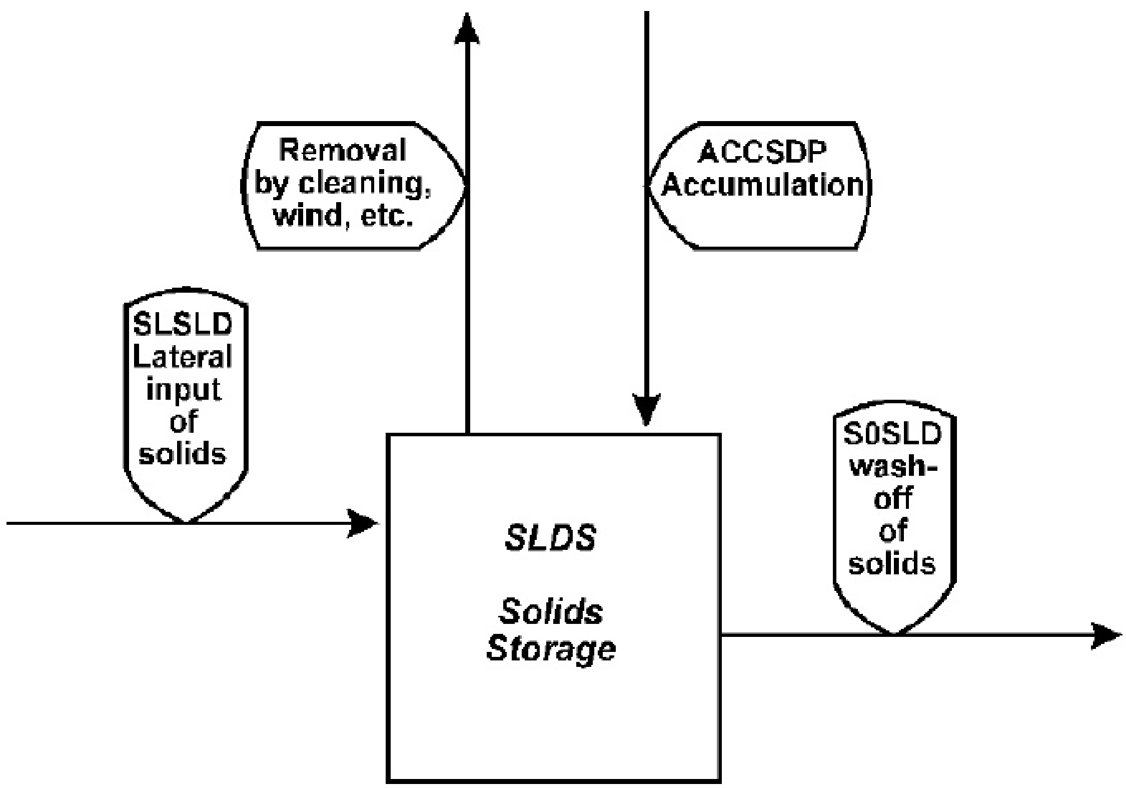


Figure E.3: Flow model for the solids processes associated with the IMPLND module in HSPF.

E.3 IMPLND Quality Constituent Development

In the IMPLND quality constituent process (Figure E.4), quality constituents are associated with both overland flow and stored sediment. The removal can take place either through direct washoff or through other means.

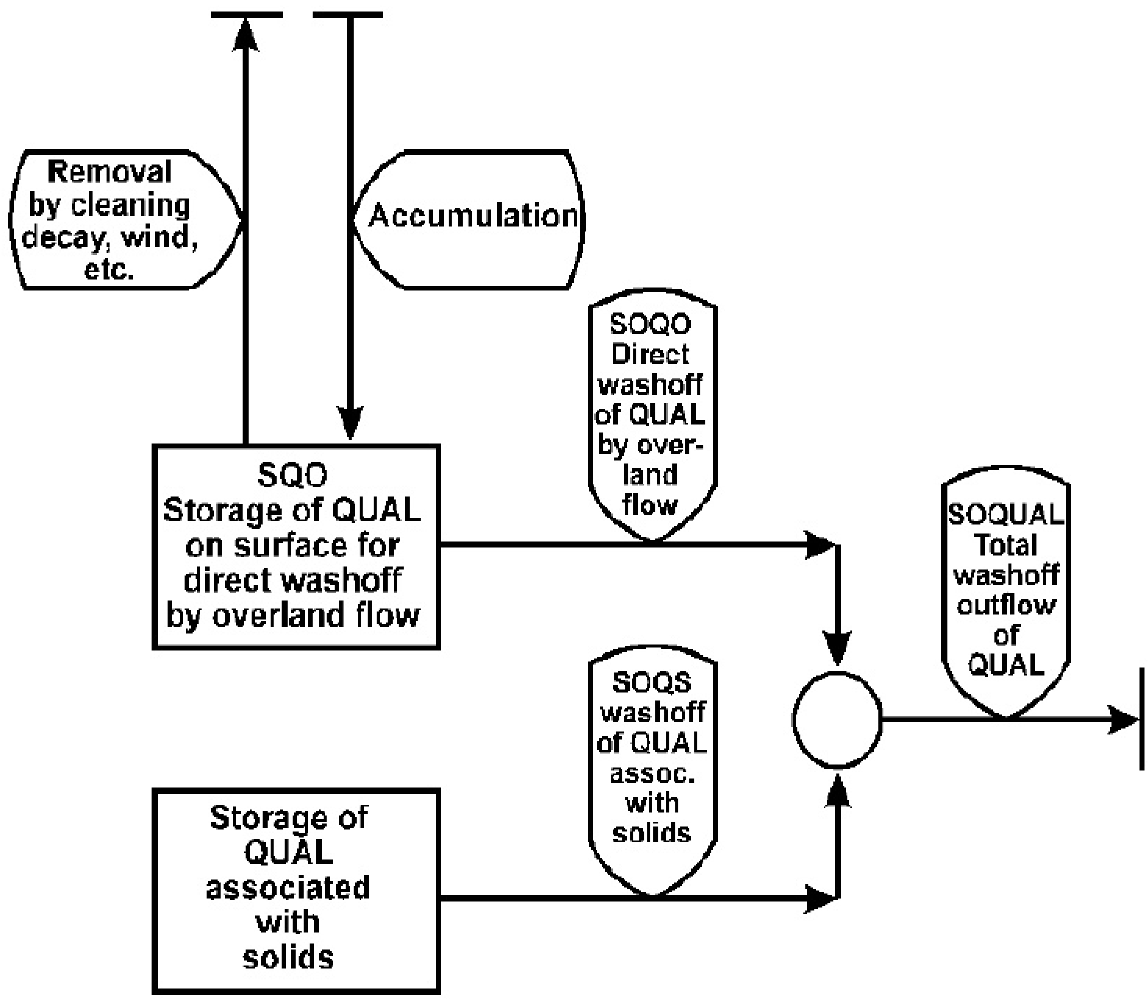


Figure E.4: Flow model for the quality constituent processes associated with the IMPLND module in HSPF.

Appendix F

HSPF PERLND Accumulation Rate Development

The development of fecal coliform production rates is dependent upon several factors: land cover type, domestic and wild animal counts/densities, and season. The Bacterial Indicator Tool (BIT) was utilized in the development of these values. Primary inputs for the BIT include land cover acreage per subwatershed, agricultural animal populations by subwatershed, wildlife population densities per land cover type, and distribution of urban land cover into commercial, residential, and transportation functions. A summary of these input parameters will be discussed below.

F.1 Agricultural Animals

Because the HSPF model was developed to simulate historical conditions, preexisting data on agricultural animal populations were used (NCDENR 2003), and are summarized with respective fecal coliform production rates from the BIT (Table F.1)

Animal	Fecal Coliform Production (CFU/animal/day)	Count
Beef cow	1.04E+11	90
Horse	4.20E+08	230

Table F.1: Population of agricultural animals in Northeast Creek watershed along with their respective fecal coliform production rates.

While agricultural animals are the primary source for fecal coliform in the pasture land cover, wildlife is the dominant source for the forest land cover. The wildlife population densities for the forest land cover, as well as their respective fecal coliform production rates from the BIT are found in Table F.2.

Animal	Fecal Coliform Production (CFU/animal/day)	Forest Density (animal/acre)
Duck	2.43E+09	0.063
Goose	4.90E+10	0.078
Deer	5.00E+08	0.039
Beaver	2.50E+08	0.016
Raccoon	1.25E+08	0.063

Table F.2: Wildlife population densities in the forest land cover, as well as their respective fecal coliform production rates.

Urban accumulation rates are also developed using the BIT. These values are dependent upon the production rate for individual uses within the urban sector, and can be found in Table F.3, as well as the fraction of urban land that is apportioned to each use

Land Use	Fecal Coliform Production (CFU/acre/day)	Fraction of Urban
Road	2.00E+05	0.2
Commercial	6.21E+06	0.2
Single family low density	1.03E+07	0.15
Single family high density	1.66E+07	0.3
Multifamily residential	2.33E+07	0.15

. *Table F.3: Fecal coliform production rates for urban land cover, as well as the fraction of the urban land cover associated with each use.*

Appendix G

HSPF Input Parameters

PERLND Hydrology Parameters and Values

Name	Definition	Units	Range of Values		Chosen
PWAT-PARM2			Min	Max	
FOREST	Fraction forest cover	none	0	0.95	0
LZSN	Lowever zone nominal soil moisture storage	inches	2	15	10
INFILT	Index to infiltration capacity	in/hr	0.001	0.5	0.2
LSUR	Length of overland flow plane	feet	100	700	100-600
SLSUR	Slope of overland flow plane	ft/ft	0.001	0.3	0.01-0.025
KVARY	Variable groundwater recession	1/inches	0	5	1
AGWRC	Base groundwater recession	none	0.85	0.999	0.95
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	32	48	40
PETMIN	Temp below which ET is set to zero	deg. F	30	40	35
INFEXP	Infiltration equation exponent	none	1	3	2
INFILD	Ratio of max/mean infiltration capacities	none	1	3	2
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.5	0.3
BASETP	Fraction of remaining ET from baseflow	none	0	0.2	0.15
AGWETP	Fraction of remaining ET from GW	none	0	0.2	0.1
PWAT-PARM4					
CEPSC	Interception Storage Capacity	inches	0.01	0.4	0.08-.4.0
UZSN	Upper zone nomical soil moisture storage	inches	0.05	2	0.6-2.0
NSUR	Manning's n for overland flow plane	none	0.05	0.5	0.075-0.37
INTFW	Interflow inflow paramter	none	1	10	1
IRC	Interflow recession parameter	none	0.3	0.85	0.3
LZETP	Lower zone ET parameter	none	0.1	0.9	0.6-0.9

PERLND Sediment Parameters and Values

Name	Definition	Units	Range of Values		Chosen
SED-PARM2			Min	Max	
SMPF	Management Practive factor from USLE	none	0	1	1
KRER	Coefficient in soil detachment equation	complex	0.05	0.75	0.4
JRER	Exponent in soil detachment equation	none	1	3	2
AFFIX	Daily reduction in detached sediment	1/day	0.01	0.5	0.002-.01
COVER	Fraction land surface protected from rain	none	0	0.98	0.1
NVSI	Atmospheric additions to sediment storage	lb/ ac-day	0	20	1
SED-PARM3					
KSER	Coefficient in soil washoff equation	complex	0.1	10	1.0-4.5
JSER	Exponent in soil washoff equation	none	1	3	1.6
KGER	Coefficient in soil matrix scour equation	complex	0	10	0
JGER	Exponent in soil matrix scour equation	none	1	5	2

PERLND Quality Constituent Parameters and Values

Name	Definition	Units	Range of Values		Chosen
QUAL-INPUT			Min	Max	
SQO	Initial storage of QUAL on surface	qty/ac			4.00E+09
POTFW	Washoff potency factor	qty/ton			0
POTFS	Scour potency factor	qty/ton			0
ACQOP	Rate of accumulation of QUAL	qty/ac-day			2e7-2e10
SQOLIM	Maximum storage of QUAL	qty/ac			7e7-6e10
WSQOP	Surface runoff rate to remove 90% of QUAL/ hr	in/hr			1.4-1.7
IOQC	QUAL concentration in interflow outflow	qty/ft3			15000
AOQC	QUAL concentration in GW outflow	qty/ft3			6000

IMPLND Hydrology Parameters and Values

Name	Definition	Units	Range of Values		Chosen
IWAT-PARM2			Min	Max	
LSUR	Length of overland flow plane	feet	50	250	350
SLSUR	Slope of overland flow plane	ft/ft	0.001	0.15	0.01
NSUR	Manning's n for overland flow plane	none	0.01	0.15	0.08
RETSC	Retention Storage Capacity	inches	0.01	0.3	0.25
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	32	48	40
PETMIN	Temp below which ET is set to zero	deg. F	30	40	35

IMPLND Sediment Parameters and Values

Name	Definition	Units	Range of Values		Chosen
SLD-PARM2			Min	Max	
KEIM	Coefficient in solids washoff equation	complex	0.1	10	2
JEIM	Exponent in solids washoff equation	none	1	3	1.8
ACCSDP	Solids accumulation rate of land surface	ton/ac-day	0	0.015	0.001
REMSDP	Fraction of solids removed per day	1/day	0.01	1	0.05

IMPLND Quality Constituent Parameters and Values

Name	Definition	Units	Range of Values		Chosen
QUAL-INPUT			Min	Max	
SQO	Initial storage of QUAL on surface	qty/ac			4.00E+09
POTFW	Washoff potency factor	qty/ton			1
ACQOP	Rate of accumulation of QUAL	qty/ac-day			4.00E+09
SQOLIM	Maximum storage of QUAL	qty/ac			7.20E+09
WSQOP	Surface runoff rate to remove 90% of QUAL/ hr	in/hr			0.9

Table G.1: Summary of HSPF Parameters

Appendix H

HSPF Input Code

```
RUN

GLOBAL
  UCI Created by WinHSPF for 01242007
  START       2001/01/01 00:00  END    2006/09/21 00:00
  RUN INTERP OUTPT LEVELS    1    0
  RESUME     0 RUN     1                       UNITS    1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
MESSU      24   01242007.ech
           91   01242007.out
WDM1       25   NECreekJan2402.wdm
WDM2       26   NCMet.wdm
BINO       92   01242007.hbn
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND      11
      PERLND      12
      PERLND      13
      PERLND      14
      PERLND      15
      PERLND      16
      PERLND      17
      IMPLND      11
      PERLND      21
      PERLND      22
      PERLND      23
      PERLND      24
      PERLND      25
      PERLND      26
      PERLND      27
      IMPLND      21
      PERLND      31
      PERLND      32
      PERLND      33
      PERLND      34
      PERLND      36
      PERLND      37
      IMPLND      31
      PERLND      41
      PERLND      42
      PERLND      43
```

PERLND	44
PERLND	45
PERLND	46
PERLND	47
IMPLND	41
PERLND	51
PERLND	53
PERLND	54
PERLND	56
PERLND	57
IMPLND	51
PERLND	111
PERLND	112
PERLND	113
PERLND	114
PERLND	116
PERLND	117
IMPLND	111
PERLND	101
PERLND	102
PERLND	103
PERLND	104
PERLND	105
PERLND	106
PERLND	107
IMPLND	101
PERLND	71
PERLND	72
PERLND	73
PERLND	74
PERLND	75
PERLND	76
PERLND	77
IMPLND	71
PERLND	92
PERLND	93
PERLND	94
PERLND	96
PERLND	97
PERLND	61
PERLND	62
PERLND	63
PERLND	64
PERLND	65
PERLND	66
PERLND	67
IMPLND	61
PERLND	81
PERLND	82
PERLND	83
PERLND	84

```
    PERLND     86
    PERLND     87
    IMPLND     81
    RCHRES      1
    RCHRES      2
    RCHRES      3
    RCHRES      4
    RCHRES     10
    RCHRES     11
    RCHRES      5
    RCHRES      6
    RCHRES      8
    RCHRES      7
    RCHRES      9
  END INGRP
END OPN SEQUENCE

PERLND
 ACTIVITY
*** <PLS >             Active Sections                         ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  11  117    1    0    1    1    1    1    1    0    0    0    0    0
 END ACTIVITY

 PRINT-INFO
*** < PLS>                  Print-flags                        PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  11  117    4    4    4    4    4    4    4    4    4    4    4    4    1    9
 END PRINT-INFO

 BINARY-INFO
*** < PLS>             Binary Output Flags                        PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  11  117    4    4    4    4    4    4    4    4    4    4    4    4    1    9
 END BINARY-INFO

 GEN-INFO
***           Name                 Unit-systems   Printer BinaryOut
*** <PLS >                            t-series Engl Metr Engl Metr
*** x -  x                           in  out
  11     Urban or Built-up La            1    1    0    0    0    0
  12     Agricultural Land               1    1    0    0    0    0
  13     Forest Land                     1    1    0    0    0    0
  14     Wetland                         1    1    0    0    0    0
  15     Barren Land                     1    1    0    0    0    0
  16     Pasture                         1    1    0    0    0    0
  17     Rangeland                       1    1    0    0    0    0
  21     Urban or Built-up La            1    1    0    0    0    0
  22     Agricultural Land               1    1    0    0    0    0
  23     Forest Land                     1    1    0    0    0    0
  24     Wetland                         1    1    0    0    0    0
```

25	Barren Land	1	1	0	0	0	0
26	Pasture	1	1	0	0	0	0
27	Rangeland	1	1	0	0	0	0
31	Urban or Built-up La	1	1	0	0	0	0
32	Agricultural Land	1	1	0	0	0	0
33	Forest Land	1	1	0	0	0	0
34	Wetland	1	1	0	0	0	0
36	Pasture	1	1	0	0	0	0
37	Rangeland	1	1	0	0	0	0
41	Urban or Built-up La	1	1	0	0	0	0
42	Agricultural Land	1	1	0	0	0	0
43	Forest Land	1	1	0	0	0	0
44	Wetland	1	1	0	0	0	0
45	Barren Land	1	1	0	0	0	0
46	Pasture	1	1	0	0	0	0
47	Rangeland	1	1	0	0	0	0
51	Urban or Built-up La	1	1	0	0	0	0
53	Forest Land	1	1	0	0	0	0
54	Wetland	1	1	0	0	0	0
56	Pasture	1	1	0	0	0	0
57	Rangeland	1	1	0	0	0	0
61	Urban or Built-up La	1	1	0	0	0	0
62	Agricultural Land	1	1	0	0	0	0
63	Forest Land	1	1	0	0	0	0
64	Wetland	1	1	0	0	0	0
65	Barren Land	1	1	0	0	0	0
66	Pasture	1	1	0	0	0	0
67	Rangeland	1	1	0	0	0	0
71	Urban or Built-up La	1	1	0	0	0	0
72	Agricultural Land	1	1	0	0	0	0
73	Forest Land	1	1	0	0	0	0
74	Wetland	1	1	0	0	0	0
75	Barren Land	1	1	0	0	0	0
76	Pasture	1	1	0	0	0	0
77	Rangeland	1	1	0	0	0	0
81	Urban or Built-up La	1	1	0	0	0	0
82	Agricultural Land	1	1	0	0	0	0
83	Forest Land	1	1	0	0	0	0
84	Wetland	1	1	0	0	0	0
86	Pasture	1	1	0	0	0	0
87	Rangeland	1	1	0	0	0	0
92	Agricultural Land	1	1	0	0	0	0
93	Forest Land	1	1	0	0	0	0
94	Wetland	1	1	0	0	0	0
96	Pasture	1	1	0	0	0	0
97	Rangeland	1	1	0	0	0	0
101	Urban or Built-up La	1	1	0	0	0	0
102	Agricultural Land	1	1	0	0	0	0
103	Forest Land	1	1	0	0	0	0
104	Wetland	1	1	0	0	0	0
105	Barren Land	1	1	0	0	0	0

```
 106     Pasture                      1    1    0    0    0    0
 107     Rangeland                     1    1    0    0    0    0
 111     Urban or Built-up La            1    1    0    0    0    0
 112     Agricultural Land              1    1    0    0    0    0
 113     Forest Land                   1    1    0    0    0    0
 114     Wetland                      1    1    0    0    0    0
 116     Pasture                      1    1    0    0    0    0
 117     Rangeland                     1    1    0    0    0    0
 END GEN-INFO

 ATEMP-DAT
*** <PLS >     ELDAT    AIRTEMP
*** x -  x      (ft)    (deg F)
  11  117       0.       33.
 END ATEMP-DAT

 SNOW-PARM1
*** < PLS>      LAT     MELEV     SHADE    SNOWCF    COVIND     KMELT     TBASE
*** x  - x   degrees      (ft)                       (in)  (in/d.F)      (F)
  11  117       40.      800.       0.3       1.2       10.        0.       32.
 END SNOW-PARM1

 PWAT-PARM1
*** <PLS >                  Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG IFRD
  11         0    1    1    1    0    0    0    0    1    1    0    0    0
  12         0    1    1    1    1    1    0    0    1    1    0    0    0
  13   21    0    1    1    1    0    0    0    0    1    1    0    0    0
  22         0    1    1    1    1    1    0    0    1    1    0    0    0
  23   31    0    1    1    1    0    0    0    0    1    1    0    0    0
  32         0    1    1    1    1    1    0    0    1    1    0    0    0
  33   41    0    1    1    1    0    0    0    0    1    1    0    0    0
  42         0    1    1    1    1    1    0    0    1    1    0    0    0
  43   61    0    1    1    1    0    0    0    0    1    1    0    0    0
  62         0    1    1    1    1    1    0    0    1    1    0    0    0
  63   71    0    1    1    1    0    0    0    0    1    1    0    0    0
  72         0    1    1    1    1    1    0    0    1    1    0    0    0
  73   81    0    1    1    1    0    0    0    0    1    1    0    0    0
  82         0    1    1    1    1    1    0    0    1    1    0    0    0
  83   87    0    1    1    1    0    0    0    0    1    1    0    0    0
  92         0    1    1    1    1    1    0    0    1    1    0    0    0
  93  101    0    1    1    1    0    0    0    0    1    1    0    0    0
 102         0    1    1    1    1    1    0    0    1    1    0    0    0
 103  111    0    1    1    1    0    0    0    0    1    1    0    0    0
 112         0    1    1    1    1    1    0    0    1    1    0    0    0
 113  117    0    1    1    1    0    0    0    0    1    1    0    0    0
 END PWAT-PARM1

 PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                 (in)   (in/hr)      (ft)              (1/in)   (1/day)
```

11	0.	10.	0.2	300.	0.015	1.	0.95
12	0.	10.	0.2	500.	0.01	1.	0.95
13	0.	10.	0.2	600.	0.025	1.	0.95
14	0.	10.	0.2	100.	0.01	1.	0.95
15	0.	9.	0.2	600.	0.015	1.	0.95
16	0.	10.	0.2	500.	0.015	1.	0.95
17	0.	10.	0.2	500.	0.02	1.	0.95
21	0.	10.	0.2	300.	0.015	1.	0.95
22	0.	10.	0.2	500.	0.01	1.	0.95
23	0.	10.	0.2	600.	0.025	1.	0.95
24	0.	10.	0.2	100.	0.01	1.	0.95
25	0.	9.	0.2	600.	0.015	1.	0.95
26	0.	10.	0.2	500.	0.015	1.	0.95
27	0.	10.	0.2	500.	0.02	1.	0.95
31	0.	10.	0.2	300.	0.015	1.	0.95
32	0.	10.	0.2	500.	0.01	1.	0.95
33	0.	10.	0.2	600.	0.025	1.	0.95
34	0.	10.	0.2	100.	0.01	1.	0.95
36	0.	10.	0.2	500.	0.015	1.	0.95
37	0.	10.	0.2	500.	0.02	1.	0.95
41	0.	10.	0.2	300.	0.015	1.	0.95
42	0.	10.	0.2	500.	0.01	1.	0.95
43	0.	10.	0.2	600.	0.025	1.	0.95
44	0.	10.	0.2	100.	0.01	1.	0.95
45	0.	9.	0.2	600.	0.015	1.	0.95
46	0.	10.	0.2	500.	0.015	1.	0.95
47	0.	10.	0.2	500.	0.02	1.	0.95
51	0.	10.	0.2	300.	0.015	1.	0.95
53	0.	10.	0.2	600.	0.025	1.	0.95
54	0.	10.	0.2	100.	0.01	1.	0.95
56	0.	10.	0.2	500.	0.015	1.	0.95
57	0.	10.	0.2	500.	0.02	1.	0.95
61	0.	10.	0.2	300.	0.015	1.	0.95
62	0.	10.	0.2	500.	0.01	1.	0.95
63	0.	10.	0.2	600.	0.025	1.	0.95
64	0.	10.	0.2	100.	0.01	1.	0.95
65	0.	9.	0.2	600.	0.015	1.	0.95
66	0.	10.	0.2	500.	0.015	1.	0.95
67	0.	10.	0.2	500.	0.02	1.	0.95
71	0.	10.	0.2	300.	0.015	1.	0.95
72	0.	10.	0.2	500.	0.01	1.	0.95
73	0.	10.	0.2	600.	0.025	1.	0.95
74	0.	10.	0.2	100.	0.01	1.	0.95
75	0.	9.	0.2	600.	0.015	1.	0.95
76	0.	10.	0.2	500.	0.015	1.	0.95
77	0.	10.	0.2	500.	0.02	1.	0.95
81	0.	10.	0.2	300.	0.015	1.	0.95
82	0.	10.	0.2	500.	0.01	1.	0.95
83	0.	10.	0.2	600.	0.025	1.	0.95
84	0.	10.	0.2	100.	0.01	1.	0.95
86	0.	10.	0.2	500.	0.015	1.	0.95

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  87          0.     10.     0.2    500.    0.02     1.    0.95
  92          0.     10.     0.2    500.    0.01     1.    0.95
  93          0.     10.     0.2    600.    0.025    1.    0.95
  94          0.     10.     0.2    100.    0.01     1.    0.95
  96          0.     10.     0.2    500.    0.015    1.    0.95
  97          0.     10.     0.2    500.    0.02     1.    0.95
 101          0.     10.     0.2    300.    0.015    1.    0.95
 102          0.     10.     0.2    500.    0.01     1.    0.95
 103          0.     10.     0.2    600.    0.025    1.    0.95
 104          0.     10.     0.2    100.    0.01     1.    0.95
 105          0.      9.     0.2    600.    0.015    1.    0.95
 106          0.     10.     0.2    500.    0.015    1.    0.95
 107          0.     10.     0.2    500.    0.02     1.    0.95
 111          0.     10.     0.2    300.    0.015    1.    0.95
 112          0.     10.     0.2    500.    0.01     1.    0.95
 113          0.     10.     0.2    600.    0.025    1.    0.95
 114          0.     10.     0.2    100.    0.01     1.    0.95
 116          0.     10.     0.2    500.    0.015    1.    0.95
 117          0.     10.     0.2    500.    0.02     1.    0.95
 END PWAT-PARM2

 PWAT-PARM3
*** < PLS>   PETMAX   PETMIN   INFEXP   INFILD   DEEPFR   BASETP   AGWETP
*** x  - x   (deg F)   (deg F)
  11  117     40.      35.      2.       2.      0.3     0.15     0.1
 END PWAT-PARM3

 PWAT-PARM4
*** <PLS >    CEPSC     UZSN     NSUR    INTFW     IRC    LZETP
*** x -  x     (in)     (in)              (1/day)
  11          0.1      1.8     0.075     1.      0.3     0.4
  12          0.1      1.8     0.2       1.      0.3     0.6
  13          0.1      2.      0.37      1.      0.3     0.7
  14   15     0.1      1.8     0.2       1.      0.3     0.5
  16   17     0.1      1.8     0.37      1.      0.3     0.5
  21          0.1      1.8     0.075     1.      0.3     0.4
  22          0.1      1.8     0.2       1.      0.3     0.6
  23          0.1      2.      0.37      1.      0.3     0.7
  24   25     0.1      1.8     0.2       1.      0.3     0.5
  26   27     0.1      1.8     0.37      1.      0.3     0.5
  31          0.1      1.8     0.075     1.      0.3     0.4
  32          0.1      1.8     0.2       1.      0.3     0.6
  33          0.1      2.      0.37      1.      0.3     0.7
  34          0.1      1.8     0.2       1.      0.3     0.5
  36   37     0.1      1.8     0.37      1.      0.3     0.5
  41          0.1      1.8     0.075     1.      0.3     0.4
  42          0.1      1.8     0.2       1.      0.3     0.6
  43          0.1      2.      0.37      1.      0.3     0.7
  44   45     0.1      1.8     0.2       1.      0.3     0.5
  46   47     0.1      1.8     0.37      1.      0.3     0.5
  51          0.1      1.8     0.075     1.      0.3     0.4
```

```
 53        0.1    2.    0.37    1.    0.3    0.7
 54        0.1    1.8   0.2     1.    0.3    0.5
 56  57    0.1    1.8   0.37    1.    0.3    0.5
 61        0.1    1.8   0.075   1.    0.3    0.4
 62        0.1    1.8   0.2     1.    0.3    0.6
 63        0.1    2.    0.37    1.    0.3    0.7
 64  65    0.1    1.8   0.2     1.    0.3    0.5
 66  67    0.1    1.8   0.37    1.    0.3    0.5
 71        0.1    1.8   0.075   1.    0.3    0.4
 72        0.1    1.8   0.2     1.    0.3    0.6
 73        0.1    2.    0.37    1.    0.3    0.7
 74  75    0.1    1.8   0.2     1.    0.3    0.5
 76  77    0.1    1.8   0.37    1.    0.3    0.5
 81        0.1    1.8   0.075   1.    0.3    0.4
 82        0.1    1.8   0.2     1.    0.3    0.6
 83        0.1    2.    0.37    1.    0.3    0.7
 84        0.1    1.8   0.2     1.    0.3    0.5
 86  87    0.1    1.8   0.37    1.    0.3    0.5
 92        0.1    1.8   0.2     1.    0.3    0.6
 93        0.1    2.    0.37    1.    0.3    0.7
 94        0.1    1.8   0.2     1.    0.3    0.5
 96  97    0.1    1.8   0.37    1.    0.3    0.5
101        0.1    1.8   0.075   1.    0.3    0.4
102        0.1    1.8   0.2     1.    0.3    0.6
103        0.1    2.    0.37    1.    0.3    0.7
104  105   0.1    1.8   0.2     1.    0.3    0.5
106  107   0.1    1.8   0.37    1.    0.3    0.5
111        0.1    1.8   0.075   1.    0.3    0.4
112        0.1    1.8   0.2     1.    0.3    0.6
113        0.1    2.    0.37    1.    0.3    0.7
114        0.1    1.8   0.2     1.    0.3    0.5
116  117   0.1    1.8   0.37    1.    0.3    0.5
END PWAT-PARM4

PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x    CEPS    SURS    UZS     IFWS    LZS     AGWS    GWVS
 11           0.01    0.01    0.04    0.01    0.35    0.02    0.01
 12           0.01    0.01    0.132   0.01    1.34    0.1     0.01
 13           0.01    0.01    4.      0.01    12.3    2.5     0.01
 14   15      0.01    0.01    0.3     0.01    1.5     0.01    0.01
 16   17      0.01    0.01    1.2     0.01    10.6    0.75    0.01
 21           0.01    0.01    0.04    0.01    0.35    0.02    0.01
 22           0.01    0.01    0.132   0.01    1.34    0.1     0.01
 23           0.01    0.01    4.      0.01    12.3    2.5     0.01
 24   25      0.01    0.01    0.3     0.01    1.5     0.01    0.01
 26   27      0.01    0.01    1.2     0.01    10.6    0.75    0.01
 31           0.01    0.01    0.04    0.01    0.35    0.02    0.01
 32           0.01    0.01    0.132   0.01    1.34    0.1     0.01
 33           0.01    0.01    4.      0.01    12.3    2.5     0.01
 34           0.01    0.01    0.3     0.01    1.5     0.01    0.01
```

```
  36  37     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  41       0.01      0.01     0.04      0.01      0.35      0.02      0.01
  42       0.01      0.01    0.132      0.01      1.34       0.1      0.01
  43       0.01      0.01       4.     0.01      12.3       2.5     0.01
  44  45     0.01      0.01       0.3      0.01       1.5      0.01      0.01
  46  47     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  51       0.01      0.01     0.04      0.01      0.35      0.02      0.01
  53       0.01      0.01       4.     0.01      12.3       2.5     0.01
  54       0.01      0.01      0.3     0.01       1.5     0.01      0.01
  56  57     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  61       0.01      0.01     0.04      0.01      0.35      0.02      0.01
  62       0.01      0.01    0.132      0.01      1.34       0.1      0.01
  63       0.01      0.01       4.     0.01      12.3       2.5     0.01
  64  65     0.01      0.01       0.3      0.01       1.5      0.01      0.01
  66  67     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  71       0.01      0.01     0.04      0.01      0.35      0.02      0.01
  72       0.01      0.01    0.132      0.01      1.34       0.1      0.01
  73       0.01      0.01       4.     0.01      12.3       2.5     0.01
  74  75     0.01      0.01       0.3      0.01       1.5      0.01      0.01
  76  77     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  81       0.01      0.01     0.04      0.01      0.35      0.02      0.01
  82       0.01      0.01    0.132      0.01      1.34       0.1      0.01
  83       0.01      0.01       4.     0.01      12.3       2.5     0.01
  84       0.01      0.01      0.3     0.01       1.5     0.01      0.01
  86  87     0.01      0.01       1.2      0.01      10.6      0.75      0.01
  92       0.01      0.01    0.132      0.01      1.34       0.1      0.01
  93       0.01      0.01       4.     0.01      12.3       2.5     0.01
  94       0.01      0.01      0.3     0.01       1.5     0.01      0.01
  96  97     0.01      0.01       1.2      0.01      10.6      0.75      0.01
 101       0.01      0.01     0.04      0.01      0.35      0.02      0.01
 102       0.01      0.01    0.132      0.01      1.34       0.1      0.01
 103       0.01      0.01       4.     0.01      12.3       2.5     0.01
 104  105     0.01      0.01       0.3      0.01       1.5      0.01      0.01
 106  107     0.01      0.01       1.2      0.01      10.6      0.75      0.01
 111       0.01      0.01     0.04      0.01      0.35      0.02      0.01
 112       0.01      0.01    0.132      0.01      1.34       0.1      0.01
 113       0.01      0.01       4.     0.01      12.3       2.5     0.01
 114       0.01      0.01      0.3     0.01       1.5     0.01      0.01
 116  117     0.01      0.01       1.2      0.01      10.6      0.75      0.01
 END PWAT-STATE1

 MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11      0.08 0.09  0.1  0.2  0.3  0.4  0.4  0.4  0.2  0.1 0.09 0.08
  12      0.08 0.09 0.13 0.13 0.21 0.26 0.26 0.23  0.2 0.18 0.09 0.08
  13      0.08 0.09 0.13 0.16  0.3  0.4  0.4  0.4 0.19 0.13 0.09 0.08
  14      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
  15      0.08 0.09 0.13 0.13 0.21 0.26 0.26 0.23  0.2  0.1 0.09 0.08
  16      0.08 0.09 0.13 0.16 0.18  0.2  0.2  0.2 0.19 0.13 0.09 0.08
  17      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
```

21	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
22	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
23	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
24	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
25	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.1	0.09	0.08
26	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
27	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
31	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
32	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
33	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
34	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
36	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
37	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
41	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
42	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
43	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
44	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
45	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.1	0.09	0.08
46	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
47	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
51	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
53	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
54	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
56	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
57	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
61	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
62	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
63	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
64	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
65	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.1	0.09	0.08
66	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
67	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
71	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
72	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
73	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
74	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
75	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.1	0.09	0.08
76	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
77	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
81	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08
82	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
83	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
84	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
86	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
87	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
92	0.08	0.09	0.13	0.13	0.21	0.26	0.26	0.23	0.2	0.18	0.09	0.08
93	0.08	0.09	0.13	0.16	0.3	0.4	0.4	0.4	0.19	0.13	0.09	0.08
94	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
96	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.13	0.09	0.08
97	0.08	0.09	0.13	0.18	0.21	0.26	0.26	0.23	0.2	0.13	0.09	0.08
101	0.08	0.09	0.1	0.2	0.3	0.4	0.4	0.4	0.2	0.1	0.09	0.08

```
 102      0.08 0.09 0.13 0.13 0.21 0.26 0.26 0.23  0.2 0.18 0.09 0.08
 103      0.08 0.09 0.13 0.16  0.3  0.4  0.4  0.4 0.19 0.13 0.09 0.08
 104      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
 105      0.08 0.09 0.13 0.13 0.21 0.26 0.26 0.23  0.2  0.1 0.09 0.08
 106      0.08 0.09 0.13 0.16 0.18  0.2  0.2  0.2 0.19 0.13 0.09 0.08
 107      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
 111      0.08 0.09  0.1  0.2  0.3  0.4  0.4  0.4  0.2  0.1 0.09 0.08
 112      0.08 0.09 0.13 0.13 0.21 0.26 0.26 0.23  0.2 0.18 0.09 0.08
 113      0.08 0.09 0.13 0.16  0.3  0.4  0.4  0.4 0.19 0.13 0.09 0.08
 114      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
 116      0.08 0.09 0.13 0.16 0.18  0.2  0.2  0.2 0.19 0.13 0.09 0.08
 117      0.08 0.09 0.13 0.18 0.21 0.26 0.26 0.23  0.2 0.13 0.09 0.08
 END MON-INTERCEP

 MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  12      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  13      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  14      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  15      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  16      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  17      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  21      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  22      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  23      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  24      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  25      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  26      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  27      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  31      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  32      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  33      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  34      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  36      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  37      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  41      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  42      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  43      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  44      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  45      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  46      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  47      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  51      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  53      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  54      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  56      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  57      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  61      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  62      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
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  63      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  64      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  65      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  66      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  67      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  71      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  72      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  73      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  74      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  75      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  76      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  77      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  81      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
  82      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  83      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  84      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  86      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  87      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
  92      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
  93      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
  94      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
  96      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
  97      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
 101      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
 102      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
 103      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
 104      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
 105      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
 106      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
 107      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
 111      0.8  0.8  0.8  0.8   1.   1.   1.   1.  0.9  0.8  0.8  0.8
 112      0.5  0.6  0.6  0.6  0.8   1.   1.   1.  0.6  0.6  0.6  0.5
 113      0.8  0.9  0.9  0.9   1.   1.   1.   1.   1. 0.95  0.9  0.8
 114      0.5  0.6  0.6  0.7   1.   1.   1.   1.   1.  0.7  0.6  0.5
 116      0.7  0.8  0.8  0.8   1.   1.   1.   1.   1.  0.8  0.8  0.7
 117      0.5  0.6  0.6  0.7  0.8   1.   1.   1.  0.8  0.7  0.6  0.5
 END MON-UZSN

 MON-MANNING
*** <PLS >  Manning's n at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  12        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  13   21   0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  22        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  23   31   0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  32        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  33   41   0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  42        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  43   61   0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  62        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
```

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  63   71  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  72       0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  73   81  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  82       0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  83   87  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  92       0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
  93  101  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
 102       0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
 103  111  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
 112       0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
 113  117  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
 END MON-MANNING

 MON-INTERFLW
*** <PLS >  Interflow inflow parameter for start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
 END MON-INTERFLW

 MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117  0.6 0.65  0.7 0.75  0.8 0.85  0.9  0.9 0.85  0.8  0.7 0.65
 END MON-LZETPARM

 SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
  11  117    1    0    1
 END SED-PARM1

 SED-PARM2
*** <PLS >      SMPF     KRER     JRER    AFFIX    COVER     NVSI
*** x -  x                       (/day)         lb/ac-day
  11   12       1.      0.4       2.     0.01      0.1       1.
  13   14       1.      0.4       2.    0.002      0.1       1.
  15            1.      0.4       2.    0.008      0.1       1.
  16   22       1.      0.4       2.     0.01      0.1       1.
  23   24       1.      0.4       2.    0.002      0.1       1.
  25            1.      0.4       2.    0.008      0.1       1.
  26   32       1.      0.4       2.     0.01      0.1       1.
  33   34       1.      0.4       2.    0.002      0.1       1.
  36   42       1.      0.4       2.     0.01      0.1       1.
  43   44       1.      0.4       2.    0.002      0.1       1.
  45            1.      0.4       2.    0.008      0.1       1.
  46   51       1.      0.4       2.     0.01      0.1       1.
  53   54       1.      0.4       2.    0.002      0.1       1.
  56   62       1.      0.4       2.     0.01      0.1       1.
  63   64       1.      0.4       2.    0.002      0.1       1.
  65            1.      0.4       2.    0.008      0.1       1.
  66   72       1.      0.4       2.     0.01      0.1       1.
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  73  74      1.     0.4      2.    0.002      0.1      1.
  75          1.     0.4      2.    0.008      0.1      1.
  76  82      1.     0.4      2.     0.01      0.1      1.
  83  84      1.     0.4      2.    0.002      0.1      1.
  86  92      1.     0.4      2.     0.01      0.1      1.
  93  94      1.     0.4      2.    0.002      0.1      1.
  96 102      1.     0.4      2.     0.01      0.1      1.
 103 104      1.     0.4      2.    0.002      0.1      1.
 105          1.     0.4      2.    0.008      0.1      1.
 106 112      1.     0.4      2.     0.01      0.1      1.
 113 114      1.     0.4      2.    0.002      0.1      1.
 116 117      1.     0.4      2.     0.01      0.1      1.
 END SED-PARM2

 SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x     KSER     JSER     KGER     JGER
  11          0.5      1.6      0.       2.
  12          4.5      1.6      0.       2.
  13  17       1.      1.6      0.       2.
  21          0.5      1.6      0.       2.
  22          4.5      1.6      0.       2.
  23  27       1.      1.6      0.       2.
  31          0.5      1.6      0.       2.
  32          4.5      1.6      0.       2.
  33  37       1.      1.6      0.       2.
  41          0.5      1.6      0.       2.
  42          4.5      1.6      0.       2.
  43  47       1.      1.6      0.       2.
  51          0.5      1.6      0.       2.
  53  57       1.      1.6      0.       2.
  61          0.5      1.6      0.       2.
  62          4.5      1.6      0.       2.
  63  67       1.      1.6      0.       2.
  71          0.5      1.6      0.       2.
  72          4.5      1.6      0.       2.
  73  77       1.      1.6      0.       2.
  81          0.5      1.6      0.       2.
  82          4.5      1.6      0.       2.
  83  87       1.      1.6      0.       2.
  92          4.5      1.6      0.       2.
  93  97       1.      1.6      0.       2.
 101          0.5      1.6      0.       2.
 102          4.5      1.6      0.       2.
 103 107       1.      1.6      0.       2.
 111          0.5      1.6      0.       2.
 112          4.5      1.6      0.       2.
 113 117       1.      1.6      0.       2.
 END SED-PARM3

 MON-COVER
```

*** <PLS > Monthly values for erosion related cover

*** x -	x	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
11		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
12		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
13		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
14		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
15	17	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
21		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
22		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
23		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
24		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
25	27	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
31		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
32		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
33		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
34		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
36	37	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
41		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
42		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
43		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
44		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
45	47	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
51		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
53		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
54		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
56	57	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
61		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
62		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
63		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
64		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
65	67	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
71		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
72		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
73		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
74		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
75	77	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
81		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
82		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
83		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
84		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
86	87	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
92		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
93		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
94		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
96	97	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
101		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9
102		0.7	0.7	0.5	0.5	0.6	0.75	0.8	0.93	0.93	0.9	0.8	0.75
103		0.9	0.9	0.92	0.95	0.97	0.97	0.97	0.97	0.95	0.93	0.91	0.9
104		0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
105	107	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
111		0.9	0.9	0.9	0.9	0.93	0.93	0.93	0.9	0.9	0.9	0.9	0.9

```
112       0.7  0.7  0.5  0.5  0.6 0.75  0.8 0.93 0.93  0.9  0.8 0.75
113       0.9  0.9 0.92 0.95 0.97 0.97 0.97 0.97 0.95 0.93 0.91  0.9
114      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
116  117  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
END MON-COVER

SED-STOR
*** <PLS >  Detached sediment storage (tons/acre)
*** x -  x      DETS
 11           0.2
 12   13       0.3
 14           0.4
 15           0.8
 16   17       0.7
 21           0.2
 22   23       0.3
 24           0.4
 25           0.8
 26   27       0.7
 31           0.2
 32   33       0.3
 34           0.4
 36   37       0.7
 41           0.2
 42   43       0.3
 44           0.4
 45           0.8
 46   47       0.7
 51           0.2
 53           0.3
 54           0.4
 56   57       0.7
 61           0.2
 62   63       0.3
 64           0.4
 65           0.8
 66   67       0.7
 71           0.2
 72   73       0.3
 74           0.4
 75           0.8
 76   77       0.7
 81           0.2
 82   83       0.3
 84           0.4
 86   87       0.7
 92   93       0.3
 94           0.4
 96   97       0.7
101           0.2
102  103       0.3
```

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 104          0.4
 105          0.8
 106  107      0.7
 111          0.2
 112  113      0.3
 114          0.4
 116  117      0.7
 END SED-STOR

 PSTEMP-PARM1
*** <PLS >  Flags for section PSTEMP
*** x -  x SLTV ULTV LGTV TSOP
  11  117    1    1    1    1
 END PSTEMP-PARM1

 PSTEMP-PARM2
*** <PLS >      ASLT      BSLT     ULTP1     ULTP2     LGTP1     LGTP2
*** x -  x   (deg F)   (deg F)            (deg F)            (deg F)
  11  117       55.      0.15       60.      0.15       50.        0.
 END PSTEMP-PARM2

 MON-ASLT
*** <PLS >  Value of ASLT at start of each month (deg F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117  45.  45.  45.  48.  55.  65.  70.  77.  73.  68.  60.  50.
 END MON-ASLT

 MON-BSLT
*** <PLS >  Value of BSLT at start of each month (deg F/F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
 END MON-BSLT

 MON-ULTP1
*** <PLS >  Value of ULTP1 at start of each month in deg F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117  52.  52.  52.  56.  62.  70.  77.  77.  73.  68.  60.  54.
 END MON-ULTP1

 MON-ULTP2
*** <PLS >  Value of ULTP2 at start of each month in Deg F/F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
 END MON-ULTP2

 MON-LGTP1
*** <PLS >  Value of LGTP1 at start of each month in Deg F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117  48.  48.  52.  58.  60.  63.  63.  64.  60.  55.  52.  48.
 END MON-LGTP1
```

```
  PSTEMP-TEMPS
*** <PLS >  Initial temperatures (deg F)
*** x -  x     AIRTC     SLTMP     ULTMP     LGTMP
  11  117       30.       30.       40.       40.
  END PSTEMP-TEMPS

  PWT-PARM1
*** <PLS >  Flags for section PWTGAS
*** x -  x  IDV  ICV  GDV  GVC
  11  117    1    0    1    0
  END PWT-PARM1

  PWT-PARM2
***          Second group of PWTGAS parms
*** <PLS >      ELEV     IDOXP     ICO2P     ADOXP     ACO2P
*** x -  x      (ft)    (mg/l)  (mg C/l)    (mg/l)  (mg C/l)
  11  117      120.       8.8        0.       8.8        0.
  END PWT-PARM2

  MON-IFWDOX
*** <PLS > Value at start of each month for interflow DO concentration (mg/l)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117 11.  10.   8.   7.   6.   5.   5.   5.   7.   8.   9.  10.
  END MON-IFWDOX

  MON-GRNDDOX
*** <PLS >Value at start of each month for groundwater DO concentration (mg/l)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11  117   9.   8.   6.   5.   5.   4.   4.   4.   5.   6.   7.   8.
  END MON-GRNDDOX

  PWT-GASES
***                  Initial DO and CO2 concentrations
*** <PLS >     SODOX     SOCO2     IODOX     IOCO2     AODOX     AOCO2
*** x -  x    (mg/l)  (mg C/l)    (mg/l)  (mg C/l)    (mg/l)  (mg C/l)
  11  117       8.8        0.       8.8        0.       8.8        0.
  END PWT-GASES

  NQUALS
*** <PLS >
*** x -  xNQUAL
  11  117    1
  END NQUALS

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  11  117F.COLIFORM      #ORG    1    0    0    1    1    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
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```
***        Storage on surface and nonseasonal parameters
***          SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3 qty/ft3
*** x -  x                       ac.day
  11       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  12   13   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  14       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  15       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  16   17   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  21       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  22   23   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  24       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  25       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  26   27   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  31       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  32   33   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  34       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  36   37   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  41       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  42   43   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  44       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  45       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  46   47   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  51       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  53       4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  54       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  56   57   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  61       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  62   63   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  64       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  65       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  66   67   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  71       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  72   73   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  74       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  75       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  76   77   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  81       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
  82   83   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  84       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  86   93   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
  94       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
  96   97   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
 101       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
 102  103   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
 104       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
 105       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
 106  107   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
 111       4E+09     0.      0.  1E+09   1E+10     1.4  15000.   5000.
 112  113   4E+09     0.      0.  1E+09   1E+10     1.5  15000.   5000.
 114       4E+09     0.      0.  1E+09   1E+10     1.7  15000.   5000.
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116  117   4E+09     0.      0.   1E+09   1E+10     1.5  15000.   5000.
END QUAL-INPUT

MON-ACCUM
*** <PLS >  Value at start of each month for accum rate of QUALOF (lb/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11     4E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  12     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  13     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  14     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  15     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
  16     7.7e87.7e87.7e88.4e88.4e88.2e88.2e88.2e88.2e88.9e89E+087.7e8
  17   214E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  22     1.8e91.9e91.8e92.2e92.2e91.9e91.8e91.8e91.9e99.2e99.5e91.8e9
  23     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  24     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  25     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
  26     1.8e91.9e91.8e91E+101E+101E+101E+101E+101E+102E+102E+101.8e9
  27   314E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  32     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  33     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  34     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  36     7.7e87.7e87.7e88.1e88.1e88E+088E+088E+088E+088.4e88.4e87.7e8
  37   414E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  42     2.7e92.9e92.7e93.5e93.4e92.8e92.7e92.7e92.8e91E+101E+102.7e9
  43     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  44     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  45     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
  46     2.7e92.9e92.7e93E+103E+103E+103E+103E+103E+104E+104E+102.7e9
  47   514E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  53     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  54     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  56     8E+088E+088E+081.1e91.1e91E+091E+091E+091E+091.4e91.4e98E+08
  57   614E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  62     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  63     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  64     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  65     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
  66     7.7e87.7e87.7e88.7e88.7e88.4e88.4e88.4e88.4e89.3e89.4e87.7e8
  67   714E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  72     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  73     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  74     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  75     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
  76     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  77   814E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
  82     9.2e89.3e89.2e89.7e89.7e89.2e89.2e89.2e89.2e82E+092E+099.2e8
  83     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  84     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  86     9.2e89.4e89.2e83.3e93.3e93.2e93.2e93.2e93.2e94.3e94.3e99.2e8
  87     4E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
```

```
  92     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
  93     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
  94     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
  96     7.8e87.8e87.8e89.9e89.8e89.3e89.3e89.3e89.3e81.1e91.1e97.8e8
  97  1014E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
 102     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
 103     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
 104     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
 105     2E+072E+072E+075E+075E+075E+075E+075E+072E+072E+072E+072E+07
 106     8.1e88.1e88.1e81.3e91.3e91.2e91.2e91.2e91.2e91.7e91.7e98.1e8
 107  1114E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
 112     7.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e87.7e8
 113     6E+096E+096E+094E+094E+094E+094E+094E+094E+096E+096E+096E+09
 114     8E+098E+098E+092E+102E+102E+102E+102E+108E+098E+098E+098E+09
 116     7.8e87.8e87.8e89E+089E+088.7e88.7e88.7e88.7e89.8e89.9e87.8e8
 117     4E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+094E+09
 END MON-ACCUM

 MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11     7.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  12     1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
  13     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
  14     6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
  15     7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
  16     1.4e91.4e91.4e91.3e91.3e91.2e91.2e91.2e91.2e91.6e91.6e91.4e9
  17   217.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  22     3.3e93.5e93.3e93.3e93.3e92.8e92.7e92.7e92.8e92E+102E+103.3e9
  23     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
  24     6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
  25     7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
  26     3.3e93.5e93.3e93E+103E+103E+103E+103E+103E+105E+105E+103.3e9
  27   317.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  32     1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
  33     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
  34     6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
  36     1.4e91.4e91.4e91.2e91.2e91.2e91.2e91.2e91.2e91.5e91.5e91.4e9
  37   417.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  42     4.9e95.3e94.9e95.2e95.1e94.2e94.1e94.1e94.2e93E+103E+104.9e9
  43     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
  44     6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
  45     7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
  46     4.9e95.3e94.9e96E+106E+106E+106E+106E+106E+109E+109E+104.9e9
  47   517.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  53     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
  54     6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
  56     1.4e91.4e91.4e91.7e91.7e91.6e91.6e91.6e91.6e92.4e92.5e91.4e9
  57   617.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
  62     1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
  63     1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
```

```
 64   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
 65   7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
 66   1.4e91.4e91.4e91.3e91.3e91.3e91.3e91.3e91.3e91.7e91.7e91.4e9
 67 717.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
 72   1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
 73   1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
 74   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
 75   7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
 76   1.4e91.4e91.4e91.2e91.2e91.2e91.2e91.2e91.2e91.4e91.4e91.4e9
 77 817.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
 82   1.7e91.7e91.6e91.5e91.5e91.4e91.4e91.4e91.4e93.6e93.6e91.6e9
 83   1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
 84   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
 86   1.7e91.7e91.7e94.9e94.9e94.8e94.8e94.8e94.8e97.7e97.8e91.7e9
 87   7.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
 92   1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
 93   1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
 94   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
 96   1.4e91.4e91.4e91.5e91.5e91.4e91.4e91.4e91.4e92E+092.1e91.4e9
 97 1017.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
102   1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
103   1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
104   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
105   7E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+077E+07
106   1.5e91.5e91.5e91.9e91.9e91.8e91.8e91.8e91.8e93E+093E+091.5e9
107 1117.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
112   1.4e91.4e91.4e91.1e91.1e91.1e91.1e91.1e91.1e91.4e91.4e91.4e9
113   1E+101E+101E+107.2e97.2e97.2e97.2e97.2e97.2e91E+101E+101E+10
114   6E+106E+106E+103E+103E+103E+103E+103E+103E+106E+106E+106E+10
116   1.4e91.4e91.4e91.3e91.3e91.3e91.3e91.3e91.3e91.8e91.8e91.4e9
117   7.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e97.2e9
END MON-SQOLIM

MON-IFLW-CONC
*** <PLS >  Conc of QUAL in interflow outflow for each month (qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 11   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 12    4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 13 1710000100001000010000100001000010000100001000010000100001000010000
 21   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 22    4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 23 2710000100001000010000100001000010000100001000010000100001000010000
 31   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 32    4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 33 3710000100001000010000100001000010000100001000010000100001000010000
 41   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 42    4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 43 4710000100001000010000100001000010000100001000010000100001000010000
 51   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 53 5710000100001000010000100001000010000100001000010000100001000010000
 61   1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
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 62     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 63   6710000100001000010000100001000010000100001000010000100001000010000
 71    1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 72     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 73   7710000100001000010000100001000010000100001000010000100001000010000
 81    1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
 82     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 83   8710000100001000010000100001000010000100001000010000100001000010000
 92     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
 93   9710000100001000010000100001000010000100001000010000100001000010000
101    1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
102     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
103  10710000100001000010000100001000010000100001000010000100001000010000
111    1.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e51.7e5
112     4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5 4.e5
113  11710000100001000010000100001000010000100001000010000100001000010000
END MON-IFLW-CONC

MON-GRND-CONC
*** <PLS >  Value at start of month for conc of QUAL in groundwater (qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
 11    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 12    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 13   1798000980009800098000980009800098000980009800098000980009800098000
 21    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 22    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 23   2798000980009800098000980009800098000980009800098000980009800098000
 31    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 32    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 33   3798000980009800098000980009800098000980009800098000980009800098000
 41    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 42    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 43   4798000980009800098000980009800098000980009800098000980009800098000
 51    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 53   5798000980009800098000980009800098000980009800098000980009800098000
 61    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 62    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 63   6798000980009800098000980009800098000980009800098000980009800098000
 71    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 72    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 73   7798000980009800098000980009800098000980009800098000980009800098000
 81    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
 82    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 83   8798000980009800098000980009800098000980009800098000980009800098000
 92    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
 93   9798000980009800098000980009800098000980009800098000980009800098000
101    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
102    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
103  10798000980009800098000980009800098000980009800098000980009800098000
111    1.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e51.4e5
112    1.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e61.9e6
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 113  117980000980009800098000980009800098000980009800098000980009800098000
 END MON-GRND-CONC

END PERLND

IMPLND
 ACTIVITY
*** <ILS >              Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  11  111    1    0    1    1    1    1
 END ACTIVITY

 PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  11  111    4    4    4    4    4    4    1    9
 END PRINT-INFO

 BINARY-INFO
*** <ILS > **** Binary-Output-flags **** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  11  111    4    4    4    4    4    4    1    9
 END BINARY-INFO

 GEN-INFO
***            Name             Unit-systems   Printer BinaryOut
*** <ILS >                        t-series Engl Metr Engl Metr
*** x -  x                        in  out
  11  111Urban or Built-up La         1    1    0    0    0    0
 END GEN-INFO

 ATEMP-DAT
*** <ILS >     ELDAT    AIRTEMP
*** x -  x      (ft)    (deg F)
  11  111        0.       33.
 END ATEMP-DAT

 IWAT-PARM1
*** <ILS >       Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  11  111    0    1    0    0    0
 END IWAT-PARM1

 IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  11  111      350.     0.001      0.08      0.25
 END IWAT-PARM2

 IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
```

```
*** x -  x   (deg F)   (deg F)
  11  111       40.       35.
 END IWAT-PARM3

 IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  11  111       0.1       0.1
 END IWAT-STATE1

 SLD-PARM1
*** <ILS >     Flags
*** x -  x VASD VRSD SDOP
  11  111    0    0    1
 END SLD-PARM1

 SLD-PARM2
***            KEIM      JEIM    ACCSDP    REMSDP
*** <ILS >                         tons/      /day
*** x -  x                        ac.day
  11  111        2.       1.8    0.0003      0.05
 END SLD-PARM2

 SLD-STOR
*** <ILS >  Solids storage (tons/acre)
*** x -  x
  11  111      0.01
 END SLD-STOR

 IWT-PARM1
*** <ILS >  Flags for section IWTGAS
*** x -  x WTFV CSNO
  11  111    0    0
 END IWT-PARM1

 IWT-PARM2
***         Second group of IWTGAS parms
*** <ILS >      ELEV      AWTF      BWTF
*** x -  x      (ft)   (deg F) (deg F/F)
  11  111      120.       34.       0.3
 END IWT-PARM2

 NQUALS
*** <ILS >
*** x -  xNQUAL
  11  111    1
 END NQUALS

 QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
```

```
  11  111F.COLIFORM      #ORG    1    0    1    0
 END QUAL-PROPS

 QUAL-INPUT
***        Storage on surface and nonseasonal parameters
***           SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                 ac.day
  11  111   4E+09      0.   4E+09 7.2E+09     0.9
 END QUAL-INPUT

END IMPLND

RCHRES
 ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
   1  11    1    1    0    1    1    1    0    0    0    0
 END ACTIVITY

 PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
   1  11    4    4    4    4    4    4    4    4    4    4    1    9
 END PRINT-INFO

 BINARY-INFO
*** RCHRES  Binary Output level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
   1  11    4    4    4    4    4    4    4    4    4    4    1    9
 END BINARY-INFO

 GEN-INFO
***            Name        Nexits   Unit Systems   Printer
*** RCHRES                            t-series  Engl Metr LKFG
*** x -  x                           in  out
   1                      1        1    1    0    0    0    0    0
   2    3Northeast Creek        1        1    1    0    0    0    0    0
   4     Burdens Creek          1        1    1    0    0    0    0    0
   5                      1        1    1    0    0    0    0    0
   6     Kit Creek              1        1    1    0    0    0    0    0
   7     Northeast Creek        1        1    1    0    0    0    0    0
   8     Panther Creek          1        1    1    0    0    0    0    0
   9     Northeast Creek        1        1    1    0    0    0    0    0
  10                      1        1    1    0    0    0    0    0
  11     Northeast Creek        1        1    1    0    0    0    0    0
 END GEN-INFO

 HYDR-PARM1
***        Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
```

```
*** x  - x  FG FG FG FG  possible   exit *** possible   exit     possible   exit
   1  11   0  1  1  1    4  0  0  0  0      0  0  0  0  0      1  1  1  1  1
 END HYDR-PARM1

 HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR       KS      DB50
*** x -  x            (miles)      (ft)      (ft)             (in)
   1       0.   1.      0.86       3.       3.2       0.5      0.01
   2       0.   2.       3.4       11.      3.2       0.5      0.01
   3       0.   3.      2.29       7.       3.2       0.5      0.01
   4       0.   4.      1.84       6.       3.2       0.5      0.01
   5       0.   5.      1.09       3.4       3.2       0.5      0.01
   6       0.   6.      3.07       9.4       3.2       0.5      0.01
   7       0.   7.      2.39       5.       3.2       0.5      0.01
   8       0.   8.      2.99       9.       3.2       0.5      0.01
   9       0.   9.      1.02       3.5       3.2       0.5      0.01
  10       0.  10.      1.11       3.       3.2       0.5      0.01
  11       0.  11.       0.1       0.3      3.2       0.5      0.01
 END HYDR-PARM2

 HYDR-INIT
***        Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible exit,ft3
  1   11      0.01       4.2  4.5  4.5  4.5  4.2       2.1  1.2  0.5  1.2  1.8
 END HYDR-INIT

 ADCALC-DATA
*** RCHRES  Data for section ADCALC
*** x -  x     CRRAT       VOL (ac-ft)
  1   11       1.7      100.
 END ADCALC-DATA

 HT-BED-FLAGS
*** RCHRES Bed Heat Conductance Flags
*** x -  x BDFG TGFG TSTP
  1   11    1    3   55
 END HT-BED-FLAGS

 HEAT-PARM
*** RCHRES      ELEV     ELDAT    CFSAEX    KATRAD     KCOND     KEVAP
*** x -  x      (ft)      (ft)
  1   11      123.        2.      0.95       9.5      6.12       2.24
 END HEAT-PARM

 HT-BED-PARM
***       Bed Heat Conduction Parameters for Single and Two-layer Methods
*** RCHRES    MUDDEP     TGRND      KMUD     KGRND
*** x -  x      (ft)   (deg F)      (kcal/m2/C/hr)
  1   11      0.33       59.       50.       1.4
 END HT-BED-PARM
```

```
  MON-HT-TGRND
*** RCHRES  Monthly values of ground temperatures (deg F)
*** x -  x  TG1  TG2  TG3  TG4  TG5  TG6  TG7  TG8  TG9 TG10 TG11 TG12
   1   11  43.  46.  53.  62.  70.  77.  79.  79.  73.  63.  53.  45.
  END MON-HT-TGRND

  HEAT-INIT
*** RCHRES       TW    AIRTMP
*** x -  x   (deg F)   (deg F)
   1  11       40.       34.
  END HEAT-INIT

  SANDFG
*** RCHRES
*** x -  x SNDFG
   1   11    3
  END SANDFG

  SED-GENPARM
*** RCHRES    BEDWID    BEDWRN      POR
*** x -  x      (ft)      (ft)
   1  11       30.        6.       0.5
  END SED-GENPARM

  SAND-PM
*** RCHRES        D         W       RHO     KSAND    EXPSND
*** x -  x      (in)  (in/sec)  (gm/cm3)
   1  11      0.01       0.1       2.5       0.1        2.
  END SAND-PM

  SILT-CLAY-PM
*** RCHRES        D         W       RHO     TAUCD     TAUCS         M
*** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
   1        0.0003    0.0005      2.17      0.03      0.07      0.01
   2        0.0003    0.0005      2.17     0.021     0.062      0.01
   3        0.0003    0.0005      2.17     0.038     0.065      0.01
   4        0.0003    0.0005      2.17     0.015     0.042      0.01
   5        0.0003    0.0005      2.17     0.043     0.082      0.01
   6        0.0003    0.0005      2.17     0.022     0.053      0.01
   7        0.0003    0.0005      2.17     0.035     0.071      0.01
   8        0.0003    0.0005      2.17     0.023     0.052      0.01
   9        0.0003    0.0005      2.17     0.041     0.081      0.01
  10        0.0003    0.0005      2.17     0.038     0.079      0.01
  11        0.0003    0.0005      2.17     0.038      0.08      0.01
  END SILT-CLAY-PM

  SILT-CLAY-PM
*** RCHRES        D         W       RHO     TAUCD     TAUCS         M
*** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
   1        0.0001   0.00005        2.      0.02      0.06      0.01
```

```
  2        0.0001   0.00005      2.     0.011     0.052     0.01
  3        0.0001   0.00005      2.     0.028     0.055     0.01
  4        0.0001   0.00005      2.     0.005     0.032     0.01
  5        0.0001   0.00005      2.     0.033     0.072     0.01
  6        0.0001   0.00005      2.     0.012     0.043     0.01
  7        0.0001   0.00005      2.     0.025     0.061     0.01
  8        0.0001   0.00005      2.     0.013     0.042     0.01
  9        0.0001   0.00005      2.     0.031     0.071     0.01
 10        0.0001   0.00005      2.     0.028     0.069     0.01
 11        0.0001   0.00005      2.     0.028     0.07      0.01
 END SILT-CLAY-PM

 SSED-INIT
*** RCHRES     Suspended sed concs (mg/l)
*** x -  x      Sand      Silt      Clay
  1   11        5.       25.       25.
 END SSED-INIT

 BED-INIT
*** RCHRES    BEDDEP  Initial bed composition
*** x -  x      (ft)      Sand      Silt      Clay
  1   11        3.       0.6       0.3       0.1
 END BED-INIT

 GQ-GENDATA
*** RCHRES NGQL TPFG PHFG ROFG CDFG SDFG PYFG  LAT
*** x -  x                                   deg
  1   11    1    1    2    2    2    2    2    0
 END GQ-GENDATA

 GQ-QALDATA
*** RCHRES              GQID      DQAL    CONCID      CONV     QTYID
*** x -  x              concid
  1   11F.COLIFORM               100.     CFU/     0.035  #ORG
 END GQ-QALDATA

 GQ-QALFG
*** RCHRES HDRL OXID PHOT VOLT BIOD  GEN SDAS
*** x -  x
  1   11    0    0    0    0    0    1    1
 END GQ-QALFG

 GQ-GENDECAY
*** RCHRES    FSTDEC     THFST
*** x -  x    (/day)
  1   11       0.8      1.07
 END GQ-GENDECAY

 GQ-SEDDECAY
*** RCHRES     KSUSP    THSUSP      KBED     THBED
*** x -  x      /day                /day
```

```
  1   11      0.6      1.07      0.2      1.07
 END GQ-SEDDECAY

 GQ-KD
*** RCHRES               Partition coefficients (l/mg)
*** x -  x ADPM(1,1) ADPM(2,1) ADPM(3,1) ADPM(4,1) ADPM(5,1) ADPM(6,1)
  1   11     1E-08    0.0034    0.0034     1E-08     1E-08     1E-08
 END GQ-KD

 GQ-ADRATE
*** RCHRES        Adsorption/desorption rate parameters (/day)
*** x -  x ADPM(1,2) ADPM(2,2) ADPM(3,2) ADPM(4,2) ADPM(5,2) ADPM(6,2)
  1   11    0.0001    10000.    10000.    0.0001    0.0001    0.0001
 END GQ-ADRATE

 GQ-ADTHETA
*** RCHRES     Adsorption/desorption temp. correction parameters
*** x -  x ADPM(1,3) ADPM(2,3) ADPM(3,3) ADPM(4,3) ADPM(5,3) ADPM(6,3)
  1   11      1.07      1.07      1.07      1.07      1.07      1.07
 END GQ-ADTHETA

 GQ-SEDCONC
*** RCHRES  Initial concentrations on sediment (concu/mg)
*** x -  x     SQAL1     SQAL2     SQAL3     SQAL4     SQAL5     SQAL6
  1   11        0.        0.        0.        0.        0.        0.
 END GQ-SEDCONC

END RCHRES

FTABLES

 FTABLE      1
 rows cols                               ***
  22    4
     depth      area    volume  outflow1 ***
        0.        0.        0.        0.
      0.02      1.08      0.02      0.01
      0.06      1.09      0.06      0.09
       0.1       1.1      0.11      0.21
       0.2      1.13      0.22      0.67
       0.6      1.26       0.7      4.25
        1.      1.38      1.23     10.09
       1.2      1.44      1.51     13.79
       1.6      1.57      2.11     22.68
        2.      1.69      2.76     33.55
        3.      2.01      4.62     69.56
        4.      2.32      6.78    118.83
        5.      2.63      9.26    182.33
        6.      2.95     12.05    261.08
        7.      3.26     15.15    356.14
      7.58      3.44     17.09    419.17
```

```
   11.37     15.05     52.13    726.29
   15.16     16.23    111.41    1868.1
   18.95     17.42    175.19   3428.92
   22.74     18.61    243.46    5384.4
   28.34     20.35    352.45    8975.1
     29.     20.56    366.05   9457.48
 END FTABLE  1

 FTABLE      2
rows cols                         ***
  19    4
   depth      area    volume  outflow1 ***
     0.        0.        0.        0.
    0.02      4.66      0.09      0.02
    0.06      4.71      0.28       0.1
     0.1      4.76      0.47      0.22
     0.2      4.88      0.95      0.71
     0.6      5.38        3.      4.48
      1.      5.87      5.25     10.62
     1.2      6.12      6.45     14.49
     1.6      6.61        9.     23.79
      2.      7.11     11.75     35.11
      3.      8.35     19.47     72.39
      4.      9.58     28.44    123.02
    4.75     10.51     35.97    170.25
    7.13    219.51    309.11    913.82
     9.5    222.44    833.93   2746.59
   11.88    225.38   1365.71   5301.46
   14.25    228.32   1904.48   8488.79
   34.48    253.32   6775.02  56273.89
   112.5    349.79  30303.79  511270.9
 END FTABLE  2

 FTABLE      3
rows cols                         ***
  22    4
   depth      area    volume  outflow1 ***
     0.        0.        0.        0.
    0.02      4.46      0.09      0.02
    0.06      4.49      0.27      0.13
     0.1      4.52      0.45      0.31
     0.2      4.61       0.9      0.98
     0.6      4.94      2.81      6.16
      1.      5.27      4.86     14.54
     1.2      5.44      5.93     19.79
     1.6      5.77      8.17     32.27
      2.      6.11     10.55     47.31
      3.      6.94     17.07     95.86
      4.      7.77     24.43    160.13
      5.       8.6     32.62    240.61
      6.      9.44     41.64    337.99
```

```
      7.     10.27     51.49    453.07
      8.      11.1     62.18    586.69
     12.    125.46    335.31   1924.96
     16.     128.8    843.83   5555.83
     20.    132.13   1365.67  10580.51
     24.    135.46   1900.84  16839.49
   39.29    148.19   4068.57  50759.91
    100.    198.74  14600.49  321350.8
  END FTABLE  3

  FTABLE      4
 rows cols                               ***
   18    4
     depth      area    volume  outflow1 ***
        0.        0.        0.        0.
      0.02      3.47      0.07      0.02
      0.06      3.49      0.21      0.13
       0.1      3.52      0.35      0.31
       0.2      3.59       0.7      0.98
       0.6      3.86      2.19      6.17
        1.      4.12      3.79     14.55
       1.2      4.26      4.63     19.81
       1.6      4.53      6.38     32.32
        2.      4.79      8.25     47.41
        3.      5.46     13.38     96.19
      3.17      5.58     14.31    106.06
      4.76    118.15    112.37    472.99
      6.34    119.21    300.48   1413.65
      7.93    120.27    490.27   2722.66
      9.51    121.33    681.74   4353.88
       31.    135.71   3443.69  50484.16
      58.5    154.11   7428.76  161202.4
  END FTABLE  4

  FTABLE     10
 rows cols                               ***
   21    4
     depth      area    volume  outflow1 ***
        0.        0.        0.        0.
      0.02      2.16      0.04      0.02
      0.06      2.18      0.13      0.12
       0.1      2.19      0.22      0.29
       0.2      2.23      0.44      0.92
       0.6      2.39      1.36      5.79
        1.      2.56      2.35     13.67
       1.2      2.64      2.87     18.61
       1.6       2.8      3.96     30.35
        2.      2.96      5.11     44.49
        3.      3.36      8.27     90.15
        4.      3.77     11.84    150.58
        5.      4.17     15.81    226.26
```

```
    6.     4.57    20.18    317.83
    7.     4.98    24.96    426.05
   10.5    46.75   115.49   1157.45
   14.     48.17   281.6    3273.95
   17.5    49.58   452.66   6191.38
   21.     50.99   628.66   9821.19
   43.15   59.93   1856.87  47026.22
  150.     103.06  10565.18  544160.5
 END FTABLE 10

 FTABLE     11
rows cols                        ***
  21    4
   depth    area   volume  outflow1 ***
    0.      0.      0.       0.
   0.02    0.19     0.      0.02
   0.06    0.2     0.01     0.13
   0.1     0.2     0.02     0.31
   0.2     0.2     0.04     0.97
   0.6     0.22    0.12     6.1
   1.      0.23    0.21     14.4
   1.2     0.24    0.26     19.6
   1.6     0.25    0.36     31.96
   2.      0.27    0.46     46.86
   3.      0.3     0.75     94.95
   4.      0.34    1.07     158.6
   5.      0.38    1.42     238.31
   6.      0.41    1.82     334.76
   7.      0.45    2.25     448.75
   10.5    4.21    10.4     1219.1
   14.     4.34    25.37    3448.35
   17.5    4.47    40.78    6521.18
   21.     4.59    56.64    10344.35
   43.26   5.4     167.91   49797.71
   150.    9.28    951.82   573147.3
 END FTABLE 11

 FTABLE      5
rows cols                        ***
  21    4
   depth    area   volume  outflow1 ***
    0.      0.      0.       0.
   0.02    2.12    0.04     0.02
   0.06    2.14    0.13     0.13
   0.1     2.15    0.21     0.31
   0.2     2.19    0.43     0.99
   0.6     2.35    1.34     6.23
   1.      2.51    2.31     14.69
   1.2     2.59    2.82     19.99
   1.6     2.75    3.89     32.6
   2.      2.91    5.02     47.8
```

```
      3.      3.3      8.13     96.85
      4.      3.7     11.63    161.78
      5.      4.1     15.52    243.09
      6.     4.49     19.82    341.47
      7.     4.89     24.51    457.74
    10.5    45.91    113.41   1243.54
     14.     47.3    276.53   3517.48
    17.5    48.69    444.51    6651.9
     21.    50.07    617.34  10551.71
   44.22    59.28   1886.61   53077.8
    150.    101.2  10374.82  584636.3
  END FTABLE  5

  FTABLE      6
 rows cols                               ***
   20    4
     depth     area    volume  outflow1 ***
       0.       0.       0.        0.
     0.02     3.56     0.07     0.01
     0.06      3.6     0.21     0.08
      0.1     3.65     0.36     0.18
      0.2     3.76     0.73     0.58
      0.6      4.2     2.32     3.69
       1.     4.65     4.09     8.78
      1.2     4.87     5.05    12.01
      1.6     5.32     7.09    19.79
       2.     5.77      9.3    29.34
       3.     6.88    15.63    61.14
       4.       8.    23.07   104.94
       5.     9.12    31.63   161.69
       6.    10.23    41.31    232.4
      6.5    10.79    46.56    273.3
     9.75   126.06   268.94  1003.27
      13.   129.68   684.52  2917.15
    16.25   133.31  1111.89  5571.26
     19.5   136.94  1551.05  8881.52
    36.66    156.1  4065.31 35791.34
  END FTABLE  6

  FTABLE      8
 rows cols                               ***
   20    4
     depth     area    volume  outflow1 ***
       0.       0.       0.        0.
     0.02     3.46     0.07     0.01
     0.06     3.51     0.21     0.08
      0.1     3.55     0.35     0.18
      0.2     3.66     0.71     0.58
      0.6      4.1     2.26     3.66
       1.     4.53     3.99      8.7
      1.2     4.75     4.91     11.9
```

```
     1.6      5.18       6.9      19.62
      2.      5.62      9.06      29.08
      3.       6.7     15.22      60.61
      4.      7.79     22.47     104.04
      5.      8.88     30.81     160.29
      6.      9.97     40.23     230.38
     6.5     10.51     45.35     270.93
    9.75    122.77    261.93     994.58
     13.     126.3    666.68    2891.89
   16.25    129.84   1082.91    5523.02
    19.5    133.37   1510.63    8804.62
    35.3    150.55   3752.87   32822.58
 END FTABLE  8

 FTABLE      7
rows cols                         ***
  23    4
   depth      area    volume  outflow1 ***
      0.        0.        0.        0.
    0.02      7.32      0.15      0.03
    0.06      7.35      0.44      0.17
     0.1      7.39      0.73       0.4
     0.2      7.47      1.48      1.28
     0.6      7.82      4.54        8.
      1.      8.17      7.73     18.82
     1.2      8.34      9.39     25.55
     1.6      8.69     12.79     41.47
      2.      9.04     16.34     60.48
      3.      9.91     25.81    120.81
      4.     10.78     36.15    198.78
      5.     11.65     47.37    294.21
      6.     12.51     59.45    407.29
      7.     13.38      72.4    538.36
      8.     14.25     86.21     687.9
     8.6     14.77     94.92    786.71
    12.9     45.09    223.63    941.42
    17.2     48.83    425.55   2186.44
    21.5     52.56    643.53   3849.75
    25.8      56.3    877.59   5913.44
   48.87     76.35   2407.71  23826.35
    130.    146.86  11462.22  196219.6
 END FTABLE  7

 FTABLE      9
rows cols                         ***
  23    4
   depth      area    volume  outflow1 ***
      0.        0.        0.        0.
    0.02      3.12      0.06      0.04
    0.06      3.14      0.19      0.22
     0.1      3.15      0.31      0.52
```

```
     0.2     3.19     0.63     1.64
     0.6     3.34     1.94    10.25
      1.     3.49      3.3    24.11
     1.2     3.56     4.01    32.74
     1.6     3.71     5.46    53.13
      2.     3.86     6.97    77.49
      3.     4.23    11.02   154.78
      4.      4.6    15.43   254.67
      5.     4.97    20.21   376.94
      6.     5.34    25.37   521.81
      7.     5.71     30.9   689.74
      8.     6.08    36.79   881.33
     8.6     6.31    40.51  1007.92
    12.9    20.61    98.38  1250.52
    17.2     22.2   190.42  2952.16
    21.5     23.8   289.33  5229.74
    25.8    25.39   395.09  8054.12
   51.67    34.99  1175.96 36459.53
    130.    64.04  5054.68 262391.2
  END FTABLE  9
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x       <Name> x x ***
*** Met Seg RALEIGH
WDM2    11 PREC     ENGL              SAME PERLND  11 117 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND  11 117 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND  11 117 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND  11 117 EXTNL  WINMOV
WDM2    15 SOLR     ENGL              SAME PERLND  11 117 EXTNL  SOLRAD
WDM2    16 PEVT     ENGL              SAME PERLND  11 117 EXTNL  PETINP
*** Met Seg RALEIGH
WDM2    11 PREC     ENGL              SAME IMPLND  11 111 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME IMPLND  11 111 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME IMPLND  11 111 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND  11 111 EXTNL  WINMOV
WDM2    15 SOLR     ENGL              SAME IMPLND  11 111 EXTNL  SOLRAD
WDM2    16 PEVT     ENGL              SAME IMPLND  11 111 EXTNL  PETINP
*** Met Seg RALEIGH
WDM2    11 PREC     ENGL              SAME RCHRES   1  11 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES   1  11 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES   1  11 EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES   1  11 EXTNL  WIND
WDM2    15 SOLR     ENGL              SAME RCHRES   1  11 EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES   1  11 EXTNL  CLOUD
WDM2    12 EVAP     ENGL              SAME RCHRES   1  11 EXTNL  POTEV

WDM1  7005 FLOW     ENGL        0.0826SAME RCHRES   1     INFLOW IVOL
WDM1  7003 SSED     ENGL              DIV  RCHRES   1     INFLOW ISED   3
WDM1  7004 SSED     ENGL              DIV  RCHRES   1     INFLOW ISED   3
```

```
WDM1  7009 SSED     ENGL           DIV  RCHRES   2     INFLOW ISED   3
WDM1  7010 SSED     ENGL           DIV  RCHRES   2     INFLOW ISED   3
WDM1  7027 FLOW     ENGL       0.0826SAME RCHRES   2     INFLOW IVOL
WDM1  7006 FLOW     ENGL       0.0826SAME RCHRES   3     INFLOW IVOL
WDM1  7007 SSED     ENGL           DIV  RCHRES   3     INFLOW ISED   3
WDM1  7008 SSED     ENGL           DIV  RCHRES   3     INFLOW ISED   3
WDM1  7021 SSED     ENGL           DIV  RCHRES   4     INFLOW ISED   3
WDM1  7022 SSED     ENGL           DIV  RCHRES   4     INFLOW ISED   3
WDM1  7001 FLOW     ENGL       0.0826SAME RCHRES  10     INFLOW IVOL
WDM1  7002 F.CO     ENGL           SAME RCHRES  10     INFLOW IDQAL  1
WDM1  7011 SSED     ENGL           DIV  RCHRES  10     INFLOW ISED   3
WDM1  7012 SSED     ENGL           DIV  RCHRES  10     INFLOW ISED   3
WDM1  7013 SSED     ENGL           DIV  RCHRES  11     INFLOW ISED   3
WDM1  7014 SSED     ENGL           DIV  RCHRES  11     INFLOW ISED   3
WDM1  7015 SSED     ENGL           DIV  RCHRES   5     INFLOW ISED   3
WDM1  7016 SSED     ENGL           DIV  RCHRES   5     INFLOW ISED   3
WDM1  7023 SSED     ENGL           DIV  RCHRES   6     INFLOW ISED   3
WDM1  7024 SSED     ENGL           DIV  RCHRES   6     INFLOW ISED   3
WDM1  7025 SSED     ENGL           DIV  RCHRES   8     INFLOW ISED   3
WDM1  7026 SSED     ENGL           DIV  RCHRES   8     INFLOW ISED   3
WDM1  7017 SSED     ENGL           DIV  RCHRES   7     INFLOW ISED   3
WDM1  7018 SSED     ENGL           DIV  RCHRES   7     INFLOW ISED   3
WDM1  7019 SSED     ENGL           DIV  RCHRES   9     INFLOW ISED   3
WDM1  7020 SSED     ENGL           DIV  RCHRES   9     INFLOW ISED   3
END EXT SOURCES

SCHEMATIC
<-Volume->               <--Area-->    <-Volume->  <ML#> ***      <sb>
<Name>   x               <-factor->    <Name>   x       ***        x x
PERLND  11                   555.9     RCHRES   1      2
PERLND  12                    21.8     RCHRES   1      2
IMPLND  11                   555.9     RCHRES   1      1
PERLND  13                   806.6     RCHRES   1      2
PERLND  14                    87.2     RCHRES   1      2
PERLND  15                    21.8     RCHRES   1      2
PERLND  16                    65.4     RCHRES   1      2
PERLND  17                    65.4     RCHRES   1      2
PERLND  21                  1084.9     RCHRES   2      2
IMPLND  21                  1084.9     RCHRES   2      1
PERLND  22                    51.7     RCHRES   2      2
PERLND  23                  2221.4     RCHRES   2      2
PERLND  24                   258.3     RCHRES   2      2
PERLND  25                    51.7     RCHRES   2      2
PERLND  26                     310     RCHRES   2      2
PERLND  27                   103.3     RCHRES   2      2
PERLND  31                  655.59     RCHRES   3      2
IMPLND  31                  655.87     RCHRES   3      1
PERLND  32                      18     RCHRES   3      2
PERLND  33                   108.1     RCHRES   3      2
PERLND  34                   288.2     RCHRES   3      2
PERLND  36                      54     RCHRES   3      2
```

PERLND 37	36	RCHRES	3	2
RCHRES 1		RCHRES	3	3
RCHRES 2		RCHRES	3	3
PERLND 41	696.8	RCHRES	4	2
IMPLND 41	696.8	RCHRES	4	1
PERLND 42	64.8	RCHRES	4	2
PERLND 43	1328.8	RCHRES	4	2
PERLND 44	226.9	RCHRES	4	2
PERLND 45	32.4	RCHRES	4	2
PERLND 46	129.6	RCHRES	4	2
PERLND 47	64.8	RCHRES	4	2
PERLND 101	358	RCHRES	10	2
IMPLND 101	358	RCHRES	10	1
PERLND 102	28.6	RCHRES	10	2
PERLND 103	386.6	RCHRES	10	2
PERLND 104	171.8	RCHRES	10	2
PERLND 105	14.3	RCHRES	10	2
PERLND 106	14.3	RCHRES	10	2
PERLND 107	100.2	RCHRES	10	2
RCHRES 3		RCHRES	10	3
RCHRES 4		RCHRES	10	3
PERLND 111	3.2	RCHRES	11	2
IMPLND 111	3.2	RCHRES	11	1
PERLND 112	3.2	RCHRES	11	2
PERLND 113	113.4	RCHRES	11	2
PERLND 114	8.1	RCHRES	11	2
PERLND 116	19.4	RCHRES	11	2
PERLND 117	11.3	RCHRES	11	2
RCHRES 10		RCHRES	11	3
PERLND 51	352.5	RCHRES	5	2
IMPLND 51	352.5	RCHRES	5	1
PERLND 53	423	RCHRES	5	2
PERLND 54	197.4	RCHRES	5	2
PERLND 56	28.2	RCHRES	5	2
PERLND 57	56.4	RCHRES	5	2
RCHRES 11		RCHRES	5	3
PERLND 61	474.5	RCHRES	6	2
IMPLND 61	474.5	RCHRES	6	1
PERLND 62	203.3	RCHRES	6	2
PERLND 66	271.1	RCHRES	6	2
PERLND 67	203.3	RCHRES	6	2
PERLND 63	4270.1	RCHRES	6	2
PERLND 64	667.8	RCHRES	6	2
PERLND 65	203.3	RCHRES	6	2
PERLND 81	257.6	RCHRES	8	2
IMPLND 81	257.6	RCHRES	8	1
PERLND 82	171.8	RCHRES	8	2
PERLND 83	3835.8	RCHRES	8	2
PERLND 84	400.8	RCHRES	8	2
PERLND 86	458	RCHRES	8	2
PERLND 87	343.5	RCHRES	8	2

```
PERLND  71                   69.5     RCHRES   7      2
IMPLND  71                   69.5     RCHRES   7      1
PERLND  72                   52.1     RCHRES   7      2
PERLND  73                 1094.9     RCHRES   7      2
PERLND  74                  312.8     RCHRES   7      2
PERLND  75                   17.4     RCHRES   7      2
PERLND  76                   52.1     RCHRES   7      2
PERLND  77                   69.5     RCHRES   7      2
RCHRES   5                            RCHRES   7      3
RCHRES   6                            RCHRES   7      3
PERLND  92                   17.8     RCHRES   9      2
PERLND  93                  622.3     RCHRES   9      2
PERLND  94                  177.8     RCHRES   9      2
PERLND  96                   44.5     RCHRES   9      2
PERLND  97                   26.7     RCHRES   9      2
RCHRES   8                            RCHRES   9      3
RCHRES   7                            RCHRES   9      3
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
RCHRES  11 HYDR   RO     1 1          AVER WDM1  1001 FLOW   1 ENGL AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT
PERLND     PEST   POPST  1                 RCHRES         INFLOW IDQAL
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
PERLND     SEDMNT SOSED  1        0.05     RCHRES         INFLOW ISED
PERLND     SEDMNT SOSED  1        0.55     RCHRES         INFLOW ISED
PERLND     SEDMNT SOSED  1        0.4      RCHRES         INFLOW ISED
PERLND     SEDMNT SOSED  1        0.05     RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED  1        0.55     RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED  1        0.4      RCHRES         INFLOW ISED   3
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT  1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW IDQAL  1
  END MASS-LINK    2

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
```

```
IMPLND     IWTGAS SODOXM               RCHRES        INFLOW OXIF
IMPLND     IWTGAS SOHT                RCHRES        INFLOW IHEAT
IMPLND     SOLIDS SOSLD  1       0.05     RCHRES        INFLOW ISED
IMPLND     SOLIDS SOSLD  1       0.55     RCHRES        INFLOW ISED
IMPLND     SOLIDS SOSLD  1        0.4     RCHRES        INFLOW ISED
IMPLND     SOLIDS SOSLD  1       0.05     RCHRES        INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1       0.55     RCHRES        INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1        0.4     RCHRES        INFLOW ISED   3
IMPLND     IWTGAS SOHT                RCHRES        INFLOW IHEAT  1
IMPLND     IQUAL  SOQUAL 1              RCHRES        INFLOW IDQAL  1
  END MASS-LINK    1

  MASS-LINK       3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>              <Name> x x  ***
RCHRES     ROFLOW                     RCHRES        INFLOW
  END MASS-LINK    3

  MASS-LINK       90
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>              <Name> x x  ***
PERLND     PWATER SURO                COPY          INPUT  MEAN   1
PERLND     PWATER IFWO                COPY          INPUT  MEAN   2
PERLND     PWATER AGWO                COPY          INPUT  MEAN   3
PERLND     PWATER PET                 COPY          INPUT  MEAN   4
PERLND     PWATER TAET                COPY          INPUT  MEAN   5
PERLND     PWATER UZS                 COPY          INPUT  MEAN   6
PERLND     PWATER LZS                 COPY          INPUT  MEAN   7
  END MASS-LINK   90

  MASS-LINK       91
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>              <Name> x x  ***
IMPLND     IWATER SURO                COPY          INPUT  MEAN   1
IMPLND     IWATER PET                 COPY          INPUT  MEAN   4
IMPLND     IWATER IMPEV               COPY          INPUT  MEAN   5
  END MASS-LINK   91

  MASS-LINK       92
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>              <Name> x x  ***
PERLND     PWATER SURO                COPY          INPUT  MEAN   1
PERLND     PWATER IFWO                COPY          INPUT  MEAN   2
PERLND     PWATER AGWO                COPY          INPUT  MEAN   3
PERLND     PWATER PET                 COPY          INPUT  MEAN   4
PERLND     PWATER TAET                COPY          INPUT  MEAN   5
PERLND     PWATER UZS                 COPY          INPUT  MEAN   6
PERLND     PWATER LZS                 COPY          INPUT  MEAN   7
  END MASS-LINK   92

  MASS-LINK       93
```

```
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>             <Name> x x  ***
IMPLND     IWATER SURO                 COPY          INPUT  MEAN   1
IMPLND     IWATER PET                  COPY          INPUT  MEAN   4
IMPLND     IWATER IMPEV                COPY          INPUT  MEAN   5
  END MASS-LINK   93

  MASS-LINK       4
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>             <Name> x x  ***
BMPRAC     ROFLOW ROVOL                RCHRES        INFLOW IVOL
BMPRAC     ROFLOW ROOX                 RCHRES        INFLOW OXIF
BMPRAC     ROFLOW ROHEAT               RCHRES        INFLOW IHEAT
BMPRAC     ROFLOW RODQAL               RCHRES        INFLOW IDQAL
BMPRAC     ROFLOW ROSQAL               RCHRES        INFLOW ISQAL
BMPRAC     ROFLOW ROSQAL               RCHRES        INFLOW ISQAL
BMPRAC     ROFLOW ROSQAL               RCHRES        INFLOW ISQAL
BMPRAC     ROFLOW ROSED                RCHRES        INFLOW ISED
BMPRAC     ROFLOW ROSED                RCHRES        INFLOW ISED
BMPRAC     ROFLOW ROSED                RCHRES        INFLOW ISED
BMPRAC     ROFLOW ROSED  1             RCHRES        INFLOW ISED   1
BMPRAC     ROFLOW ROSED  2             RCHRES        INFLOW ISED   2
BMPRAC     ROFLOW ROSED  3             RCHRES        INFLOW ISED   3
BMPRAC     ROFLOW ROHEAT 1             RCHRES        INFLOW IHEAT  1
BMPRAC     ROFLOW RODQAL 1             RCHRES        INFLOW IDQAL  1
  END MASS-LINK    4

  MASS-LINK       5
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>             <Name> x x  ***
PERLND     PWATER PERO      0.0833333     BMPRAC        INFLOW IVOL
PERLND     PWTGAS PODOXM               BMPRAC        INFLOW IOX
PERLND     PWTGAS POHT                 BMPRAC        INFLOW IHEAT
PERLND     PEST   POPST  1             BMPRAC        INFLOW IDQAL
PERLND     PEST   SOSDPS 1             BMPRAC        INFLOW ISQAL
PERLND     PEST   SOSDPS 1             BMPRAC        INFLOW ISQAL
PERLND     PEST   SOSDPS 1             BMPRAC        INFLOW ISQAL
PERLND     SEDMNT SOSED  1      0.05     BMPRAC        INFLOW ISED
PERLND     SEDMNT SOSED  1      0.55     BMPRAC        INFLOW ISED
PERLND     SEDMNT SOSED  1       0.4     BMPRAC        INFLOW ISED
PERLND     SEDMNT SOSED  1      0.05     BMPRAC        INFLOW ISED   1
PERLND     SEDMNT SOSED  1      0.55     BMPRAC        INFLOW ISED   2
PERLND     SEDMNT SOSED  1       0.4     BMPRAC        INFLOW ISED   3
PERLND     PWTGAS POHT                 BMPRAC        INFLOW IHEAT  1
PERLND     PQUAL  POQUAL 1             BMPRAC        INFLOW IDQAL  1
  END MASS-LINK    5

  MASS-LINK       6
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>          <Name> x x<-factor->     <Name>             <Name> x x  ***
IMPLND     IWATER SURO      0.0833333     BMPRAC        INFLOW IVOL
```

```
IMPLND     IWTGAS SODOXM              BMPRAC        INFLOW IOX
IMPLND     IWTGAS SOHT              BMPRAC        INFLOW IHEAT
IMPLND     SOLIDS SOSLD  1       0.05     BMPRAC        INFLOW ISED
IMPLND     SOLIDS SOSLD  1       0.55     BMPRAC        INFLOW ISED
IMPLND     SOLIDS SOSLD  1        0.4     BMPRAC        INFLOW ISED
IMPLND     SOLIDS SOSLD  1       0.05     BMPRAC        INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1       0.55     BMPRAC        INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1        0.4     BMPRAC        INFLOW ISED   3
IMPLND     IWTGAS SOHT              BMPRAC        INFLOW IHEAT  1
IMPLND     IQUAL  SOQUAL 1              BMPRAC        INFLOW IDQAL  1
  END MASS-LINK    6
END MASS-LINK

END RUN
```

Appendix I

Calibration Data

From January, 2001 until November, 2002, the Triangle WWTP monitored in-stream fecal coliform concentrations at three locations in accord with NPDES requirements. In addition, there is a limited amount of data available from EPA STORET, which corresponds to NPDES data at the Downstream 1 location. These data (Table I.1) were used to calibrate both PERLND and IMPLND quality constituent parameters.

	NPDES Monitoring Data			EPA STORET Data
Date	Fecal Coliform Concentration (CFU/100mL)			
	Upstream	Downstream 1	Downstream 2	
1/4/2001	98	127	6	
1/10/2001	42	63	16	
1/18/2001	55	2000	10	
1/24/2001	60	6000	1275	
2/1/2001				67
2/8/2001	23	230	5	
2/15/2001	84	60	42	
2/21/2001	118	108	88	
2/28/2001	46	5900	220	
3/6/2001	57	230	240	
3/12/2001	39	21	56	
3/19/2001	60	62	32	
3/26/2001	62	58	70	
4/5/2001	38	78	40	
4/11/2001	86	540	108	
4/16/2001	63	68	52	
4/19/2001				360
4/24/2001	46	4100	100	
5/1/2001	92	3000	70	
5/9/2001	120	70	260	
5/15/2001	240	45	164	
5/24/2001	2700	280	270	
5/31/2001	552	220	136	
6/7/2001	600	200	72	
6/13/2001	620	310	88	
6/21/2001	390	3000	145	
6/26/2001	360	350	220	
6/28/2001				130
7/2/2001	150	230	210	
7/12/2001	66	945	350	

7/19/2001	4100	3000	220	
7/26/2001	600	580	220	
7/30/2001	600	1160	990	
8/9/2001	410	100	173	
8/14/2001	280	330	6000	
8/15/2001				260
8/23/2001	460	3000	340	
8/27/2001	152	129	250	
9/7/2001	310	220	380	
9/11/2001	185	600	700	
9/17/2001	104	124	104	
9/26/2001	600	600	600	
10/2/2001	590	600	200	
10/4/2001				280
10/10/2001	104	590	260	
10/16/2001	600	600	600	
10/24/2001	270	227	210	
10/30/2001	38	60	60	
11/5/2001				72
11/6/2001	42	470	190	
11/14/2001	32	770	270	
11/20/2001	72	38	104	
11/29/2001	22	3000	215	
12/4/2001	70	170	250	
12/11/2001	600	600	4400	
12/19/2001	720	420	670	
12/27/2001	47	92	39	
1/2/2002	74	66	15	
1/8/2002	6500	6000	6400	
1/14/2002				200
1/15/2002	140	1100		
1/23/2002	1800	2	260	
1/29/2002	120	609	38	
2/5/2002	230		56	
2/12/2002	144		92	
2/19/2002	62	6700	56	
2/26/2002	42	96	10	
3/5/2002	210	92	50	
3/12/2002	100	112	96	
3/15/2002				67
3/19/2002	480			
3/26/2002	25		48	
4/2/2002	850	670		
4/4/2002				77
4/12/2002	33	440	125	
4/16/2002	130	94	80	
4/23/2002	190	310	88	
4/30/2002	74	210	130	

5/7/2002				1600
5/9/2002	60	160	270	
5/14/2002	66		180	
5/17/2002				1300
5/21/2002	112		180	
5/23/2002				2800
5/28/2002	33	300	114	
5/31/2002				770
6/4/2002	470	520	111	
6/11/2002	94		20	
6/18/2002	42	490	155	
6/25/2002	114	1850	205	
6/27/2002				9
7/2/2002	250		370	
7/9/2002	220	760		
7/12/2002				400
7/19/2002	48	130	120	
7/23/2002	200	100	220	
8/6/2002	144		270	
8/13/2002	98	270	260	
8/20/2002	30		170	
8/27/2002	700			
9/4/2002	180	300	450	
9/10/2002	94	340	430	
9/17/2002	910			
9/24/2002	370	640	100	
10/1/2002	58	108	100	
10/2/2002				340
10/8/2002	28	290	240	
10/14/2002	700	760		
10/18/2002				380
10/22/2002	700		340	
10/29/2002	700			
11/5/2002	96	660	116	
11/11/2002	48	110	66	
11/19/2002	320	340	210	
11/26/2002	48	260	84	
12/17/2002				43

Table I.1: Summary of in-stream FC data used for calibration and verification.

Appendix J

Error Quantification

In terms of error quantification for observed vs. modeled in-stream fecal coliform concentrations, error is most closely defined in terms of what percentage of points are within one order of magnitude of each other. For this work, observed data points were compared with modeled data points over a 3-day window, which includes the modeled values for both the day before and after an observed value was recorded. Then, a best estimate from the values from this 3-day window was chosen for comparison with observed data. This is done due to the fact that HSPF outputs in-stream FC concentrations on a daily basis, which does not allow for direct correlation with a sample that was taken at a certain time on that day. Rather, that sample could be much more representative of modeled conditions for either the day before or the day after depending upon the time during the day when the sample was taken.

For the calibration stage, 88% (51 out of 58) of compared data points in Reach 5 and 84% (42 out of 50) in Reach 3 fall within this order of magnitude approximation (Figure J.1).

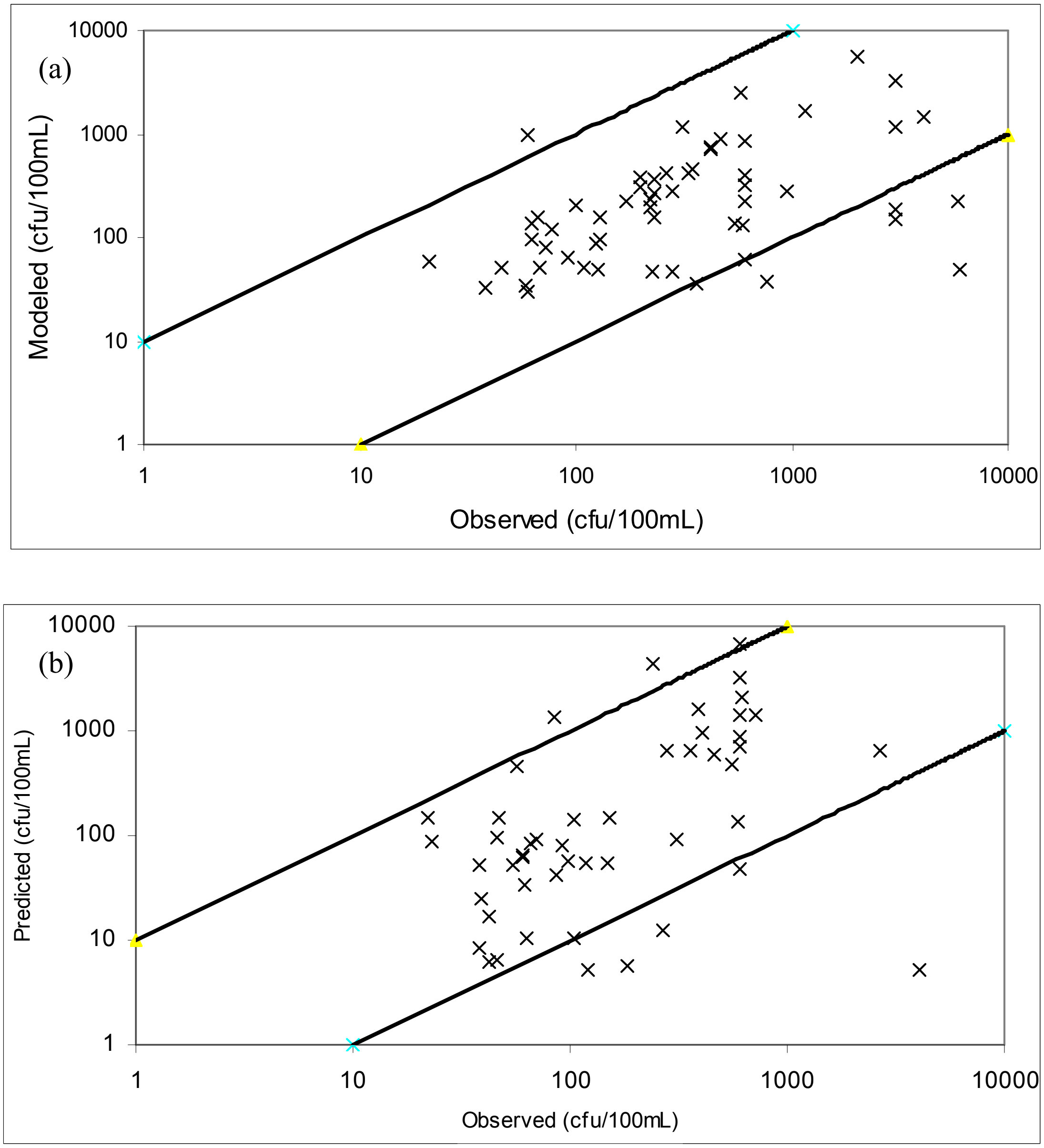


Figure J.1: Comparison of observed vs. modeled in-stream concentrations of fecal coliform for the calibration period of January 1,2001-December 31, 2001 with order of magnitude boundaries for (a) Reach 5 and (b) Reach 3.

Further analysis was completed using a Spearman's rank correlation coefficient (Clarke 1994) to determine if these data points are in fact related. This is completed according to:

$$r = 1 - \frac{6\sum_{i=1}^{n} d^2}{n(n^2 - 1)}$$

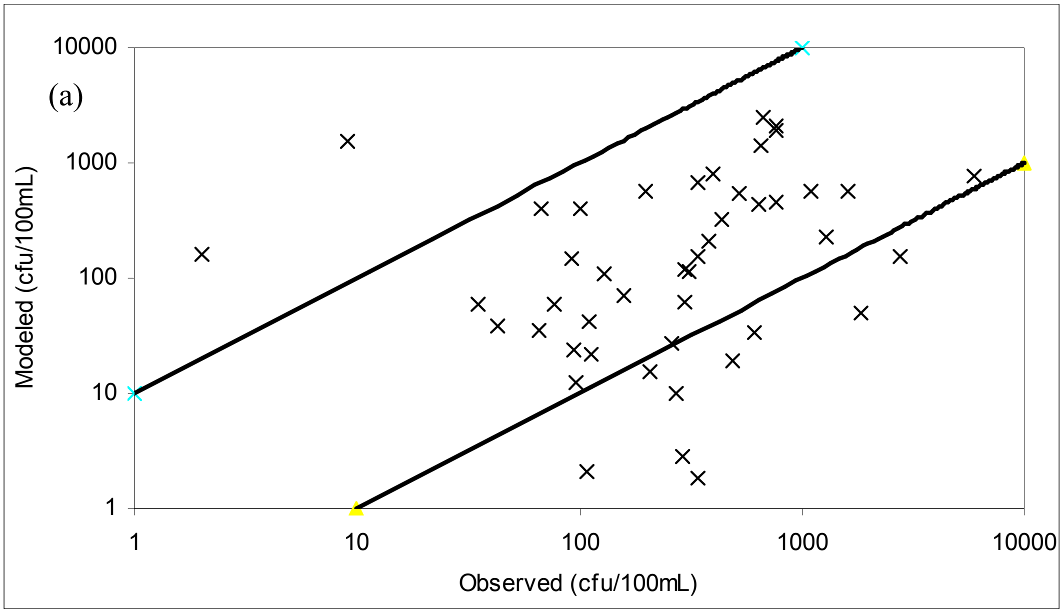
where:

n : number of samples

d : difference between the rank of corresponding datasets.

Using this quantification method, a Spearman's rank correlation coefficient of 0.49 for Reach 5 and 0.52 for Reach 3 was calculated, which equates to a significance of greater than 0.001 for observed and modeled data.

For the validation stage, 82% (36 out of 44) of compared data points in Reach 5 and 90% (43 out of 48) in Reach 3 fall within this order of magnitude approximation (Figure J.2). Further examination revealed a Spearman's rank correlation coefficient of 0.42 for Reach 5 and 0.63 for Reach 3, which equates to a significance of greater than 0.001 between modeled and observed data for Reach 3 and slightly less than 0.001 for Reach 5.



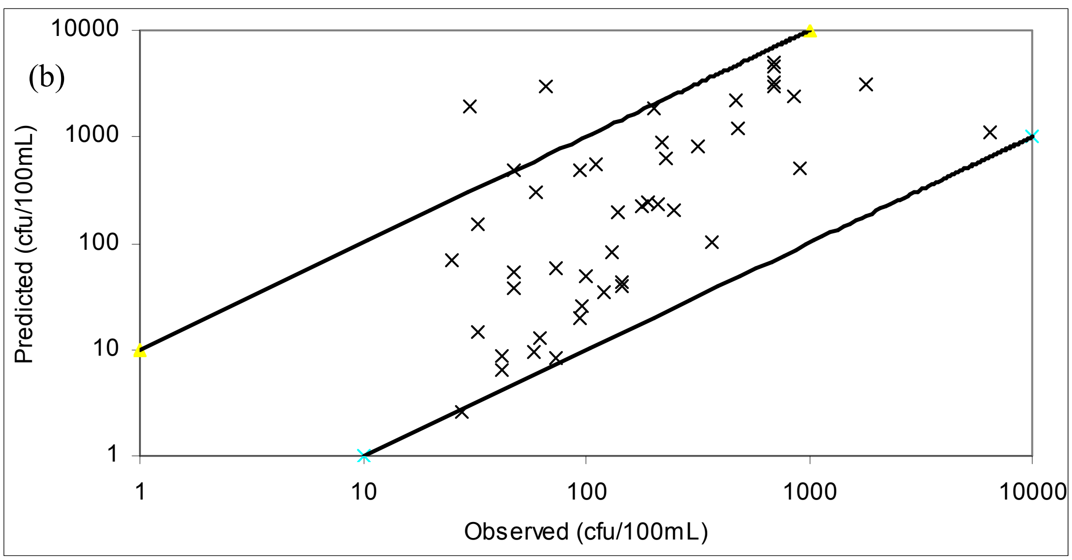


Figure J.2: Comparison of observed vs. modeled in-stream concentrations of fecal coliform for validation period of January 1, 2002-December 31, 2002 with order of magnitude boundaries for (a) Reach 5 and (b) Reach 3.

Appendix K

BMP Characteristics

A collection of BMP efficiency assessments was collected in order to determine the average efficiency (Table K.1).

BMP	Percent Removal	Source
Dry Basin	-122%	(CADOT 2004)
	-3%	(Lovern 2000)
Wet Basin	99%	(CADOT 2004)
	48%	(Borden 2001)
	90%	(Claytor and Schueller 1996)
	90%	(Davies and Bavor 2000)
	61%	(Gerba et al. 1999)
	-46%	(Lovern 2000)
	86%	(Mallin et al. 2002)
	70%	(Winer 2000)
Swales	-30%	(CADOT 2004)
	-192%	(Barrett et al. 1998)
	-25%	(Winer 2000)
Wetlands	97%	(Sayre et al. 2006)
	76%	(Birch et al. 2004)
	90%	(Claytor and Schueller 1996)
	87%	(Davies and Bavor 2000)
	97%	(Ottova et al. 1997)
	98%	(Gerba et al. 1999)
	92%	(Jin et al. 2002)
	98.60%	(Karim et al. 2004)
	49%	(Reinelt and Horner 1994)
	99%	(Khatiwada and Polprasert 1999)
	98%	(Lau and Chu 2000)
	78%	(Winer 2000)
Bioretention	74%	(Sayre et al. 2006)
	87.80%	(Ruscianoo and Obropta 2005)
	>90%	(Hunt and Lord 2005)
Riparian Buffers	50-99.4%	(Casteel et al. 2005)
	80%	(Kay et al. 2006)
	53.85%	(Goel et al. 2004)
	100%	(Lim et al. 1998)
	83.50%	(Mankin and Okoren 2003).
	99%	(Roodsari et al. 2005)
	92%	(CADOT 2004)
	74%	(Coyne et al. 1995)
	75%	(Fajardo et al. 2001)
	99%	(Barnett et al. 2004)

Appendix L

Source Loading Characterization

Though it was shown that impervious land surfaces contribute the greatest amount of FC loading to Northeast Creek, further characterizations are possible. Figure L.1 characterizes the pervious surface loadings.

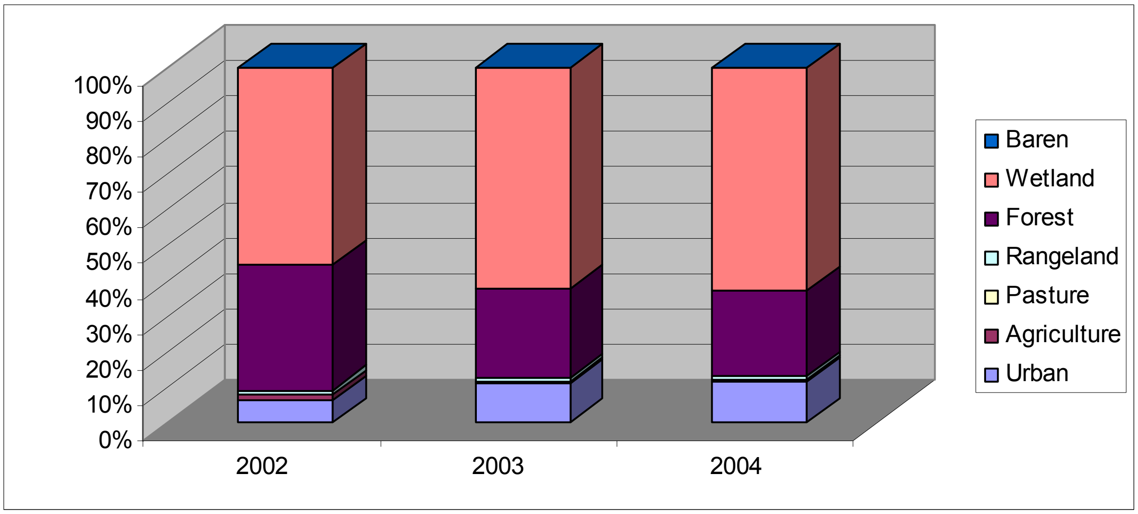


Figure L.1: Relative fraction of FC loading as attributable to each of the pervious land surface areas, with wetlands and forest land cover types having the highest fraction of total contributions.

These results make sense when considering that wetlands are a source of large amounts of fecal matter direct deposit primarily from both geese and ducks, as well as from other wildlife. These values are also higher when considering that these wetland systems are interconnected with Northeast Creek and its tributaries, meaning that pathways for bacterial removal do not exist. Forest land cover also provides habitat for wildlife, though the reason for a lower contribution from forest is that there is generally a longer overland flow plane with greater potential for infiltration from the forest into Northeast Creek.

Appendix M

BMP Linear Optimization Model

$$Z = \sum C_i(X_{jk}, F_{ijk}) + M_i(X_{jk}, F_{ijk}) + O_i(A_i)$$

Xj,k=	land area (acres) of land cover k in subwatershed j		
	k1=	PERLND urban	
	k2=	Cropland	
	k3=	Forest	
	k4=	Wetlands	
	k5=	Barren	
	k6=	Pasture	
	k7=	Rangeland	
	k8=	IMPLND Urban	
Qj,k=	loading (quantity/acre) of land cover k in subwatershed j		
Yi,k=	efficiency of BMP i applied to land cover k		
	i1=	Stormwater wetland	(not applicable for wetlands)
	i2=	Wet retention pond	(not applicable for wetlands)
	i3=	Buffer strip	(not applicable for urban areas)
	i4=	Bioretention	(not applicable for wetlands)
Fi,j,k=	fraction of BMPi applied to land cover k in subwatershed j		
Ai(Xj,k,Fi,j,k)=	area of BMPi required for land cover k in subwatershed j		
Ci(Xj,k,Fi,j,k)=	capital cost of BMPi associated with fraction of BMPi applied to land cover k in subwatershed j		
Mi(Xj,k,Fi,j,k)=	20-year maint cost of BMPi associated with fraction of BMPi applied to land cover k in subwatershed j		
Oi(Ai)=	opportunity cost associated with Ai of BMPi applied to land cover k in subwatershed j		

Xj,k

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	556	22	807	87	22	65	65	556
Sub 2	1085	52	2221	258	52	310	103	1085
Sub 3	656	18	108	288	0	54	36	656
Sub 4	697	65	1329	227	32	130	65	697
Sub 5	353	0	423	197	0	28	56	353
Sub 6	475	203	4270	668	203	271	203	475
Sub 7	70	52	1095	313	17	52	70	70
Sub 8	258	172	3836	401	0	458	344	258
Sub 9	0	18	622	178	0	45	27	0
Sub 10	358	29	387	172	14	14	100	358
Sub 11	3	3	113	8	0	19	11	3
[redacted]								

Qj,k

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	1.000E+08	1.510E+07	6.777E+07	2.010E+07	4.557E+05	7.777E+06	4.977E+07	2.550E+09
Sub 2	1.000E+08	1.103E+08	6.777E+07	2.010E+07	4.557E+05	1.713E+08	4.977E+07	2.550E+09
Sub 3	1.000E+08	1.510E+07	6.777E+07	2.010E+07	-	7.590E+06	4.977E+07	2.550E+09
Sub 4	1.000E+08	1.637E+08	6.777E+07	2.010E+07	4.557E+05	3.307E+08	4.977E+07	2.550E+09
Sub 5	1.000E+08	-	6.777E+07	2.010E+07	-	1.029E+07	4.977E+07	2.550E+09
Sub 6	1.000E+08	1.510E+07	6.777E+07	2.010E+07	4.557E+05	8.207E+06	4.977E+07	2.550E+09
Sub 7	1.000E+08	1.510E+07	6.777E+07	2.010E+07	4.557E+05	7.453E+06	4.977E+07	2.550E+09
Sub 8	1.000E+08	2.707E+07	6.777E+07	2.010E+07	-	2.883E+07	4.977E+07	2.550E+09
Sub 9	-	1.510E+07	6.777E+07	2.010E+07	-	9.040E+06	4.977E+07	-
Sub 10	1.000E+08	1.510E+07	6.777E+07	2.010E+07	4.557E+05	1.183E+07	4.977E+07	2.550E+09
Sub 11	1.000E+08	1.510E+07	6.777E+07	2.010E+07	-	8.337E+06	4.977E+07	2.550E+09
[redacted]								

Yi,k — Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0.95	0	0	0	0	0	0	0.95
Sub 2	0.95	0	0	0	0	0	0	0.95
Sub 3	0.95	0	0	0	0	0	0	0.95
Sub 4	0.95	0	0	0	0	0	0	0.95
Sub 5	0.95	-	0	0	0	0	0	0.95
Sub 6	0.95	0	0	0	0	0	0	0.95
Sub 7	0.95	0	0	0	0	0	0	0.95
Sub 8	0.95	0	0	0	0	0	0	0.95
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0.95	0	0	0	0	0	0	0.95
Sub 11	0.95	0	0	0	0	0	0	0.95

Yi,k — Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0.65	0.65	0	0	0	0.65	0	0.65
Sub 2	0.65	0.65	0	0	0	0.65	0	0.65
Sub 3	0.65	0.65	0	0	0	0.65	0	0.65
Sub 4	0.65	0.65	0	0	0	0.65	0	0.65
Sub 5	0.65	-	0	0	0	0.65	0	0.65
Sub 6	0.65	0.65	0	0	0	0.65	0	0.65
Sub 7	0.65	0.65	0	0	0	0.65	0	0.65
Sub 8	0.65	0.65	0	0	0	0.65	0	0.65
Sub 9	-	0.65	0	0	0	0.65	0	-
Sub 10	0.65	0.65	0	0	0	0.65	0	0.65
Sub 11	0.65	0.65	0	0	0	0.65	0	0.65

Yi,k	Riparian Buffer							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 2	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 3	0	0.85	0.85	0.85	-	0.85	0.85	0
Sub 4	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 5	0	-	0.85	0.85	-	0.85	0.85	0
Sub 6	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 7	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 8	0	0.85	0.85	0.85	-	0.85	0.85	0
Sub 9	-	0.85	0.85	0.85	-	0.85	0.85	-
Sub 10	0	0.85	0.85	0.85	0.85	0.85	0.85	0
Sub 11	0	0.85	0.85	0.85	-	0.85	0.85	0

Yi,k	Bioretention							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0.8	0.8	0	0	0	0.8	0	0.8
Sub 2	0.8	0.8	0	0	0	0.8	0	0.8
Sub 3	0.8	0.8	0	0	0	0.8	0	0.8
Sub 4	0.8	0.8	0	0	0	0.8	0	0.8
Sub 5	0.8	-	0	0	0	0.8	0	0.8
Sub 6	0.8	0.8	0	0	0	0.8	0	0.8
Sub 7	0.8	0.8	0	0	0	0.8	0	0.8
Sub 8	0.8	0.8	0	0	0	0.8	0	0.8
Sub 9	-	0.8	0	0	0	0.8	0	-
Sub 10	0.8	0.8	0	0	0	0.8	0	0.8
Sub 11	0.8	0.8	0	0	0	0.8	0	0.8

[redacted]

Fi,j,k

Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0.512790298	0	0	0	0	0	0	0.5127903
Sub 2	1	0	0	0	0	0	0	1
Sub 3	1	0	0	0	0	0	0	1
Sub 4	1	0	0	0	0	0	0	1
Sub 5	1	-	0	0	0	0	0	1
Sub 6	0.19559438	0	0	0	0	0	0	0.1955944
Sub 7	1	0	0	0	0	0	0	1
Sub 8	1	0	0	0	0	0	0	1
Sub 9	-	0	0	0	0	0	0	-
Sub 10	1	0	0	0	0	0	0	1
Sub 11	0	0	0	0	0	0	0	0

Fi,j,k

Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

Fi,j,k	Riparian Buffer							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

Fi,j,k	Bioretention							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

Ri,j,k Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	2.708E+10	0	0	0	0	0	0	6.905E+11
Sub 2	1.03066E+11	0	0	0	0	0	0	2.628E+12
Sub 3	62281050000	0	0	0	0	0	0	1.589E+12
Sub 4	66196000000	0	0	0	0	0	0	1.688E+12
Sub 5	33487500000	-	0	0	0	0	0	8.539E+11
Sub 6	8816905660	0	0	0	0	0	0	2.248E+11
Sub 7	6602500000	0	0	0	0	0	0	1.684E+11
Sub 8	24472000000	0	0	0	0	0	0	6.24E+11
Sub 9	-	0	0	0	0	0	0	-
Sub 10	34010000000	0	0	0	0	0	0	8.673E+11
Sub 11	0	0	0	0	0	0	0	0

Ri,j,k Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

Ri,j,k	Riparian Buffer							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

Ri,j,k	Bioretention							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

A(XF) Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	5.701202534	0	0	0	0	0	0	5.7009964
Sub 2	21.698	0	0	0	0	0	0	21.6982
Sub 3	13.1118	0	0	0	0	0	0	13.1174
Sub 4	13.936	0	0	0	0	0	0	13.936
Sub 5	7.05	-	0	0	0	0	0	7.05
Sub 6	1.856190665	0	0	0	0	0	0	1.8561907
Sub 7	1.39	0	0	0	0	0	0	1.39
Sub 8	5.152	0	0	0	0	0	0	5.152
Sub 9	-	0	0	0	0	0	0	-
Sub 10	7.16	0	0	0	0	0	0	7.16
Sub 11	0	0	0	0	0	0	0	0

A(XF) Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

A(FX) Riparian Buffer

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

A(FX) Bioretention

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

N(A) Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	9.502004223	0	0	0	0	0	0	9.5016607
Sub 2	36.16333333	0	0	0	0	0	0	36.163667
Sub 3	21.853	0	0	0	0	0	0	21.862333
Sub 4	23.22666667	0	0	0	0	0	0	23.226667
Sub 5	11.75	-	0	0	0	0	0	11.75
Sub 6	3.093651109	0	0	0	0	0	0	3.0936511
Sub 7	2.316666667	0	0	0	0	0	0	2.3166667
Sub 8	8.586666667	0	0	0	0	0	0	8.5866667
Sub 9	-	0	0	0	0	0	0	-
Sub 10	11.93333333	0	0	0	0	0	0	11.933333
Sub 11	0	0	0	0	0	0	0	0

N(A) Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

N(A)	Riparian Buffer							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

N(A)	Bioretention							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

C(XF) Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	$189,858	0	0	0	0	0	0	$189,851
Sub 2	$722,572	0	0	0	0	0	0	$722,579
Sub 3	$436,640	0	0	0	0	0	0	$436,827
Sub 4	$464,087	0	0	0	0	0	0	$464,087
Sub 5	$234,774	-	0	0	0	0	0	$234,774
Sub 6	$61,814	0	0	0	0	0	0	$61,814
Sub 7	$46,289	0	0	0	0	0	0	$46,289
Sub 8	$171,568	0	0	0	0	0	0	$171,568
Sub 9	-	0	0	0	0	0	0	-
Sub 10	$238,438	0	0	0	0	0	0	$238,438
Sub 11	$0	0	0	0	0	0	0	$0

C(XF) Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

C(FX) Riparian Buffer

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

C(FX) Bioretention

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

M(XF) Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	$196,351	0	0	0	0	0	0	$196,344
Sub 2	$747,286	0	0	0	0	0	0	$747,293
Sub 3	$451,574	0	0	0	0	0	0	$451,767
Sub 4	$479,960	0	0	0	0	0	0	$479,960
Sub 5	$242,804	-	0	0	0	0	0	$242,804
Sub 6	$63,928	0	0	0	0	0	0	$63,928
Sub 7	$47,872	0	0	0	0	0	0	$47,872
Sub 8	$177,436	0	0	0	0	0	0	$177,436
Sub 9	-	0	0	0	0	0	0	-
Sub 10	$246,593	0	0	0	0	0	0	$246,593
Sub 11	$0	0	0	0	0	0	0	$0

M(XF) Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

M(FX)	Riparian Buffer							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

M(FX)	Bioretention							
	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

[redacted]

O(A) Stormwater Wetlands

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	$285,060	0	0	0	0	0	0	$285,050
Sub 2	$1,084,900	0	0	0	0	0	0	$1,084,910
Sub 3	$655,590	0	0	0	0	0	0	$655,870
Sub 4	$696,800	0	0	0	0	0	0	$696,800
Sub 5	$352,500	-	0	0	0	0	0	$352,500
Sub 6	$92,810	0	0	0	0	0	0	$92,810
Sub 7	$69,500	0	0	0	0	0	0	$69,500
Sub 8	$257,600	0	0	0	0	0	0	$257,600
Sub 9	-	0	0	0	0	0	0	-
Sub 10	$358,000	0	0	0	0	0	0	$358,000
Sub 11	$0	0	0	0	0	0	0	$0

O(A) Wet Retention Pond

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

O(A) Riparian Buffer

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	-	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	-	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	-	0	0	0
Sub 9	0	0	0	0	-	0	0	0
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	-	0	0	0

O(A) Bioretention

	P Urban	Cropland	Forest	Wetlands	Barren	Pasture	Rangeland	I Urban
Sub 1	0	0	0	0	0	0	0	0
Sub 2	0	0	0	0	0	0	0	0
Sub 3	0	0	0	0	0	0	0	0
Sub 4	0	0	0	0	0	0	0	0
Sub 5	0	-	0	0	0	0	0	0
Sub 6	0	0	0	0	0	0	0	0
Sub 7	0	0	0	0	0	0	0	0
Sub 8	0	0	0	0	0	0	0	0
Sub 9	-	0	0	0	0	0	0	-
Sub 10	0	0	0	0	0	0	0	0
Sub 11	0	0	0	0	0	0	0	0

Appendix N

BMP Optimization Model Sensitivity Analysis

Scenario	A	B	C				D
BMP	Stormwater Wetlands	Stormwater Wetlands	Stormwater Wetlands	Buffer Strip	Bioretention	Bioretention	Biorention
Land Cover	All Urban	All Urban	All Urban	Forest	Cropland	Pasture	All Urban
Coverage 1	51.3%	0.0%	100.0%	0.0%	100.0%	0.0%	71.5%
2	100.0%	32.9%	100.0%	100.0%	100.0%	100.0%	100.0%
3	100.0%	100.0%	100.0%	17.9%	100.0%	0.0%	100.0%
4	100.0%	29.1%	100.0%	0.0%	100.0%	100.0%	100.0%
5	100.0%	100.0%	100.0%	0.0%	-	100.0%	100.0%
6	19.6%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%
7	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	67.5%
8	100.0%	0.0%	100.0%	100.0%	100.0%	100.0%	0.0%
9	-	-	-	0.0%	100.0%	0.0%	-
10	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
11	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	0.0%
Cost	$18,145,867	$9,072,621	$145,730,503				$16,692,506

A Baseline optimized strategy
B 50% of baseline reductions
C 125% of baseline reductions
D All controls set to 90% efficiency

Table N.1 Sensitivity Analysis of BMP Linear Optimization Model.

From this analysis, there are several important aspects that are revealed. In looking at Scenario B, that of only requiring half of the total reduction in FC bacteria, stormwater wetlands remain the only BMP necessary to meet the reductions. This can also be done at just about half of the cost, but would not be sufficient to meet in-stream water quality standards. In fact, more than 17% of all geometric mean samples in Reach 3 and 7% in Reach 5 would be in violation of the state standard. Scenario C requires additional bacterial removal, and while this can be achieved, the costs to meet this requirement increase dramatically. While it is true that in-stream standards would never be broken, such a project would require an investment of $375/year by each resident in the watershed over the next twenty years. Finally, in looking at Scenario D, that of having each treatment control option have the same removal efficiency, it is shown that bioretention controls would actually be the most cost-effective were they to have the same efficiency as stormwater wetlands. However, in the baseline scenario, the extra efficiency generated through stormwater wetland controls offsets the added costs.

Under the base scenario, it was not possible to achieve the necessary reductions were the individual BMPs to have an efficiency of no greater than 80%. Were these to be the maximum removal efficiencies possible, there would need to be additional pretreatment through either non-structural or point source controls. Also, it was not possible to achieve greater than 130% of the necessary reductions under this scenario without further control by non-structural BMPs.

Appendix O

Assessment of BMP Costs

In order to determine whether the costs associated with this restoration plan are reasonable, several steps must be taken and will be outlined here.

To begin, it is necessary to determine the population that would be expected to contribute toward this total cost. This was done through the examination of those census tracts that fell within the boundaries of Northeast Creek Watershed. These tracts were accessed through the University of North Carolina GIS DataFinder, and its most recent data was from 2005. For those tracts that were not wholly contained by the boundaries of the watershed, overlapping areas were determined and multiplied by the individual tract's population density. Applicable census tracts were 001805, 002010, 002012, 002013, 002014, 020700, 053403, and 053600. This method yielded a 2005 population of 21,840 people that would live within the boundaries of Northeast Creek Watershed and would be responsible for bearing the costs of any restoration plan. Using the same method, a population of 17,876 people was found for 2000, meaning that the population growth rate over that 5-year period was 4.087%. Given that the costs associated with this plan were based upon 20 years, the population that would be contributing to this initiative in 20 years will have risen to 48,661 people, which is not unlikely given the large amounts of urbanization that are occurring.

Though there are grants and other funds available for the implementation of nonpoint source controls, this procedure will develop a conservative estimate for the per capita contribution necessary to raise the requisite funds. This is done by assessing every individual in the watershed a yearly tax or fee that would be used toward the development and upkeep of these nonpoint source control initiatives. It is necessary to solve for a uniform payment that would be assessed to every individual each year, which would generate a certain amount of revenue each year. These values would then be converted to 2005 dollars assuming a 6% discount rate, the sum of which would need to be greater than the total costs associated with these initiatives (Table O.1).

Year	Population	Revenue	Net Present Value
0	21840	$1,244,880	$1,244,880
1	22733	$1,295,758	$1,222,413
2	23662	$1,348,716	$1,200,352
3	24629	$1,403,838	$1,178,689
4	25635	$1,461,213	$1,157,417
5	26683	$1,520,933	$1,136,529
6	27774	$1,583,093	$1,116,018
7	28909	$1,647,794	$1,095,877
8	30090	$1,715,139	$1,076,100
9	31320	$1,785,237	$1,056,679
10	32600	$1,858,200	$1,037,609
11	33932	$1,934,144	$1,018,883
12	35319	$2,013,193	$1,000,495
13	36763	$2,095,472	$982,439
14	38265	$2,181,114	$964,709
15	39829	$2,270,256	$947,299
16	41457	$2,363,042	$930,203
17	43151	$2,459,619	$913,415
18	44915	$2,560,144	$896,930
19	46750	$2,664,777	$880,743
20	48661	$2,773,686	$864,848
	Sum	$40,180,247	$21,922,529

Table O.1: Table displaying the population growth that would be expected over the next 20 years, as well as verifying that a contribution of $57/person/year would be sufficient to cover the total costs.

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