Abstract

VanBrunt, Daniel Kent. Modeling Stream Flow Using GIS. (Under the direction of Hugh A. Devine.)

The Delaware Water Gap National Recreation Area (DEWA) would like to utilize hydrologic modeling coupled with GIS to help with the prediction of water quality changes in the watersheds entering the upper Delaware River. The first step towards completing this goal is to create a model that can accurately predict flow. The hydrologic model SWAT was used to model flow in the Broadhead watershed for DEWA by the Center for Earth Observation (CEO) at North Carolina State University (NCSU). The Broadhead watershed is located in North Eastern Pennsylvania and flows through DEWA on its way to the Delaware River.

Based on limited data and the criteria set forth by DEWA, SWAT was chosen from 11 different models as best suited to meet DEWA's needs. The data used to run the SWAT model included a 30-meter DEM, STATSGO soils data, a USGS landuse/ landcover map, and daily weather data from January 1, 1993 through October 20, 1999. The data used to calibrate the model consisted of flow data from two USGS gage stations, Minisink Hills and Anamolink, which are located within the Broadhead basin. The flow data from the two USGS gage stations were separated into surface flow and base flow using the USGS model HYSEP.

The Broadhead basin was separated into ten sub-watersheds. Two sub-watersheds contributed to the Anamolink catchment and eight sub-watersheds contributed to the Minisink catchment (the Minisink catchment contains the Anamolink catchment). The

Hydrologic Response Units (HRUs) were set to include soil types and landuse/ landcover types greater than or equal to 5% of the sub-watershed area. The calibration period of the model was run from January 1, 1993 to December 31, 1995, and the validation period was run from January 1, 1996 through October 20, 1999.

The model was run on both an annual and monthly time step. For the monthly time step the model was tested for both winter and non-winter months. The model predicted total flow on an annual time step within 16% of observed flow for the Anamolink basin, and within 18% of observed flow for the Minisink basin. However, more data and calibration is required to achieve the goal of predicting flow on a monthly time step.

MODELING STREAM FLOW USING GIS

by

DANIEL VANBRUNT

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

NATURAL RESOURCES,
SPATIAL INFORMATION SYSTEMS TECHNICAL OPTION

Raleigh

2002

APPROVED BY:

Dr. John E. Parsons   Dr. Casson Stallings

Chair of Advisory Committee
Dr. Hugh A. Devine

DEDICATION

This work is dedicated to everyone who has been a part of my life. You have all helped shape me into the person I am. Thank you.

BIOGRAPHY

The author was born April 8, 1974 in Baltimore, Maryland to Walter J. and Barbara G. VanBrunt. His grade school years were spent in the town of Frederick, Maryland. After graduating from Linganore High School he attended West Virginia University, graduating in May of 1997. After graduating he moved to Raleigh, North Carolina to work for the North Carolina State University Water Quality Group. He spent two years working with the Water Quality Group before entering North Carolina State University's graduate school to obtain a Master's of Science in Natural Resources with a Spatial Information Systems technical option.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my parents for always being there for me. I will never be able to thank them enough. I would also like to thank my brother Greg and his wife Patti. They have been great friends and I love them dearly.

Additionally, I would like to thank my advisory committee and all of the CEO family for helping me obtain my degree.

Finally, I would like to thank all of my friends who have been there to listen and give advice over these last few years. Your encouragement has been greatly appreciated.

Table of Contents

Appendices

List of Equations

List of Figures

List of Tables

Chapter 1: Introduction and Background Information

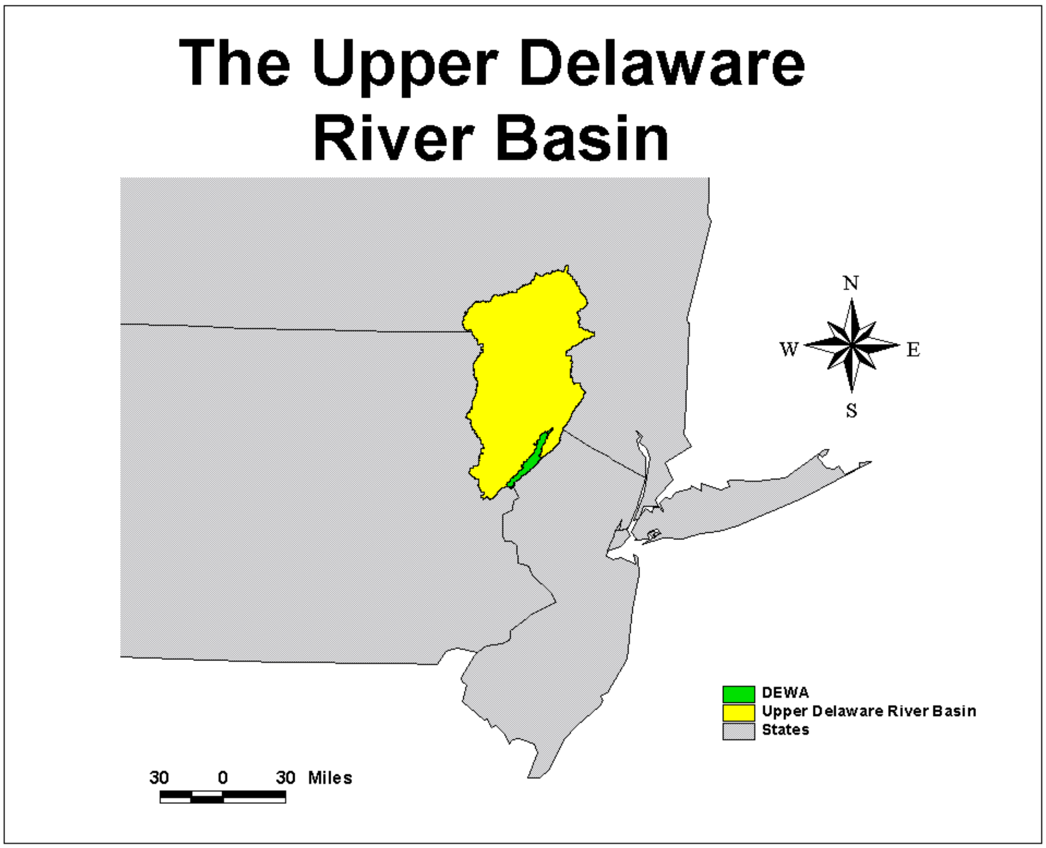
Introduction

The Delaware River is approximately 330 miles long and drains roughly 12,675 square miles of Delaware, New Jersey, New York, and Pennsylvania. It flows from northwest to southeast, transecting five topographic provinces: The Appalachian Plateau; the Ridge and Valley Province; the Reading Prong; the Piedmont; and the Atlantic Coastal Plain. The river's main stem is unimpeded by dams or control structures as it flows across these provinces, making it one of the few large free flowing rivers remaining in the contiguous United States. This "free flowing" characteristic has allowed in excess of 100 miles of the Delaware River to be designated as National Wild and Scenic Rivers System (http://www.nps.gov/dewa).

The Delaware River is an irreplaceable natural resource. It provides nearly 10 percent of the U.S. population with water while covering only 0.4 percent of the country's land area. The current water quality conditions of the river are considered above average, and to maintain this standard the Delaware River Basin Commission (DRBC), the U.S. Army Corps of Engineers, and state and local authorities have put heavy regulations on land and water degradation (http://www.nps.gov/dewa).

Three parks encompass approximately 120 miles of the Delaware River: The Delaware Water Gap National Recreation Area (DEWA), the Middle Delaware Scenic and Recreational River, and the Upper Delaware Scenic and Recreational River. In accordance with the regulations issued by the DRBC and the U.S. Army Corps of Engineers, the waters in these parks have been designated as "special protection waters" and can have no measurable decrease in water quality. Land ownership however, causes an inherent problem with the parks' ability to meet this mandate. There are over 4,000 square-miles of watersheds contributing flow to these "special protection waters", of which the parks only manage 110 square-miles. (http://www.nps.gov/dewa). Figure 1 shows the relative size of the upper Delaware River basin compared to DEWA.

Figure 1: The Upper Delaware River Basin

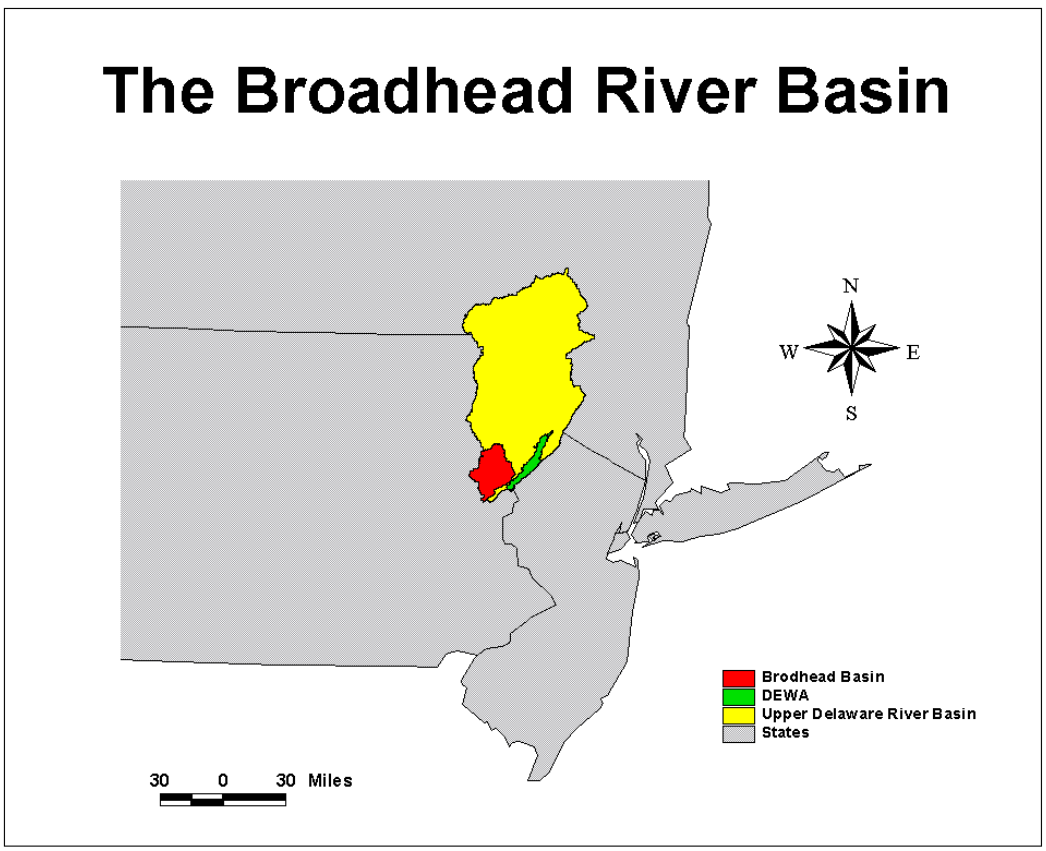


Due to this overwhelmingly large portion of the Upper Delaware River Basin not under federal or state protection, the personnel at DEWA would like to utilize Geographic Information Systems (GIS) in conjunction with hydrologic modeling in an effort to help monitor and predict future problems in their "special protection waters". The first step in this process is identifying a model that will reasonably predict flow.

Background

In the early 1990's, North Carolina State University (NCSU) began working cooperatively with DEWA to create a model of the Broadhead watershed. The Broadhead basin drains approximately 290 square-miles of Monroe and Pike Counties in North Eastern Pennsylvania. The majority of this watershed lies outside of the park boundary and consists mainly of forested, rural, and agricultural land. However, there is some development pressure on the East side of the basin that includes both commercial and non-commercialization of private lands. Figure 2 shows the Broadhead basin relative to the Upper Delaware basin and DEWA.

Figure 2: The Broadhead River Basin



Sung-Min Cho, an NCSU doctoral student, developed the original hydrologic model for the Broadhead. He tested a series of hydrologic models and concluded the SWAT model run in ArcInfo to be the most suitable (Cho, 1995). Unfortunately, this program was not user friendly and needed a great deal of training to be implemented. To try and alleviate this problem Dr. Casson Stallings created a GUI interface that would allow the majority of the model to run in ArcView (Stallings, 1998). This program was completed in June of 1998 and was called SAVI. SAVI was given to the park, but due to changes in park personnel and project priority the program was not widely utilized.

In the intervening four years, faster computer speeds, greater storage capacities, and more robust software has raised the potential for more accurate and user-friendly hydrologic modeling. In addition, personnel changes and more proposed development has led DEWA to again becoming interested in integrating hydrologic models into the management of the park's watersheds.

Project Objective

The objective of this project is to attempt to produce a working model that can accurately predict flow for the Broadhead basin. This is the first step in developing a complete hydrologic model that DEWA can utilize to predict and monitor water quality of the Delaware River.

Chapter 2: Literature Review

Introduction to Literature Review

“Prior to the advent of the unit hydrograph by Sherman (1932), hydrologic modeling was mostly empirical and based on limited data. [In] those days, graphs, tables, and simple analytical solution were the standard models, and hand calculations, in conjunction with sliderule, reflected computing prowess” (Singh and Fiorentino, 1996). Since the advent of the hydrograph, hydrologic modeling has developed into a data intensive, computer software driven science. Today, there are models covering every facet of water’s interaction with the environment. As stated in the background section of this paper, DEWA would like to posses a model that will reasonably predict flow and water quality changes resulting from development or other land use changes within the basins that flow into their park. The criteria the park has asked of the model are 1) the capability of predicting long term effects of changes in land use, 2) fairly easy to use with a quick learning curve, and 3) able to visually display outputs in map and table form. The purpose of the literature review is to evaluate the different types of hydrologic models, compare those models that could be used for the Broadhead basin, and then to provide a detailed outline of the most appropriate model for the project.

Model Types

Lumped and Distributed models are the two basic types of models used for Hydrologic Modeling. They can be deterministic or stochastic in nature, meaning the outputs are given as raw values or as probability of occurrences respectively. The goal of this portion of the project is to find a model that will most effectively utilize the available data for the Broadhead basin and not require any additional data collection and fieldwork, such as drilling monitoring wells, collecting soil samples, and creating stream profiles.

Lumped Models

Lumped hydrologic models are those models that commonly ignore spatial variations of precipitation, water flow, and other related processes, focusing instead on spatially averaged inputs, outputs, and parameter values. Their usefulness is limited due to their inability to account for the complexities of hydrologic processes and systems. Lumped models therefore are usually limited to those catchments where spatial variability does not dictate the outcome of an event (Muszik, 1996).

Distributed Models

"A truly distributed model of a process is possible only if the process can be described by an equation having an analytical solution" (Muszik, 1996). These types of models are physically based; meaning they are based on observed parameters rather then estimations. While the majority of distributed models require some degree of lumping, their objective is to account for spatial variations of hydrologic processes and parameters. Previously, limitations of distributed models came from computing the vast amount of data required to run the model. However, do to advancements in computers and modeling software, the current limitation for distributed modeling is the lack of available distributed hydrologic data (Muszik, 1996).

Model Comparisons

Based on the criteria set forth by the park**,** 11 models were compared.

Flow Models

The first three models, DR3M (Distributed Routing Rainfall-Runoff Model—version II), GLSNET (Regional hydrologic regression and network analysis using generalized least squares), and PRMS (Precipitation-Runoff Modeling System), have been grouped together based on their designation as flow prediction models. All three models are free-ware and can be downloaded through the USGS website. These models were eliminated upon first review due to their inability in calculating nutrient predictions, which will eventually be required.

Flow and Nutrient models

ANSWERS 2000

ANSWERS (Nonpoint Source Nutrient Planning Model) is an event based, distributed non-point source pollution model. "The model was developed for use by nonpoint source pollution managers to study the long-term effectiveness of best management practices (BMPs) in reducing runoff, sediment, and nutrient losses from agricultural watersheds" (Bouraoui and Dillaha, 1994). It simulates infiltration, evapotranspiration, percolation, and runoff and losses of nitrate, adsorbed and dissolved ammonium, absorbed total Kjeldahl nitrogen, and absorbed and dissolved phosphorus losses. During rainfall/ runoff events it runs a 30-second time step, otherwise it uses a 24-hour time step. The cells that make up the catchment's array may not exceed 1 ha, but can be made as small as the designer wishes.

ANSWERS was run for 25-months on two small watersheds, 1.4 ha and 1.3 ha, near Watkinsville, GA. It simulated runoff and nutrient loss well without any form of calibration. The model was then validated on a large watershed, 1153 ha, in Fauquier County, VA. It was run for five months after the calibration of two sediment detachment parameters. Predictions of cumulative runoff along with sediment and nutrient losses were within 39% of observed values. Predictions of individual runoff event losses were considerably less accurate (Bouraoui and Dillaha, 2000).

While this model seems to predict long term effects reasonably well, its inability to create cells larger than one ha and its use of an hourly time step exclude it from being used in this project. ANSWERS is also better suited for strictly agricultural watersheds.

ESWAT

ESWAT (Extended Soil Water Assessment Tool) is an extension of SWAT (discussed in detail later). Developed by A. van Griensven at the Vrije Universiteit Brussels, ESWAT is meant to completely model water quality and quantity processes in river basins. ESWAT models on an hourly time step, introduces reaeration at structures, and has a multi-objective auto-calibration module. (van Griensven)

ESWAT was not chosen because the extended capabilities of SWAT were of no use to DEWA. The park is more interested in monthly and annual predictions rather than hourly.

MIKE SHE coupled with MIKE 11

MIKE SHE is distributed and physically based hydrologic modeling program produced by the Danish Hydraulic Institute (DHI). Its goal is to allow the user to simulate water, solutes and sediments in the entire land phase of the hydrological cycle. It has a modular design that can be used to create an integrated model. Its individual components can be used together or independently depending on data availability and project goals. Coupled with MIKE 11, DHI's one-dimensional model used for channel networks, MIKE SHE has the power to create an integrated surface water / ground water or drainage system / ground water model.

MIKE SHE's basic modular components are pre and post processing (PP), and water movement (WM). The WM module is the core of MIKE SHE containing several process simulation modules that when put together describes the entire land phase of the hydrologic cycle. The WM module components are: evapotranspiration (ET), unsaturated zone flow (UZ), saturated zone flow (SZ), overland and channel flow (OC), and irrigation (IR).

MIKE SHE also contains a number of add-on modules to make the program more robust. The add-on modules are: linear reservoir (LR), advection/dispersion solute transport (AD), particle tracking (PT), adsorption/degradation (SD), geochemistry (GM), biological degradation (BM), crop yield and nitrogen consumption (DAISY), macro pore flow (MP), soil erosion module (SE), soil plant system simulation (DAISY).

MIKE SHE coupled with MIKE 11 was originally chosen as one of the two models for this program because of its recognition as leading modeling software and their willingness to donate software for educational purposes. The park staff was interested in testing the MIKE SHE/ MIKE 11 software because of its robustness. However, after attempting to create the input data sets it was realized that MIKE SHE required too much data and was therefore excluded from the project. MIKE SHE and MIKE 11 are explained in detail on DHI's web-site http://www.dhi.dk/index.htm.

WEPP

WEPP (Water Erosion Prediction Project) is a distributed parameter, continuous simulation, and erosion prediction model. The input parameters include rainfall amounts and intensity, soil textural qualities, plant growth, plant growth parameters, residue decomposition, effects of tillage implements, slope shape, steepness, and aspect, and soil erodibility. WEPP's strengths lie in modeling field areas that include only ephemeral gullies and not those catchments that contain permanent channels such as perennial streams (Becker *et al.*, 1997).

Though WEPP has been validated and tested on numerous sites, it is meant for much smaller watersheds than that of the Broadhead, and was therefore excluded from the project.

WMS

The WMS (Watershed Modeling System) is a program containing a suite of hydrologic models bundled into one user interface. It is produced by a private vendor and can be retrieved online at http://www.scisoft-gms.com/html/wms_details.html. The cost of the program is approximately $2000.

Though WMS has a user-friendly interface that utilizes GIS data, its cost, along with its sole use of HSPF (discussed later) as the complete watershed model, exclude it from being used in this project.

BASINS

BASINS is also a suite of hydrologic models packaged into one program by the Environmental Protection Agency (EPA). Its current release is 3.0 and can be downloaded as free-ware from the EPA's website, http://www.epa.gov/OST/BASINS/. It was originally released in September, 1996 with the intention of facilitating the examination of environmental data, providing an integrated watershed and modeling framework, and supporting the analysis of point and non-point source management alternatives. It contains a multitude of hydrologic models used for different aspects in modeling. Among the models it contains, HSPF and SWAT are the only two relevant to DEWA at this juncture and they are discussed in detail below.

HSPF

HSPF is a distributed model that is currently free-ware through the USGS. Developed in the early 60's, as the Stanford Watershed Model, its current release is version 11. Its goal is to simulate a number of hydrological processes, listed below, for extended periods of time. These processes include water quality issues involved with processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. It uses records of meteorological phenomenon and continuous rainfall to calculate stream-flow hydrographs and pollutographs (Flynn *et al.*, 1995).

> HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snow-pack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, fecal coliform, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. The model can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from 1 minute to 1 day that divides equally into 1 day can be used, and any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or non-point source treatment alternatives, flow diversions, etc (Flynn *et al.*, 1995).

While HSPF can produce all the necessary outputs required by DEWA, it is data intensive requiring inputs such as daily dew-point temperature, wind speed, solar radiation, humidity, and cloud cover. The watersheds entering the park have very little background data, making it difficult to work with a model like HSPF.

SWAT

The SWAT (Soil Water Assessment Tool) model is a river basin, or watershed, scale model developed for the United States Department of Agriculture (USDA) Agriculture Research Service (ARS). It has the capability to be a distributed model if there is enough detailed data describing the watershed. However, the model also allows the user to lump information if detailed data is lacking. It requires specific information about weather, soil properties, topography, vegetation, and land management practices within the watershed. It was designed to predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions. Though the model operates on a daily time step, it is efficient enough to run for many years. It is a long-term yield model not capable of detailed single event flood predictions (Arnold *et al.*, 1998).

Though SWAT is considered a distributed and physically based model, it has more of a quazi-physical base. It utilizes Hydrologic Response Units (HRU's) to account for a basin's spatial variability instead of using a true spatial model. HRU's work by assigning characteristics to the basin being modeled by way of weighted percentages. For example, if a land area equaling 25% of a basin's area is described as having soil type "x" and land cover type "y", the model will attribute that characteristic to the entire basin with a weighted average of 25%. This quazi-physical based approach allows users to assume in cases where data is lacking. It is this ability combined with SWAT's tested use in large, ungaged watersheds that make it the choice for the Broadhead project.

History of SWAT

Dr. Jeff Arnold developed SWAT in the early 1990's. It utilizes several ARS models and is a direct descendant of the SWRRB (Simulator for Water Resources in Rural Basins) model (Arnold *et al.*, 1990). Specific models incorporated into the original SWAT are CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Kinsel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Lenord *et al.*, 1987), and EPIC (Erosion-Productivity Impact Calculator) (Williams *et al.*, 1984). Since its original configuration it has undergone several revisions:

- the ability to incorporate multiple HRUs,
- the ability to handle storage of water in the canopy,
- a CO_2 component in the crop growth model to handle climatic changes,
- the addition of the Penman-Monteith equation for potential evapotranspiration,
- the ability to handle lateral water flow through soil,
- the addition of an in-stream nutrient water quality equation,
- the addition of urban build up/wash off equations,
- the addition of bacteria transport routines,
- the addition of the Green & Ampt equation for infiltration, and finally
- the addition of several agricultural management options.

(Arnold *et al.*, 1999B)

Description of the SWAT Model

SWAT uses the same modeling process developed by Williams and Hann (1973) for routing runoff and chemicals through a watershed. This modeling process allows a basin to be subdivided into grid cells or subwatersheds, called HRUs.

The model is divided into subbasin components, channel routing components and reservoir routing components. Subbasin components describe hydrology, weather, sedimentation, crop growth, nutrients, pesticides, and agricultural management. Channel routing components describe channel flood routing, channel sediment routing, and channel nutrient and pesticide routing. Reservoir routing components describe reservoir water balance and routing, reservoir sediment routing, and reservoir nutrients and pesticides. SWAT's command structure, model components, and subbasin components can be found in appendices A, B, and C respectively.

The following is a more detailed description of SWAT's subbasin components, channel routing components and reservoir routing components. All the material comes from the SWAT manual (Arnold *et al.*, 1999B) unless otherwise noted.

Subbasin Components

Hydrology

The hydrology model for SWAT is based on the water balance equation:

Equation 1: The SWAT water balance equation

$$SW_t = SW + \sum_{i=1}^{t} (R_i - Q_i - ET_i - P_i - QR_i)$$ (Arnold *et al.*, 1999B)

Where SW is the soil water content minus the 15-bar water content (often referred to as available soil water content), t is time in days, SW represents current state, R represents daily amounts of rainfall, Q represents runoff, ET represents evapotranspiration, P represents percolation, and QR represents return flow; all units are in mm.

Surface Runoff

This part of the model simulates runoff volume and peak runoff rates from daily rainfall. Runoff volume is estimated using a modification of the Soil Conservation Service curve number technique (USDA-SCS, 1972). Peak runoff rates are estimated using a modification of the Rational Formula. Details on the equations that calculate surface runoff can be found in the SWAT manual (Arnold *et al.*, 1999B).

Percolation

Flow is predicted through each soil layer in the root zone using a storage routing technique. Flow may move upward or downward through the soil profile if some soil layer exceeds field capacity. Downward flow occurs if an unsaturated soil layer lies beneath a soil layer that has exceeded field capacity. Its rate is regulated by the saturated conductivity of the soil layer. Upward flow may occur if field capacity is reached in a lower soil layer. Soil temperature may also affect percolation. Most notably, if a soil layer has a temperature less than or equal to 0° Celsius, no percolation will be allowed for that layer.

Lateral Subsurface Flow

Lateral subsurface flow is calculated simultaneously with percolation. Lateral flow is predicted in each soil layer from zero through two meters in depth, accounting for variations in conductivity, slope, and soil water content. The model also allows upward flow to an adjacent layer or to the surface.

Groundwater Flow. Groundwater flow contribution to total stream flow is simulated by creating a shallow aquifer storage (Arnold *et al*., 1993). Percolation exiting the bottom of the root zone is recharge for the shallow aquifer. "A recession constant derived from daily stream flow records is used to lag flow from the aquifer to the stream. Other components include evaporation, pumping withdrawals, and seepage to the deep aquifer" (Arnold *et al.*, 1999B).

Evapotranspiration

SWAT provides three options for estimating potential evapotranspiration: Hargreaves (Hargreaves and Samani, 1985), Priestly-Taylor (Priestly and Taylor, 1972), and Penman-Monteith (Monteith, 1965).

> The model computes evaporation from soils and plants separately as described by Ritchie (1972). Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plat leaves relative to the soil surface area). Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as linear function of potential ET and leaf area index (Arnold *et al.*, 1999B).

Snowmelt

Similar to CREAMS (Kinsel, 1980), SWAT uses a linear function to estimate snowmelt on days when maximum temperature exceeds 0° C. Estimating runoff from snowmelt is treated the same as rainfall. However, rainfall energy is set to 0.0 and peak runoff rates are estimated assuming a uniform distribution of rainfall over a 24-hour time step.

Transmission Losses

Transmissions losses reduce runoff volumes as the flood wave travels downstream. "SWAT uses Lane's method described in Chapter 19 of the SCS Hydrology Handbook (USDA, 1983) to estimate transmission losses. Channel losses are a function of channel width and length. Both runoff volume and peak rate are adjusted when transmission losses occur" (Arnold *et al.*, 1999B).

Ponds

The requirements for pond inputs are capacity and surface area. Storage is simulated as a function of pond capacity, daily inflow and outflow, seepage, and evaporation. In the scenario of overflow, ponds are assumed to have only emergency spillways.

Weather

SWAT uses precipitation, air temperature, solar radiation, wind speed, and relative humidity as weather variables. The variables for precipitation and minimum and maximum daily temperature can be input directly into the model, or can be simulated by SWAT's weather generator. Solar radiation, wind speed, and relative humidity are always simulated.

Precipitation

> The SWAT precipitation model developed by Nicks (1974) is a first-order Markov chain model. Thus, input to the model must include monthly probabilities of receiving precipitation if the previous day was dry and if the previous day was wet. Given the wet-dry state, the model determines stochastically if precipitation occurs or not. When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution. The amount of daily precipitation is partitioned between rainfall and snowfall using average daily air temperature (Arnold *et al.*, 1999B).

Air Temperature and Solar Radiation

The maximum and minimum daily air temperature and solar radiation are generated from a normal distribution that is corrected for wet-dry probability state. The correction factor is used to increase deviation in temperature and radiation when there is a change in weather or on rainy days, and decrease deviations on dry days. This is done to maintain the long-term standard deviations of daily variables.

Wind Speed and Relative Humidity

Using a modified exponential equation, daily wind speeds are simulated using a mean value of the monthly wind speed. The daily average relative humidity is simulated using a triangular distribution of the monthly average. The mean daily relative humidity is adjusted for wet- and dry-day effects just like temperature and radiation.

Sedimentation

Sediment Yield

The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) is used to estimate the sediment yield for each subbasin.

Soil Temperature

The soil surface temperature is estimated using maximum and minimum temperature, snow cover, plant cover, and residue cover for the day of interest plus the four days immediately proceeding the day of interest. Damping depth, surface temperature, and mean annual air temperature is used to simulate the temperature for each soil layer. "The daily average soil temperature is simulated at the center of each soil layer for use in hydrology and residue decay" (Arnold *et al.*, 1999B).

Crop Growth

> A single model is used in SWAT for simulating all crops. Energy interception is estimated as a function of solar radiation and the crop's leaf are index. The potential increase in biomass for a day is estimated as the product of intercepted energy and a crop parameter for converting energy to biomass. The leaf area index is simulated with equations dependent upon heat units. Crop yield is estimated using the harvest index concept. Harvest index increase as a non-linear function of heat units from zero at playing to the optimal value at maturity. The harvest index may be reduced by water stress during critical crop stages (usually between 30 and 90% of maturity) (Arnold *et al.*, 1999B).

Nutrients

Nitrogen

The amount of nitrate contained in runoff, lateral flow, and percolation is estimated as average concentration per volume of water. Leaching and lateral subsurface flow is treated with the same approach only without the consideration of surface runoff. Organic nitrogen losses are estimated using a loading function developed by McElroy *et al.* (1976) and modified by Williams and Hann (1978) to handle individual runoff events. It estimates daily organic nitrogen runoff loss based on concentration levels of organic nitrogen level in the topsoil layer, the sediment yield, and the enrichment ratio. The use of nitrogen by crops is estimated using a supply and demand approach.

Phosphorus

SWAT uses a concept originally developed for partitioning pesticides into solution and sediment phases, described by Leonard and Wauchope (Kinsel, 1980), to estimate the amount of soluble phosphorus in surface runoff. Soluble phosphorus loss occurring in runoff is predicted using liable phosphorus concentration in the topsoil layer, runoff volume and a portioning factor. Sediment transport of phosphorus is simulated with a loading function as described in organic nitrogen transport. The use of phosphorus by crops is estimated using a supply and demand approach.

Pesticides

SWAT uses GLEAMS (Kinsel, 1980) for the simulation of pesticide transport by runoff, percolate, soil evaporation, and sediment. "Each pesticide has a unique set of parameters including solubility, half life in soil and on foliage, wash off fraction, organic carbon adsorption coefficient, and cost" (Arnold *et al.*, 1999B).

Agricultural Management

SWAT has the ability to rotate up to three crops per year for an unlimited amount of years. Irrigation, nutrient, and pesticide application dates and amounts can all be input into the model. For a more detailed description of Agricultural Management functions in SWAT refer to the SWAT manual (Arnold *et al.*, 1999B).

Routing Components

Channel Routing

Channel Flood Routing

SWAT uses a variable storage coefficient method developed by Williams (1969) for channel routing. Inputs for the model include reach length, channel slope, bankfull width and depth, channel side slope, flood plain slope, and Manning's n for channel and floodplain. Manning's equation is used to estimate flow rate and average velocity. Travel time for flow is estimated by dividing channel length by velocity. Transmission losses evaporation, diversions and return flow are taken into consideration for estimating the outflow.

Channel Sediment Routing

The sediment routing model has two components, deposition and degradation, that operate simultaneously. Deposition is based on fall velocity, which is calculated as a function of particle diameter squared using Stokes Law. "The depth of fall through a routing reach is the product of fall velocity and reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth" (Arnold *et al.*, 1999B). Stream power, originally defined by Bagnold (1977) as the product of water density, flow rate, and water surface slope, is the basis for how SWAT predicts degradation. Williams (1980) later adjusted this prediction by raising stream power by 1.5 to place more weight on high values of stream flow.

Channel Nutrient and Pesticide Routing

"Currently no transformations or degradation of nutrients or pesticides are simulated in channels. Soluble chemicals are considered conservative, while chemicals adsorbed to the sediment are allowed to be deposited with the sediment" (Arnold *et al.*, 1999B).

Reservoir Routing

The model for the Broadhead does not currently have any reservoirs that require this component. Reservoir routing is described in the SWAT manual (Arnold *et al.*, 1999B).

SWAT Projects

The purpose of watershed modeling is to predict, and hopefully improve, the effects of management techniques within a watershed area. Arnold *et al.*, (1998) states that integrated water management can be viewed as a three, or more, dimensional process centered around the need for water, the policy to meet those needs, and the management to implement the policy. Grayson *et al.*, (1992) suggested that the analysis of any model should at least have the following procedures. First, the model should be tested and calibrated on a wide variety of watersheds with a wide range of conditions. Second, negative results should be reported along with positive results, and any uncertainty involved in the model predictions should also be discussed. Finally, the sources and precision of all the input data should be presented.

Sophocleous *et al.*, (1999) combined SWAT and MODFLOW to create SWATMOD, a model capable of simulating the surface water, ground water, and stream-aquifer interactions on a continuous basis. SWATMOD was developed for analyzing conditions in the Rattlesnake Creek basin during periods of water shortage. The Rattlesnake Creek basin is an elongated flat basin, measuring roughly 145 km by 25 km, located in south-central Kansas. A series of trial and error techniques were used to calibrate the model with measured data for ground water levels, stream flows, and reported irrigation techniques over a 40-year period (1955 – 1980). The model was then validated using recorded data from 1981 – 1994. Both the calibration and validation periods' yielded satisfactory results upon comparison of observed vs. simulated ground water levels and stream flow. Given their calibration and verification results, the model was run for an additional 40-year (1995 – 2034) simulation period using 1994 boundary and land use conditions, and a repeat of the past 40 years of climatic data to use as baseline data. The final step was to implement a series of hypothetical management scenarios geared at reducing and varying current withdrawal rates to run in the model for comparison with the baseline data. Given model uncertainties, "the interpretations of the model are going to be much more reliable in a comparative mode, rather than a predictive sense" (Sophocleous *et al.*, 1999).

In a related study Perkins and Sophocleous (1999) used SWATMOD to examine relative increases in stream yield due to the restriction of irrigation during periods of drought on the Lower Republican River Basin in north-central Kansas. The results of the study showed that tributary flow was the dominant component of stream yield and "that a reduction of irrigation water use produces a corresponding increase in base flow and stream yield" (Perkins and Sophocleous, 1999). However, the increase in stream flow resulting from the restrictions did not appear to restore the minimum desirable stream flow.

Manguerra and Engel (1998) did a study to show the importance of parameterization for predicting runoff using SWAT with an emphasis on improving model performance without resorting to "tedious and arbitrary parameter by parameter calibration." This study involved comparing SWAT's three schemes of decomposition on three watersheds, 3.28, km2, 22.48 km2, and 113.38 km2. The first scheme allowed the user to subdivide a watershed into several subwatersheds, preserving natural flow paths, boundaries, and channels for routing water, sediment, and nutrients. The second allowed the user to subdivide the watershed into smaller, more homogeneous areas by superimposing a grid. The third involved using HRU's, which aggregate areas associated with unique combinations of soil and land use regardless of their spatial position in the watershed. The results showed that for the three basins studied, the use of HRU's was sufficient in explaining spatial variability. They continued on to say:

> Subdividing the watershed into spatially-referenced and individually routed subwatersheds or grid elements may be required only for the following scenarios: in the presence of site-specific water impoundments such as reservoirs or ponds, for large basins, when significant channel abstractions or losses are expected, and in the cases where detailed visualization of the spatial distribution of an output parameter such as runoff or erosion is desired (Manguerra and Engel, 1998).

Arnold and Allen (1996) stated, "it is important to simulate the major components of the hydrologic budget to determine the impact of proposed land management, vegetative changes, groundwater withdrawals, and reservoir management on water supply and water quality." They also stated the majority of studies completed at the watershed scale often attempt to measure only one component. Arnold and Allen (1996) used SWAT for estimating a large portion of the hydrologic budgets for three watersheds in central Illinois. The basins have areas of 122, 246, and 188 km^2 with topography ranging from level uplands, to gently undulating uplands, to rugged uplands respectively. The land use for the three watersheds consisted mostly of cropland, pastureland, and woodland. They validated their multi-component water budget model using field study data collected on the three watersheds in the 1950's, which consisted of measured data for surface runoff, groundwater flow, groundwater ET, ET in the soil profile, groundwater recharge, and groundwater heights. Upon comparison of measured vs. predicted values, "the model gave reasonable output" and "interaction among the components was realistic" (Arnold and Allen, 1996).

Arnold *et al.*, (1999) used SWAT for a continental scale simulation of the hydrologic water balance using soils, landuse, and topography data at a scale of 1:250,000. Water balance is represented by snow, soil profile, shallow aquifer and deep aquifer. The hydrologic balance for the contiguous United States was simulated without calibration for 20 years using dominant land use and soil properties for each of the 78,683 polygons. Long term average annual runoff from USGS stream gage stations were compared to the simulated average annual runoff for validation.

> Results indicate over 45 percent of the modeled U.S. are within 50 mm of measured, and 18 percent are within 10 mm without calibration. The model tended to underpredict runoff in mountain areas due to lack of climate stations at high elevations. Given the limitations of the study (i.e., spatial resolution of the data bases and model simplicity), the results show that the large-scale hydrologic balance can be realistically simulated using a continuous water balance model (Arnold *et al.*, 1999).

SWAT was used by Arnold, Jeffery G. *et al.* (2001) in a study to asses the ability of Walker Creek, located near Dallas, TX, in maintaining ample flow to sustain a proposed bottomland wetland for use in mitigation. A modification to SWAT was made to allow ponded water within the proposed wetland to interact with the soil profile and shallow aquifer. The model simulation period was run for 14 years and validated using flow data from a nearby stream with similar characteristics since there was no available data available for Walker Creek. Results indicated that the wetland should be equal to or greater than 85% capacity over 60% of the time, 40% capacity was reached less than 1% of the time, and the wetland would not dry up. "The advantages of the continuous simulation approach used in this study include (1) validation of wetland function (hydroperiod, soil water storage, plant water uptake) over a range of climatic conditions and (2) the ability to assess the long-term impact of land-use and management changes" (Arnold *et al.*, 2001).

Chapter 3: Methodology

Overview

In order to apply a model to the Broadhead watershed, the project was separated into several steps. These included:

- getting the necessary modeling software,
- collecting and manipulating the necessary data for input into the model,
- entering the data into the model,
- running the model,
- handling the model outputs,
- analyzing the model outputs and calibrating the model, and finally,
- validating the model.

The modeling software used for this project included SWAT version 1999B with the ArcView GIS interface, and HYSEP (Hydrograph Separation Program). SWAT can be downloaded from the SWAT website http://www.brc.tamus.edu/swat/swatvers.html. HYSEP is a USGS model used for the separation of total flow into base flow and surface flow, an important step needed for calibration of the SWAT model. The model can be downloaded from the USGS website http://water.usgs.gov/software/hysep.html. Both models are freeware that have been widely used and tested.

The data used for this project included a 30 Meter DEM, a Landuse/ Landcover shapefile, a STATSGO soils coverage, daily weather data, and USGS gage data. The 30 Meter DEM and the Landuse/ Landcover shapefile were retrieved from DEWA's records. The STATSGO soils data was downloaded from the Natural Resources Conservation

Service's (NRCS) website http://www.ftw.nrcs.usda.gov/stat_data.html. The weather data was obtained from the U.S. Forest Service weather station, Bushkill Weather Station. The USGS gage data came from two gage stations, Broadhead Creek near Anamolink and Broadhead Creek at Minisink Hills, which were retrieved from the USGS website http://pa.waterdata.usgs.gov/nwis/current?type=flow.

The data was manipulated for input into the SWAT using ESRI's ArcView 3.2®, ESRI's ArcInfo 8.01®, Microsoft Excel 2000®, and Microsoft Access 2000®.

Model output conversions and analysis of results were done in Microsoft Excel and SAS' Jump 4.0®.

Data Manipulation

The data for this project needed several adjustments in order to be used in the Broadhead. Since most data was already projected in 1983 Universal Transverse Mercator (UTM) meters it was decided that this would be projection for all spatial data entered into the model. SWAT also requires that measured data be in metric units, so unless otherwise noted all model parameters are metric.

The first step was to create a shapefile of the Broadhead watershed for use in clipping desired areas. This was done by bringing the 30 Meter DEM into SWAT and utilizing its stream definition tool to delineate the Broadhead basin (see appendix D). The resulting shapefile had a 500-meter buffer added to it using ArcView and was saved as brdhdbuff500.shp. This shapefile was also converted into a grid with cell sizes equaling 190 meters squared, the default value, for later use in running the model.

The Landuse/ Landcover shapefile was converted to a grid with cell sizes equaling 30 meters, equal to the DEM.

The STATSGO soil coverage had to be reprojected from 1927 Albers Conical Equal Area meters to 1983 UTM meters using ArcInfo. It was then converted to a shapefile, brought into ArcView, and clipped with the brdhdbuff500.shp using the geoprocessing wizard to cut out all extraneous area not involved in the project. The shapefile was converted to a grid with a cell size of 30 meters for inclusion into SWAT. The soil attribute tables necessary for SWAT to function were then built from the .dbf files that came with the STATSGO download (see appendix E).

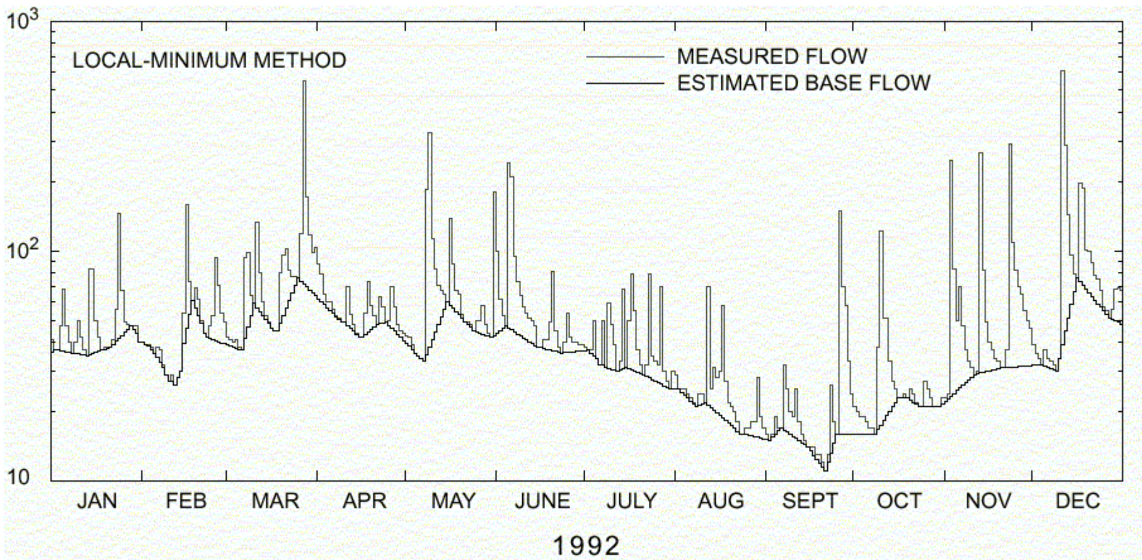
The weather data retrieved from the Forest Service was in hardcopy form dating from January 1, 1993 through October 20, 1999. Daily precipitation in inches and maximum and minimum temperature in Fahrenheit were entered into an excel spreadsheet. Daily precipitation was converted to millimeters and maximum and minimum temperatures were converted from Fahrenheit to Celsius, all values were set to two decimal places.

Using the data from the weather table, a precipitation and a temperature table were made for inclusion into SWAT. The precipitation table contained a column labeled "DATE" which contained daily date values, and a column labeled "PCP" which contained daily values for precipitation in mm. The temperature table contained a column labeled "DATE" which contained daily date values, "MAX" which contained daily maximum temperature values in Celsius, and "MIN" which contained daily minimum temperature in Celsius. The daily values for both tables were extended by copying the data from January 1, 1993 through December 31, 1995 and pasting them in for the dates of January 1, 1990 through December 31, 1992 and then again for the dates of January 1, 1987 through December 31, 1989. This was done get the initial flow conditions to match the flow at the beginning of calibration period. The end result was a precipitation table and a temperature table containing daily values for January 1, 1987 through October 20, 1999.

Look up tables were then made so SWAT would be able to call the STATSGO soil attribute data and the weather data. The STATSGO lookup table contains a field called "VALUE", which represents the grid attribute code in the STATSGO soils grid, and a field called "STMUID", which identifies the file name for the soil attribute data (see appendix F). The precipitation look up table contains a field called "ID", which represents the weather station, a field called "NAME", which points to the daily precipitation table created above, a field called "XPR" which represents the x coordinate of the weather station, and a field called "YPR", which represents the Y coordinate of the weather station (see appendix G). The daily temperature look up table is set up the same way as the daily precipitation data table, except the "NAME" field points to the daily temperature file (see appendix H).

In order to calibrate and validate the SWAT model, measured daily flow data from within the Broadhead basin had to be obtained, separated into base flow and surface flow, and averaged into annual and monthly values. Since there is not any flow or gage data at the outlet of the Broadhead, calibrations and validation of the model would have to be done on smaller subbasins within the Broadhead. The flow data was obtained from the USGS gage sites Anamolink and Minisink in the form of daily average discharge in Cubic Feet per Second (CFS) for the same time period as the weather data, January 1, 1993 through October 20, 1999. The program HYSEP was recommended by the USGS for base flow/ surface flow separation (Robbins, personal communication, Oct 30, 2001). Both data sets were set up for inclusion into HYSEP (see appendix I), and then run in HYSEP for surface flow/ base flow separation (see appendix J) using the local minimum method (see figure 3).

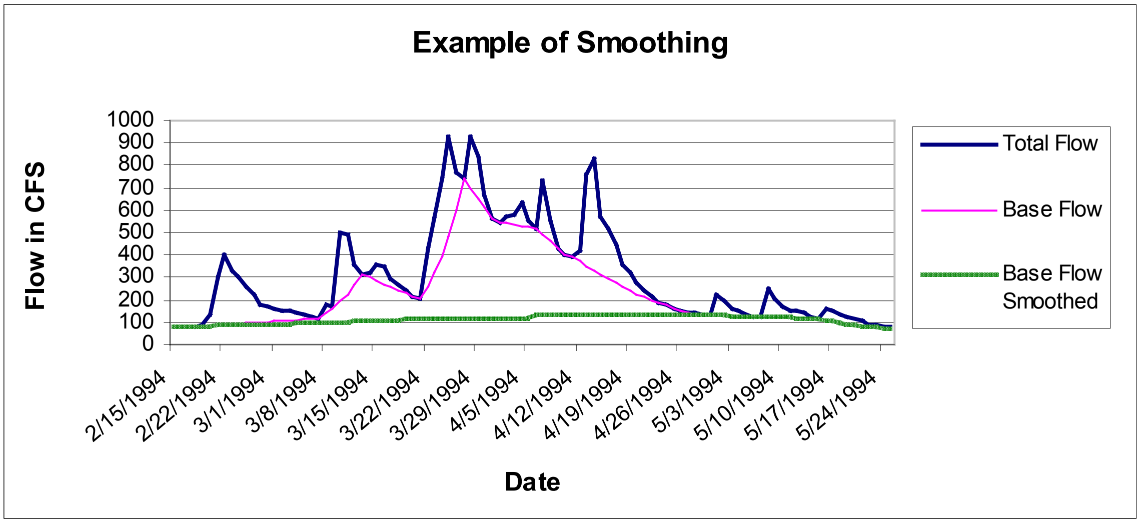
Figure 3: Local Minimum Method Technique



The outputs from HYSEP for both Anamolink and Minisink were put into their respective spreadsheets, containing columns for date, total flow in CFS, base flow in CFS, and surface flow in CFS. The data for total flow and base flow were put into line graphs for both Anamolink and Minisink and adjustments were made to smooth base flow where over-estimations occurred in the separation process (see figure 4). These over-estimations stemmed from high surface runoff over extended periods of time, which subsequently caused a spike in base flow. The smoothing was done by averaging the base flow's variability so it more closely resembled the values before and after the spike.

The daily values were then averaged into monthly and annual values for comparison with the SWAT outputs.

Figure 4: Example of Smoothing Base Flow

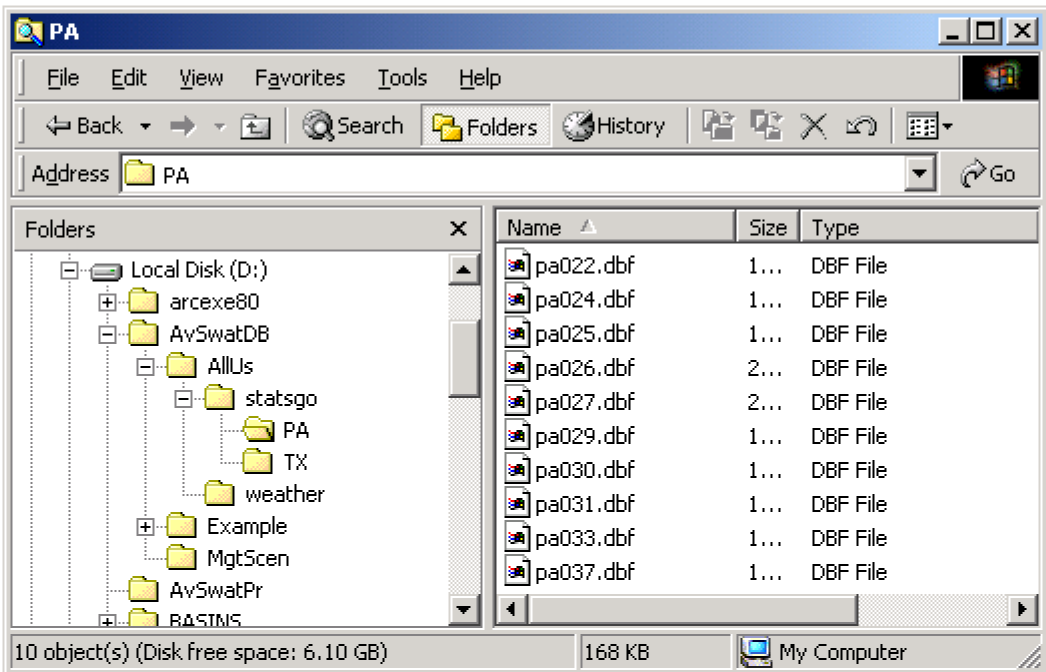


Finally, the gage locations were needed to properly set up the model so that outputs could be checked against real data. The USGS websites for the gage stations list the Lat/ Long coordinates of the gage. These coordinates were entered into a .dbf file, changed to decimal degrees and added as an event theme in ArcView. The resulting point data was converted to a shapefile, and then converted to a coverage in ArcInfo. The file was reprojected in ArcInfo to UTM 1983 Meters and converted back to a shapefile.

Folder Structures and File Arrangement

Once all the input data had been placed in proper form, SWAT was an easy model to run if particular attention was paid to folder structures. First, a folder named "PA" containing all the STATSGO soil data must be placed into the AvSwatDB\AllUs\statsgo folder located in the AVSWAT directory (see figure 5).

Figure 5: Folder Structure

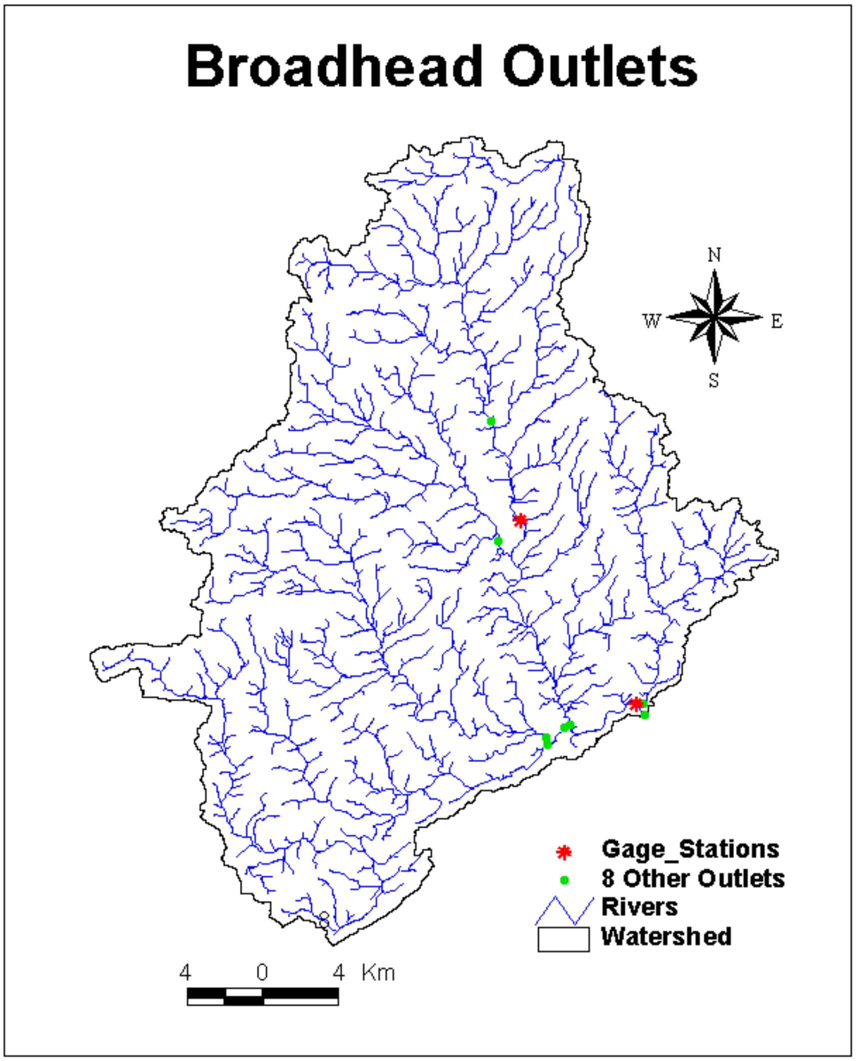


This step is very important because SWAT is hard-coded to search for the soil data in this folder. The rest of the necessary data (the 30 meter DEM, the Landuse/ Landcover grid, the STATSGO soil GRID, the buffered Broadhead watershed grid, the Gage Station shapefile, the daily precipitation table, the daily temperature table, the STATSGO look up table, the precipitation look up table, and the temperature look up table) can be placed anywhere in the computers directory structure, however they should be in the same folder. This is particularly important regarding the precipitation and temperature data with regard to their look up tables. If they are not in the same folder SWAT will not be able to find the data.

Setting up the Model

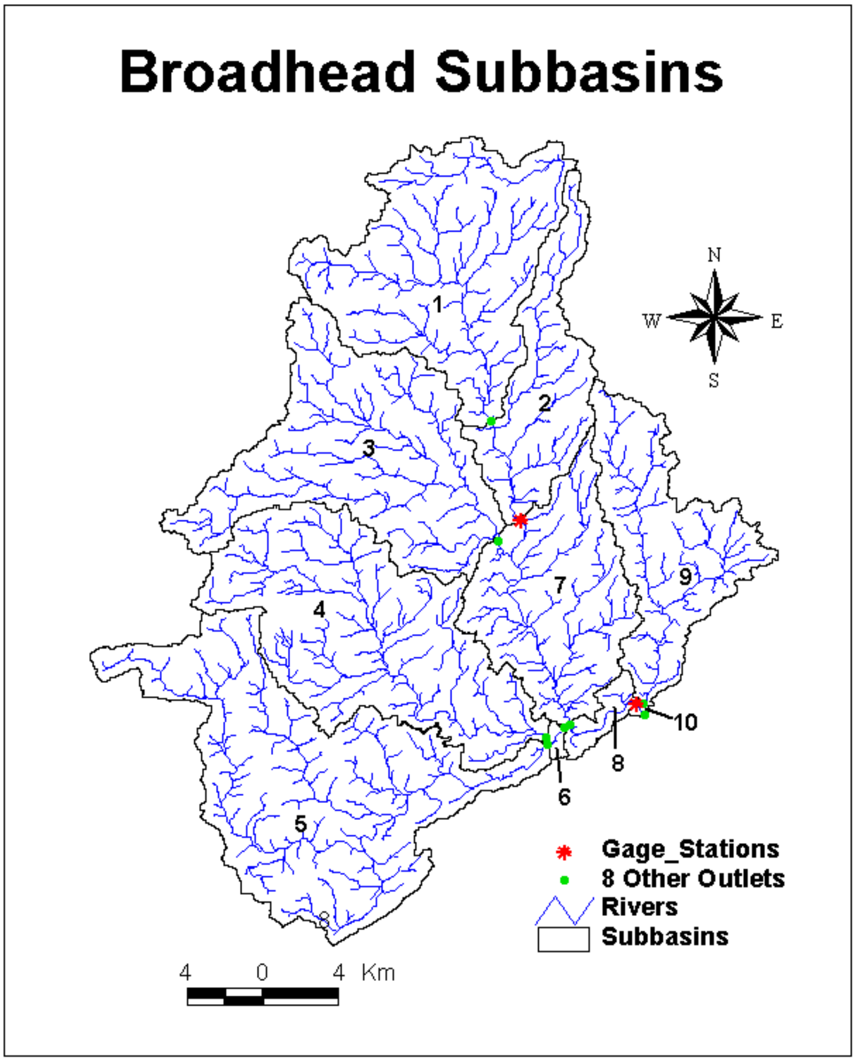
A new project was created in the folder containing all the necessary input data. The 30-meter DEM was loaded into the Watershed, Subbasin and Stream Definition GUI interface and the projection properties were set to UTM 1983 meters, Zone 18. The DEM was masked using the buffered Broadhead grid and then preprocessed. In the Stream definition section, the Threshold Area was set to 30 (ha). This created 1311 outlets/ subbasins. All these outlets were selected and deleted. The gage station shapefile was added to the view and two outlets were placed corresponding to these points. Eight other outlets were also placed in the Broadhead basin to separate it into smaller subbasins for a more accurate model. The outlets were based on natural stream breaks; an attempt was made to separate the basin at the confluence of 3rd order streams (see figure 6).

Figure 6: Broadhead Outlet Locations



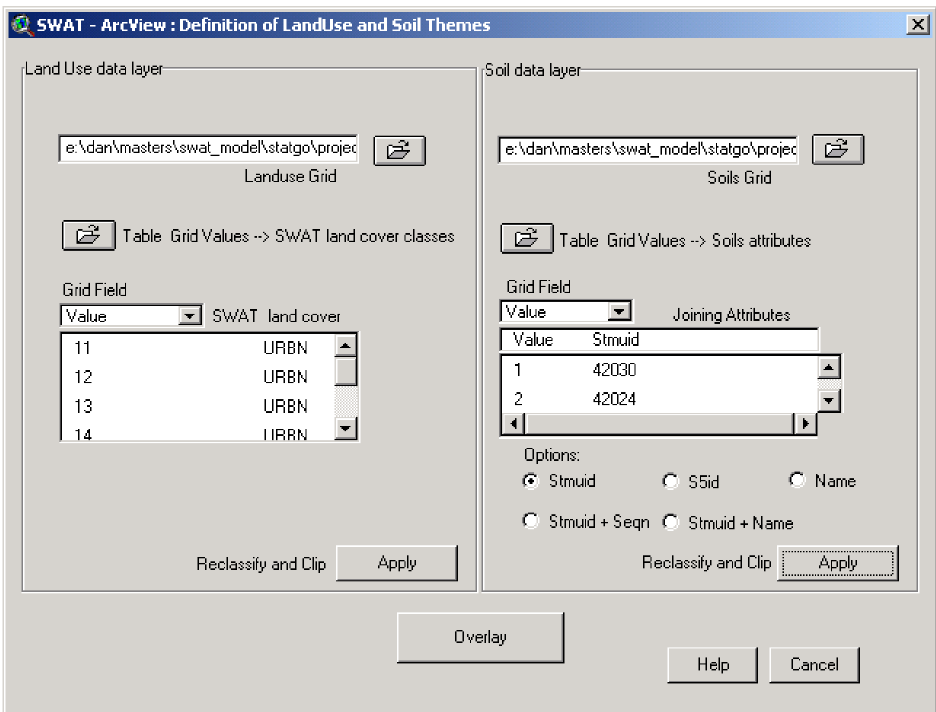
This resulted in the separation of the Broadhead into 10 subwatersheds: Two of the watersheds contributing to the Anamolink gage, eight contributing to the Minisink gage (the Minisink subbasin includes the two subwatersheds that make up the Anamolink subbasin), and two subbasins that are ungaged. Figure 7 shows the Broadhead divided into these subwatersheds, subbasin 9 and 10 are the ungaged outlets.

Figure 7: Broadhead Subbasins



The next step required loading the landuse/ landcover grid and the STATSGO soil grid. This step was completed in the Definition of Landuse and Soil Themes GUI (see figure 8). The landuse/ landcover grid was loaded and pointed to the USGS LULC/ SWAT land cover table. The SWAT model comes equipped with attribute data for landuse/ landcover maps that are classified using the USGS LULC classification system (See appendix K). Once the landuse/ landcover grid was set, the STATSGO soils grid was loaded. The soils grid was pointed to the STATGO lookup table that was described in the data manipulation portion of this section. The lookup table contains an STMUID column, so the option section on the GUI was set to read STMUID. The lookup table points to the AvSwatDB\AllUs\statsgo folder located in the AVSWAT directory. *If the attribute data is not placed in this folder the model will not be able to locate the soil information*. After both the landuse/ landcover and the soil grids were loaded, they were merged in SWAT by using the overlay function in the GUI.

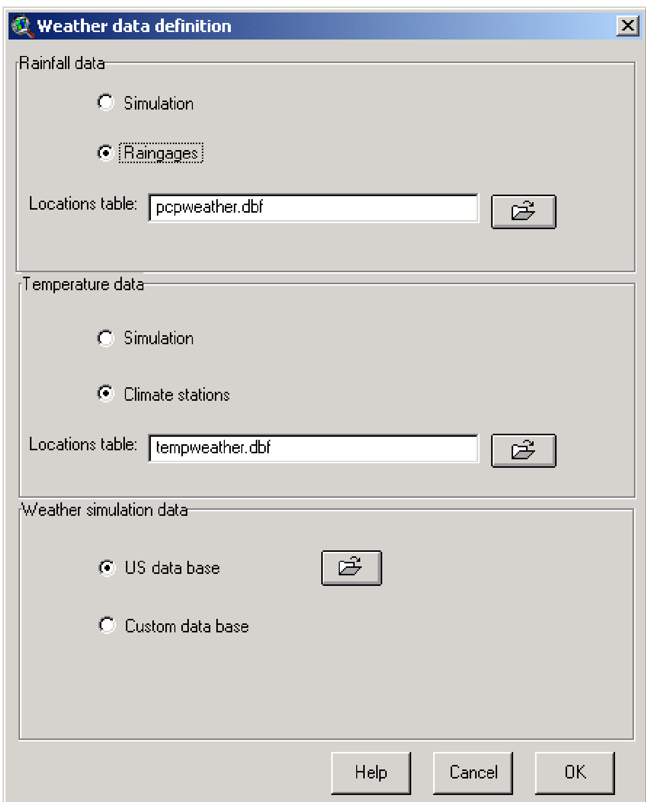
Figure 8: Definition of LandUse and Soil Themes GUI



Before the overlay would run, the model asked for the definition for Multiple Hydrologic Response Units. Both Land Use (%) over Subbasin Area and Soil Class [%] over Subbasin Area were set to 5%. This means that any land use or soil class representing 5% or more of the land area within a subbasin will be represented in the model. This low percentage was chosen based on Manguerra and Engel's finding that "a user who is not familiar with the spatial nature of the watershed in question should select a fine threshold area [meaning HRU %] since it does not correspond to a significant increase in computational time" (Manguerra and Engel, 1998). With the threshold set to 5%, 98 hydrologic response units were created (See Appendix L).

The weather data was then added to the model using the "Weather data definition" GUI (see figure 9).

Figure 9: Weather Data Definition GUI



The first step required loading the precipitation look up table, created earlier, in the "Raingages" section of "Rainfall data". The second step required loading the temperature lookup table, created earlier, in the "Climate stations" section of "Temperature data". In the Weather simulation data section, "US data base" was selected. The "US data base" was chosen because SWAT comes equipped with weather simulation data for majority of the continental United States, and it is the only data currently available for this project.

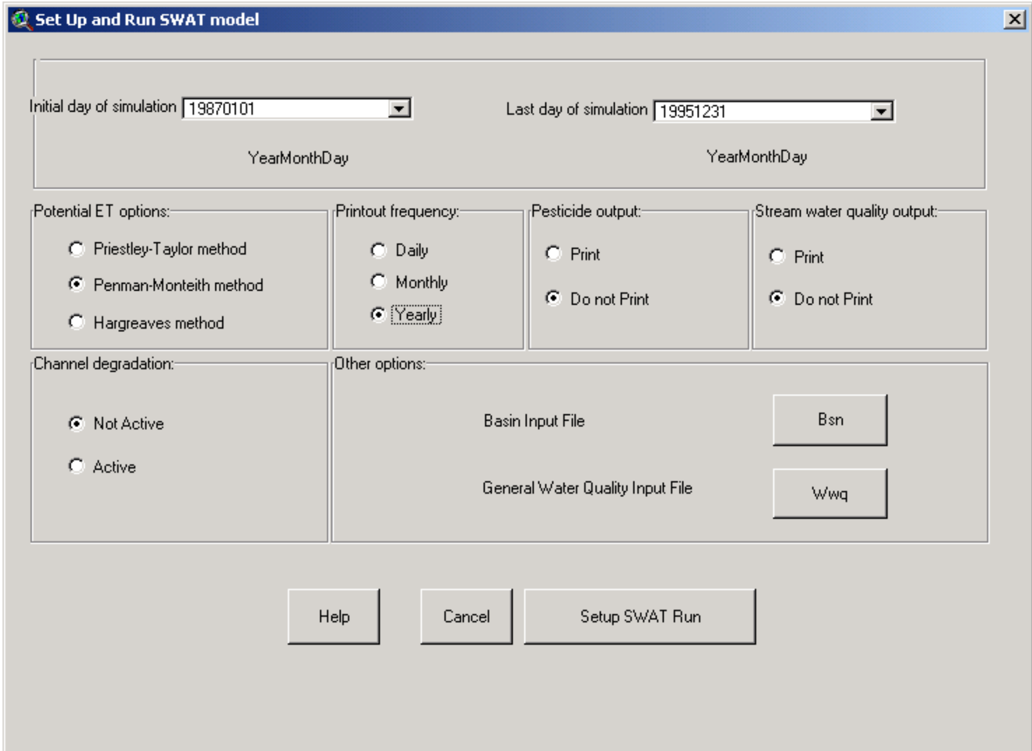
The last step in setting up the model was to have SWAT write all the input files. This included the watershed configuration file (.fig), the soil data file (.sol), the weather generator data file (.wgn), the general HRU file (.sub), the main channel data file (.rte), the groundwater file (.gw), water use data file (.wus), management data file (.mgt), soil chemical data file (.chm), pond data file (.pnd), and the stream water quality data file (.swq). The only manual input needed in this section was to set the plant growth heat units during the writing of the management data file. The option was chosen to use default values based on local climatic data since no other data was available.

Running the Model

The first step in running the model was to make a decision on the separation of data for use in calibration and validation. The weather data and USGS gage data obtained for this project went from January 1, 1993 to October 20, 1999. The three years with the most flow were 1993, 1994, and 1996. A decision was made to make a separation before 1996 so the calibration data would not contain all the high flow years. The separation was placed at the end of 1995, effectively making the calibration data run from January 1, 1993 to December 31, 1995 and the validation data run from January 1, 1996 through October 20, 1999. Once the dates were set for calibration data and validation data the model was run in four stages.

The first stage was run for calibration of the model on an annual basis. Figure 10 shows the settings of the annual run for the calibration period. The dates were set so the model included the priming years and the calibration years of the weather data. The Penman-Monteith method was chosen based on preliminary runs of the model; it yielded, by far, the most consistent results to the observed USGS gage flow data. Pesticide outputs and stream water quality output were not printed because their outputs were not being used in this project. Channel degradation was set to "Not Active" due to a lack of data. The model was then run. The initial output was considered as having no-calibration. This data was put into the conversion spreadsheets and compared against the observed data (conversions will be discussed in the following section). The model was then calibrated based on a comparison with the USGS data and run again (calibrations will be discussed in the following section). This step was repeated until calibration yielded satisfactory results.

Figure 10: Set Up and Run SWAT Model GUI



The second stage required running and calibrating the model on a monthly time step. All parameters for the monthly calibration model were set to the same values as the annual run, except the printout frequency was changed to monthly. The calibration steps were also handled the same as they were in the annual model, which will be explained in the following section.

The third and fourth stages required validation of the annual and monthly models. The model was run on both an annual and monthly time step after changing the last day of simulation to October 20, 1999. The annual and monthly model outputs for the time period of January 1, 1995 through October 20, 1999 were then converted to CFS and compared to the observed USGS gage data for the same time period.

Conversions

Before any calibrations were made, the SWAT outputs had to be converted to CFS for both the Anamolink and Minisink subbasins. This step was necessary for the model outputs to be compared to the HYSEP separated USGS gage data. This process was completed in several steps. First, each subbasin, one through eight, was in turn queried for in the subbasin output file and exported as a .dbf file. The subbasin output file was obtained by using the "Read Result" function under the simulation menu. Second, the desired years for the SWAT model outputs in each .dbf file being used for flow comparison, GWQ, SURQ, and WYLD, were cut and pasted into a separate spreadsheet. Third, the values were converted from mm over an area per model time step to CFS. The equation used for the conversions is listed below.

Equation 2: Conversion Equation

$$CFS = \frac{x(mm) * a(area\_Km^2) * 1.07638x10^7\, ft^2 * 0.00328083\, ft * 1 day}{y(time\_step\_in\_days) * 1Km^2 * 1mm * 86400 \sec onds}$$

Where "x" equals the model output value to be converted, "y" equals the time step of the model in days, "a" equals the area of the subbasin in Km^2, $1.07638x10^7$ ft^2 is the conversion between Km^2 to ft^2, 0.00328083 ft is the conversion to change mm to ft, and 86400 seconds is the conversion to change days to seconds. The time step in days was 365 for annual conversions, 366 for leap years, and for monthly runs the time steps varied between 31, 30, 29, and 28 depending on the month and year. Finally, after the conversions were made, the values for WYLD, SURQ, and GWQ (now in CFS) for subbasins one and two were totaled to obtain Anamolink's Total Flow, Surface Flow, and

Base Flow respectively. Minisink's values were obtained by taking the same steps except the values for subbasins one through eight were totaled.

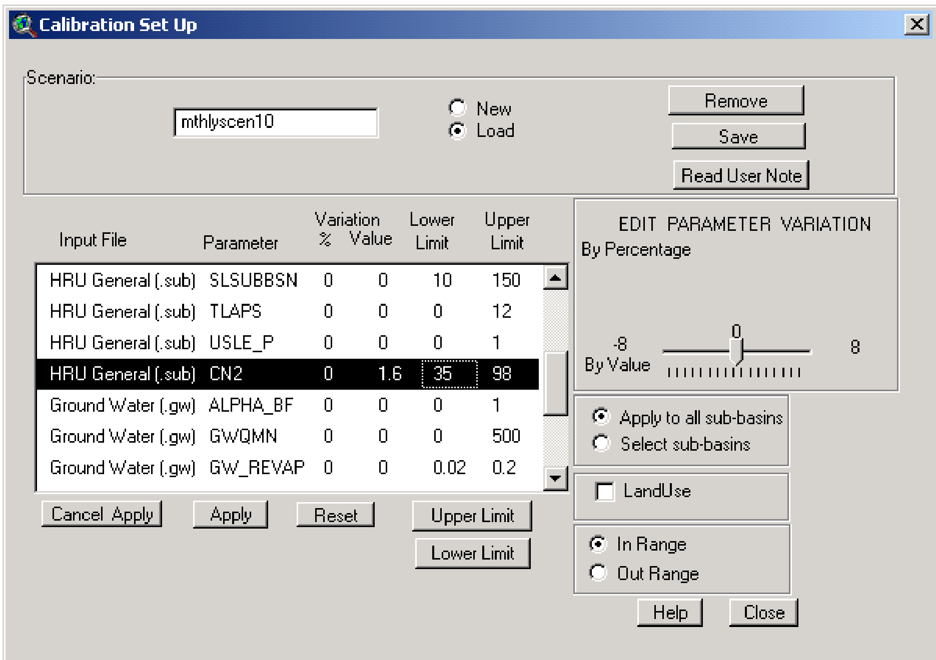
Comparisons

Comparisons were made by both simple visual inspection and statistical analyses. Visual inspections were done by plotting the observed values against the model-estimated values for total flow, base flow, and surface flow in bar charts. Statistical analysis for annual comparison consisted only of an average of the residuals since there were so few observations to compare. The residuals were calculated by taking the absolute value of the observed values minus the model-calculated values. The statistical tests used for the comparison of monthly data were the coefficient of determination (R^2), Root Mean Square Error (RMSE), and an analysis of variance (F statistic

Calibrations

Calibrations were completed using the Calibration Tool under the Simulation tab of SWAT. Following the methods stated in the SWAT Model Calibration guide, found at http://www.brc.tamus.edu/swat/newmanual/calib/calibration.html, the first step was to calibrate surface flow. This involved adjusting the Curve Number, or CN2 value, and the maximum and minimum Snowmelt rates (SMFX and SMFN), up or down until the predicted surface flow most closely resembled the observed surface flow. The CN2 values were kept within plus or minus six percent of the SWAT derived value to keep from entering unrealistic curve numbers. For example, if cover type was forest it would not be adjusted so far that the curve number resembled pavement. Once surface flow rates were calibrated to the best achievable accuracy, base flow was calibrated by adjusting the ground water revap coefficient, GWREVAP. Figure 11 shows SWAT's calibration tool GUI.

Figure 11: Calibration Set Up GUI



Validation

Validation of the model outputs consisted of running the same statistics listed in the calibration section and calculating the percent difference between observed flow vs. model predicted flow

Chapter 4: Results and Discussion

Results of Anamolink and Minisink Annual Calibration

Surface Flow

As stated in the Methodology section, the first step in the calibration process requires the adjustment of surface flow. Seven different scenarios were run to calibrate annual surface flow. This consisted of adjusting the Curve Number value in SWAT's calibration GUI in a stepped fashion from -5.6% to +5.12%. Table 1 shows the run descriptions for annual surface flow calibration. Tables 2 and 3 show the results of the surface flow calibrations for Anamolink and Minisink respectively. The raw results of the calibrations are located in quotation marks. The residuals, located above the raw values, of the calibration runs equal the difference between the raw value and the HYSEP Separated Surface Flow value. The most accurate run for the calibration of annual surface flow was determined by averaging the residuals for the three calibration years.

Table 1: Run Descriptions for Annual Surface Flow Calibration

Run Number	Description
Run 1	CN2 decreased by .8%
Run 2	CN2 decreased by 1.6%
Run 3	CN2 decreased by 3.2%
Run 4	CN2 decreased by 5.6%
Run 5	CN2 increased by 1.6%
Run 6	CN2 increased by 3.2%
Run 7	CN2 increased by 5.12%

Table 2: Surface Flow Comparisons for Anamolink, in CFS

Year	HYSEP Separated Surface Flow	No-Calibration	Run1	Run2	Run3	Run4	Run5	Run6	Run7
1993	**76.37**	10.89 "65.49"	13.48 "62.89"	16.01 "60.36"	20.89 "55.49"	26.41 "49.96"	5.49 "70.88"	0.19 "76.56"	7.41 "83.78"
1994	**97.50**	26.89 "124.38"	23.27 "120.77"	19.72 "117.22"	12.81 "110.30"	4.86 "102.35"	34.47 "131.96"	42.24 "139.74"	52.04 "149.53"
1995	**40.60**	27.17 "67.77"	24.94 "65.54"	22.77 "63.37"	18.60 "59.19"	13.88 "54.47"	31.88 "72.47"	36.78 "77.38"	43.07 "83.66"
AVG Residual		21.65	20.56	19.50	17.43	15.05	23.95	26.41	34.17

Table 3: Surface Flow Comparisons for Minisink, in CFS

Year	HYSEP Separated Surface Flow	No-Calibration	Run1	Run2	Run3	Run4	Run5	Run6	Run7
1993	**396.78**	153.33 "243.45"	163.08 "233.70"	172.57 "224.21"	190.81 "205.97"	211.46 "185.32"	133.02 "263.76"	111.61 "285.17"	84.28 "312.50"
1994	**399.87**	64.94 "464.81"	51.24 "451.10"	37.80 "437.67"	11.61 "411.49"	18.50 "381.37"	93.31 "493.18"	122.78 "522.65"	159.69 "559.56"
1995	**203.28**	49.09 "252.36"	40.76 "244.04"	32.65 "235.93"	17.09 "220.36"	0.47 "202.80"	66.52 "269.80"	84.89 "288.17"	108.51 "311.79"
AVG Residual		89.12	85.02	81.01	73.17	76.81	97.62	106.43	117.49

Conflicting results for the best surface flow calibration occurred between the two subbasins. The best calibration for the Anamolink subbasin was Run 4, while the best calibration for the Minisink Subbasin was Run 3. Since the average residual values were so close between Runs 3 and 4, either scenario would have been a valid choice. Calibration Run 3, which was the result of a decrease in the curve number by 3.2%, was ultimately chosen as the best annual surface flow calibration due to the larger size of the Minisink subbasin than that of the Anamolink Subbasin.

Base Flow

To adjust for annual base flow, the Curve Number value was set to the most accurate annual calibration for surface flow, a decrease of 3.2%, and the Ground Water Revap coefficient was adjusted from 0.075 to 0.15. The adjustments were made over four calibration scenarios. Table 4 shows the run descriptions for annual base flow calibration. Tables 5 and 6 show the results of the base flow calibrations for Anamolink and Minisink respectively. The raw results of the calibrations are located in quotation marks. The residuals, located above the raw values, of the calibration runs equal the difference between the raw value and the HYSEP Separated Base Flow value. The most accurate run for the calibration of annual base flow was determined by averaging the residuals for the three calibration years.

Table 4: Run Descriptions for Annual Base Flow Calibration

Run Number	Description
Run 8	CN2 was decreased by 3.2%; GWREVAP was set to 0.075
Run 9	CN2 was decreased by 3.2%;gwrevap was set to 0.1
Run 10	CN2 was decreased by 3.2%;gwrevap was set to 0.125
Run 11	CN2 was decreased by 3.2%;gwrevap was set to 0.15

Table 5: Base Flow Calibration Comparisons for Anamolink Subbasin

Year	HYSEP Separated Base Flow	No-Calibration	Run8	Run9	Run10	Run11
1993	**57.23**	11.16 "68.39"	6.11 "63.34"	2.03 "59.26"	2.06 "55.17"	6.45 "50.78"
1994	**70.56**	28.43 "98.99"	25.73 "96.29"	21.46 "92.02"	16.99 "87.55"	13.00 "83.56"
1995	**60.10**	19.99 "80.08"	15.32 "75.42"	9.85 "69.95"	5.81 "65.90"	1.37 "61.47"
AVG Residual		19.86	15.72	11.12	8.28	6.94

Table 6: Base Flow Calibration Comparisons for Minisink Subbasin

Year	HYSEP Separated Base Flow	No-Calibration	Run8	Run9	Run10	Run11
1993	**205.25**	36.85 "242.10"	12.14 "217.39"	7.58 "197.67"	27.43 "177.82"	42.43 "162.82"
1994	**248.39**	107.67 "356.05"	93.17 "341.56"	69.61 "317.99"	44.63 "293.02"	21.93 "270.32"
1995	**207.41**	78.49 "285.91"	58.36 "265.78"	37.28 "244.69"	19.02 "226.44"	1.35 "206.06"
AVG Residual		74.34	54.56	38.16	30.36	21.91

Run 11 was the best calibration scenario for both the Anamolink and Minisink subbasins and was therefore the used to run the Annual Validation test. The settings for Run 11 consisted of a Curve Number adjustment of – 3.12% for surface flow, and a Ground Water Revap Coefficient of 0.15.

Results of Anamolink and Minisink Monthly Calibration

Description of Separation

The monthly calibration comparisons were separated into three different time frames. The first included all months of the year. The second included non-winter months (May through November). The third contained winter months (December through April). This separation step was taken to check the accuracy of the model during time periods of freeze / thaw cycles with snow accumulation and snowmelt.

Surface Flow

A total of 11 different scenarios were run in an attempt to calibrate average monthly surface flow. These scenarios consisted of (1) adjusting the Curve Number value CN2 from –5.12% to +5.12% of the no-calibration value and (2) adjusting the snowmelt rates by decreasing the no-calibration values for SMFX and SMFN from 20 to 75%. The outputs of these 11 scenarios were then put into the three tables and evaluated statistically. The first table consisted of all of the months for the calibration period. The second table consisted of non-winter months, May through November, for the three years of the calibration period. The third table consisted of winter months, December through April, for the three years of the calibration period. Table 7 shows the run descriptions for monthly surface flow calibrations. Tables 8 through 13 show the statistical outputs for surface flow comparisons of the different scenarios and pairings for the Anamolink and the Minisink subbasins. The tables containing the actual values used to calculate these statistics can be found in Appendix M through O.

Table 7: Run Descriptions for Monthly Surface Flow Calibration

Run Number	Description
Run1	CN2 was decreased by .8%
Run2	CN2 was decreased by 1.6%
Run3	CN2 was decreased by 3.2%
Run4	CN2 was decreased by 5.12%
Run5	CN2 was increased by 1.6%
Run6	CN2 was increased by 3.2%
Run7	CN2 was increased by 5.12%
Run8	CN2 was decreased by 5.12%, SMFX and SMFN were decreased by 20%
Run9	CN2 was decreased by 5.12%, SMFN and SMFX were increased by 26%
Run10	CN2 was decreased by 5.12%, SMFN and SMFX were decreased by 50%
Run11	CN2 was decreased by 5.12%, SMFN and SMFX were decreased by 75%

Table 8: Statistics For Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, All Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.1287	0.1255	0.1190	0.1110	0.1386	0.1445	0.1514	0.1363	0.1252	0.1159	0.1065
RMSE =	87.60	87.76	88.09	88.49	87.11	86.81	86.45	87.22	87.78	88.25	88.71
Prob>F =	0.0317	0.0340	0.0393	0.0471	0.0254	0.0222	0.0190	0.0267	0.0342	0.0422	0.0520

Table 9: Statistics For Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, All Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.1188	0.1156	0.1092	0.1013	0.1282	0.1342	0.1413	0.1213	0.1106	0.1041	0.0979
RMSE =	391.81	392.51	393.94	395.67	389.71	388.37	386.77	391.26	393.63	395.05	396.41
Prob>F =	0.0396	0.0425	0.0490	0.0585	0.0320	0.0280	0.0239	0.0374	0.0475	0.0549	0.0671

Table 10: Statistics For Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, Non-Winter Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.4191	0.4217	0.4266	0.4314	0.4102	0.4035	0.3948	0.4299	0.4339	0.4325	0.4305
RMSE =	36.78	36.70	36.54	36.39	37.06	37.27	37.54	36.44	36.31	36.35	36.42
Prob>F =	0.0015	0.0014	0.0013	0.0012	0.0018	0.0020	0.0023	0.0013	0.0012	0.0012	0.0012

Table 11: Statistics For Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, Non-Winter Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.3772	0.3786	0.3809	0.3833	0.3722	0.3682	0.3627	0.3817	0.3861	0.3845	0.3822
RMSE =	149.22	149.05	148.77	148.49	149.82	150.29	150.95	148.69	148.16	148.34	148.62
Prob>F =	0.0031	0.0030	0.0029	0.0028	0.0033	0.0035	0.0039	0.0028	0.0026	0.0027	0.0028

Table 12: Statistics For Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, Winter Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.0522	0.0474	0.0385	0.0292	0.0687	0.0810	0.0974	0.0888	0.0629	0.0372	0.0237
RMSE =	120.68	120.99	121.55	122.13	119.62	118.84	117.77	118.32	119.99	121.63	122.48
Prob>F =	0.4128	0.4359	0.4834	0.5424	0.3452	0.3041	0.2575	0.2806	0.3671	0.4912	0.5839

Table 13: Statistics For Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, Winter Months

	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
R^2 =	0.0607	0.0556	0.0461	0.0360	0.0777	0.0904	0.1073	0.1029	0.0729	0.0438	0.0304
RMSE =	529.18	530.61	533.26	536.07	524.36	520.73	515.89	517.16	525.71	533.90	537.63
Prob>F =	0.3672	0.3977	0.4421	0.4979	0.3144	0.2761	0.2334	0.2438	0.3303	0.4539	0.5341

None of the calibration scenarios showed promising results. There were conflicting statistical values between the different time frames, showing there were issues with how the model handled winter versus non-winter months. Based on the F value, it is unlikely that there was a correlation between any of the scenarios and the observed surface flow during the winter months. Therefore, to pick the most appropriate scenario most weight was placed on the value for "Non-Winter Months". Though Run 9 had the best statistical significance in the "Non-Winter Months," Run 8 had virtually identical results for the same time frame and was ultimately chosen because of its better correlation with "All Months". The calibration settings for Run 8 were (1) a decrease in the no-calibration curve number value CN2 by 5.12% and (2) a decrease in the snowmelt values SMFX and SMFN by 20%.

Base Flow

To adjust for base flow on a monthly time step, the calibration values were set to the most accurate scenario for surface flow, CN2 = -5.12% and SMFX and SMFN = -20%, and the Ground Water Revap coefficient was adjusted from 0.1 to 0.15. The adjustments were made over 3 calibration scenarios. The outputs of these three scenarios were then put into the three tables based on time frame and tested statistically. Table 14 shows the run descriptions for monthly base flow calibration. Tables 15 through 20 show the statistical outputs for base flow comparisons of the different scenarios and pairings for the Anamolink and the Minisink subbasins. The tables containing the actual values used to calculate these statistics can be found in Appendix P through R.

Table 14: Run Descriptions for Monthly Base Flow Calibration

Run Number	Description
Run12	CN2 decreased by 5.12%, SMFX and SMFN were decreased by 20%, GWREVAP was set to 0.1.
Run13	CN2 decreased by 5.12%, SMFX and SMFN were decreased by 20%, GWREVAP was set to .13
Run14	CN2 decreased by 5.12%, SMFX and SMFN were decreased by 20%, GWREVAP was set to 0.15

Table 15: Statistics For Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, All Months

	Run12	Run13	Run14
R^2 =	0.4868	0.4813	0.4871
RMSE =	25.2302	25.3648	25.2244
Prob>F =	0.0001	0.0001	0.0001

Table 16: Statistics For Monthly Base Flow Calibration Comparisons of Minisink Subbasin, All Months

	Run12	Run13	Run14
R^2 =	0.5791	0.5749	0.5749
RMSE =	53.1044	53.3725	53.3739
Prob>F =	0.0001	0.0001	0.0001

Table 17: Statistics For Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, Non-Winter Months

	Run12	Run13	Run14
R^2 =	0.5649	0.5450	0.5275
RMSE =	17.5795	17.9783	18.3200
Prob>F =	0.0001	0.0001	0.0002

Table 18: Statistics For Monthly Base Flow Calibration Comparisons of Minisink Subbasin, Non-Winter Months

	Run12	Run13	Run14
R^2 =	0.5752	0.5240	0.5118
RMSE =	45.0531	47.6859	48.2948
Prob>F =	0.0001	0.0003	0.0004

Table 19: Statistics For Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, Winter Months

	Run12	Run13	Run14
R^2 =	0.0274	0.0100	0.0103
RMSE =	23.9030	24.1157	24.1119
Prob>F =	0.5554	0.7225	0.7184

Table 20: Statistics For Monthly Base Flow Calibration Comparisons of Minisink Subbasin, Winter Months

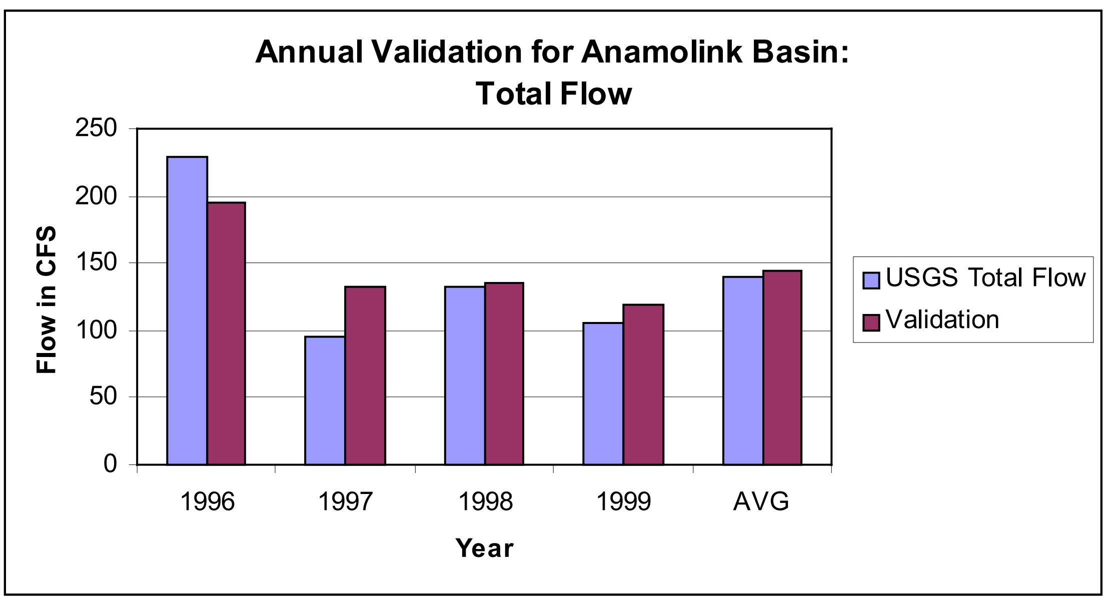
	Run12	Run13	Run14
R^2 =	0.0635	0.0513	0.0274
RMSE =	33.1174	33.3326	33.7490
Prob>F =	0.3465	0.3990	0.5399

The model predicted base flow fairly well in all three of the calibration scenarios for "All Months" and "Non-Winter Months". However, the results for "Winter Months were poor, and based on the Prob>F it is unlikely there was a statistical correlation between the observed vs. predicted. Run 12 was chosen as the most accurate calibration for monthly base flow based on the results of "All Months" and Non-Winter Months". The calibration settings for Run12 were (1) CN2 = -5.12% (2) SMFX and SMFN = -20% and (3) GWREVAP = 0.1.

Results of Anamolink and Minisink Annual Validation

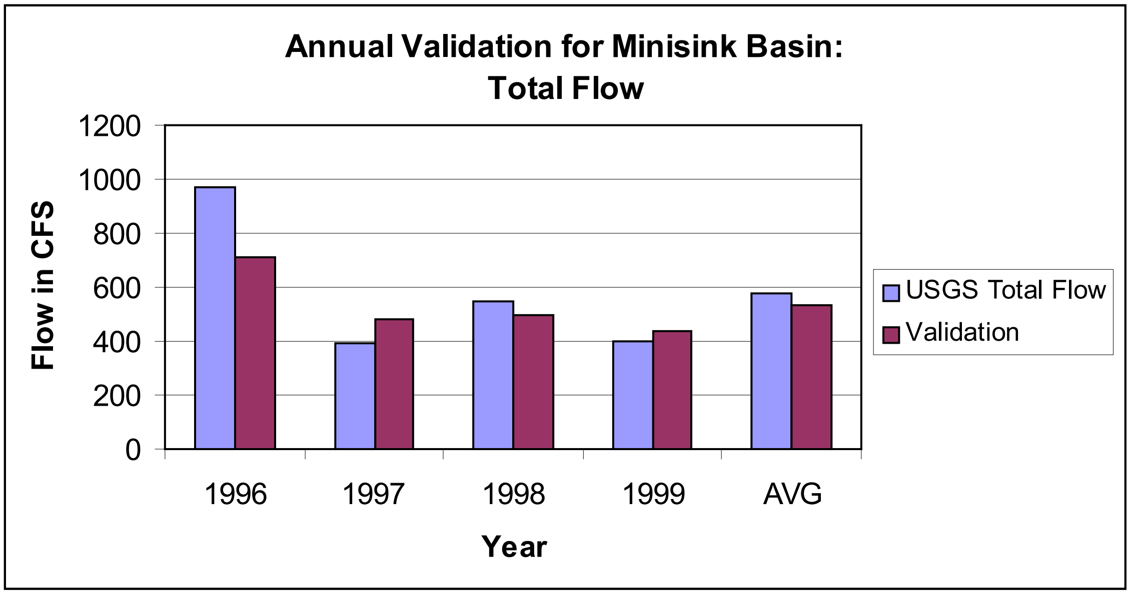
To test annual validation of the model, the calibration settings were set to the most accurate annual scenario, Run 11, and the model was run on an annual time step from January 1, 1987 through October 20, 1999. The model outputs were then compared with the observed total flow data from the USGS gage data and the HYSEP created surface flow and base flow values for the dates of January 1, 1996 through October 20, 1999, the validation data. Figure 12 through 17 show annual validation comparisons for the Anamolink and Minisink subbasins. The tables these graphs were made from can be seen in appendices S through U.

Figure 12: Annual Validation for Anamolink Subbasin: Total Flow



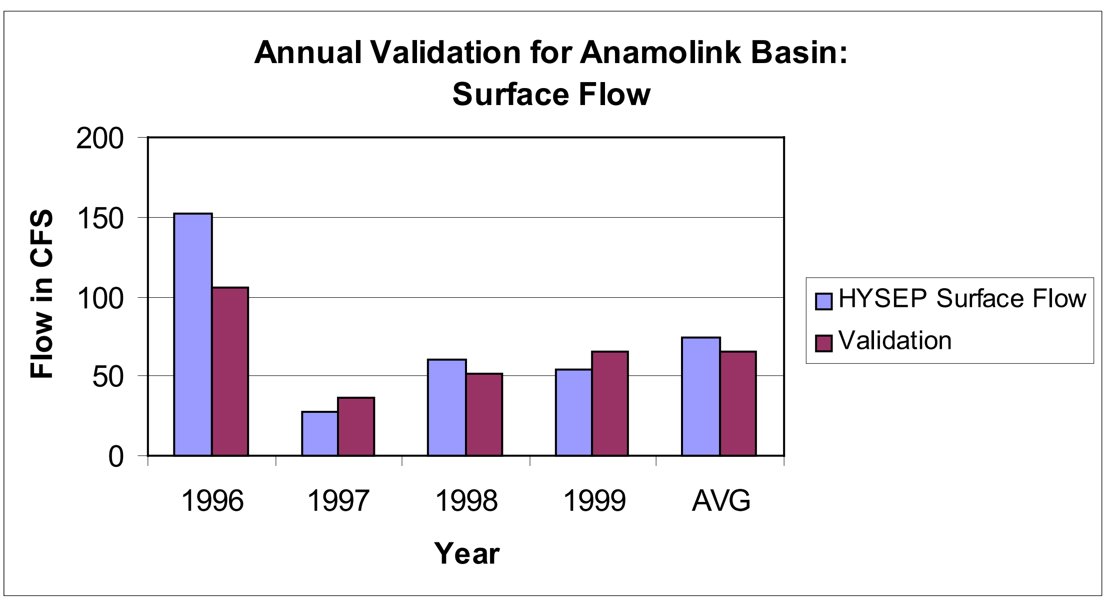
The average difference between observed vs. model predicted total flow for the Anamolink subbasin = 16 %

Figure 13: Annual Validation for Minisink Subbasin: Total Flow



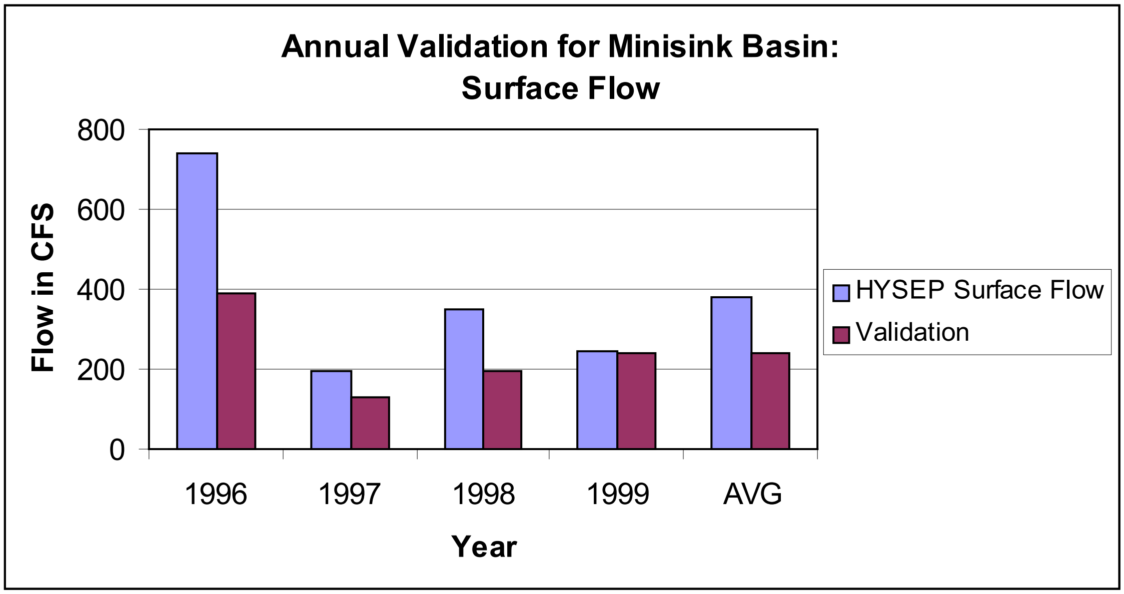
The average difference between observed vs. model predicted total flow for the Minisink subbasin = 18 %

Figure 14: Annual Validation for Anamolink Subbasin: Surface Flow



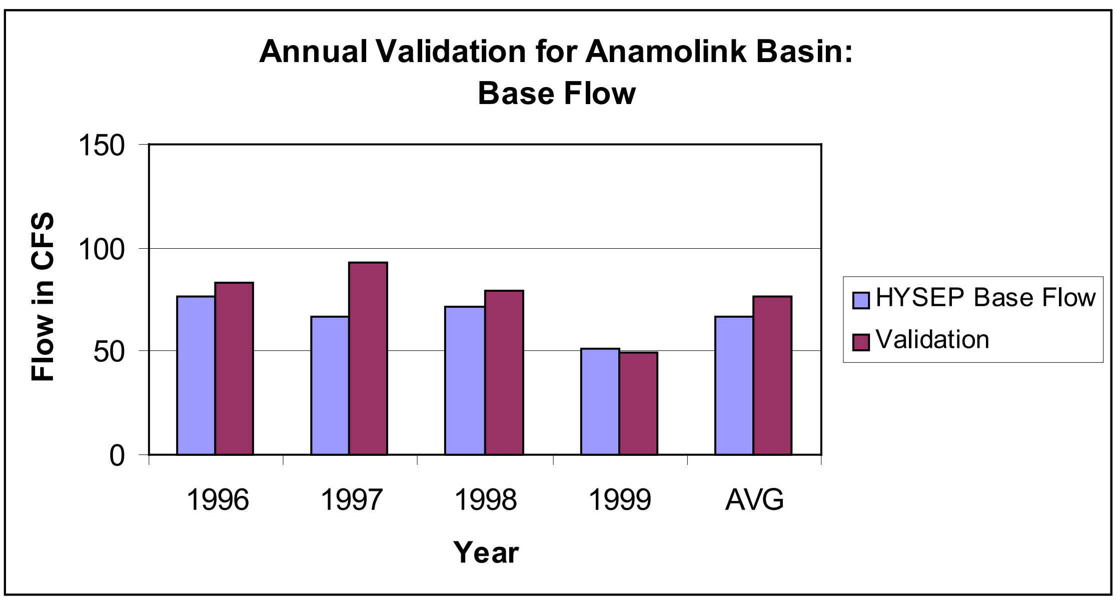
The average difference between observed vs. model predicted surface flow for the Anamolink subbasin = 25 %

Figure 15: Annual Validation for Minisink Subbasin: Surface Flow



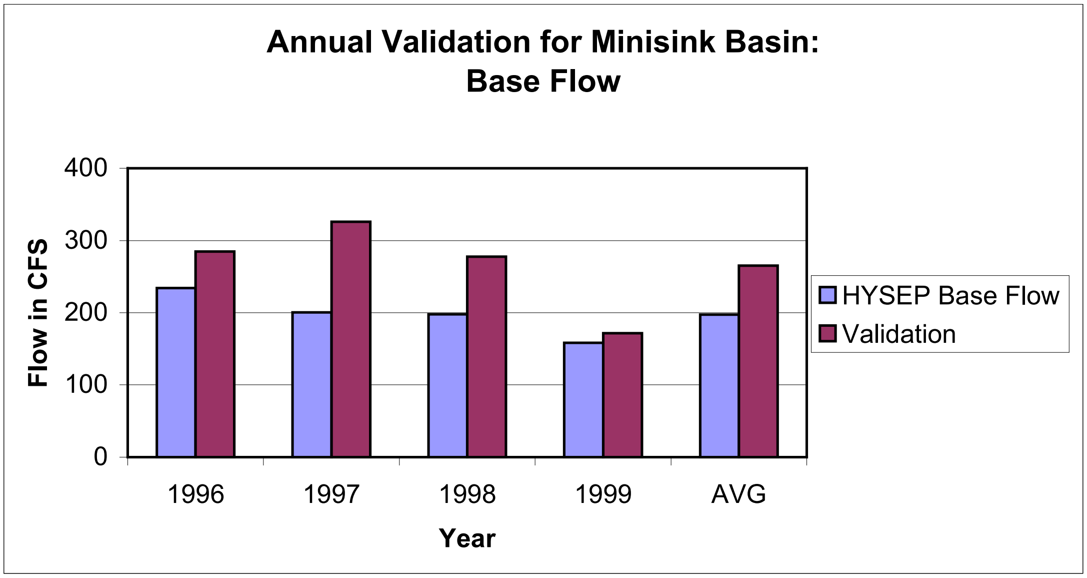
The average difference between observed vs. model predicted surface flow for the Minisink subbasin =37 %

Figure 16: Annual Validation for Anamolink Subbasin: Base Flow



The average difference between observed vs. model predicted base flow for the Anamolink subbasin = 16 %

Figure 17: Annual Validation for Minisink Subbasin: Base Flow



The average difference between observed vs. model predicted surface flow for the Minisink subbasin = 34 %

A model prediction within 20% of the observed flow was viewed as a successful model. Therefore, it can be said that on an annual basis the SWAT model accurately predicted total flow with values of 16 and 18% average annual difference for the Anamolink and Minisink subbasins respectively.

Annual surface flow for the Anamolink subbasin was close to 20% of the observed value, with an average annual percent difference of 25%. The majority of error for the Anamolink surface flow comparison occurred in the year of 1996, which contained two months of exceptionally high surface runoff. Annual surface flow for the Minisink subbasin was almost double the accepted value for percent difference. However the majority of this difference also came from the year of 1996.

Base flow was consistently over predicted with the Anamolink subbasin having an average annual difference of 16 % and the Minisink subbasin having an average annual difference of 34%. Though the Minisink subbasin had an average annual percent difference greater than 20%, it appeared to have a consistent over-prediction and could possibly be corrected to yield more accurate results, given further study.

Results of Anamolink and Minisink Monthly Validation

To test monthly validation of the model, the calibration settings were set to the most accurate monthly scenario, Run 12, and the model was run on a monthly time step from January 1, 1987 through October 20, 1999. The model outputs were then compared with the observed total flow data from the USGS gage data and the HYSEP created surface flow and base flow values for the dates of January 1, 1996 through October 20, 1999. Tables 21 through 26 show the statistical measures of monthly validation comparisons for the Anamolink and Minisink subbasins. The tables these statistics were calculated from can be seen in appendices V through AD.

Table 21: Monthly Validation Statistics For Anamolink Subbasin, All Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.4263	0.3828	0.3915
RMSE =	97.6991	37.5646	79.3178
Prob>F =	<.0001	<.0001	<.0001
AVG Predicted Flow	156.07	95.06	56.74
AVG Observed Flow	143.22	67.49	75.73

Table 22: Monthly Validation Statistics For Minisink Subbasin, All Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.5558	0.3738	0.4135
RMSE =	338.0327	73.6948	350.3300
Prob>F =	<.0001	<.0001	<.0001
AVG Predicted Flow	575.49	338.61	208.02
AVG Observed Flow	591.02	200.01	391.02

Table 23: Monthly Validation Statistics For Anamolink Subbasin, Non-Winter Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.2735	0.2307	0.3692
RMSE =	62.3945	29.6632	38.5352
Prob>F =	0.0051	0.0112	0.0008
AVG Predicted Flow	138.05	82.96	51.20
AVG Observed Flow	76.53	40.34	36.19

Table 24: Monthly Validation Statistics For Minisink Subbasin, Non-Winter Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.4205	0.2882	0.3657
RMSE =	241.2656	75.6895	206.7705
Prob>F =	0.0003	0.0039	0.0008
AVG Predicted Flow	502.68	291.85	185.90
AVG Observed Flow	354.31	159.42	194.89

Table 25: Monthly Validation Statistics For Anamolink Subbasin, Winter Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.6495	0.1158	0.7518
RMSE =	79.5960	35.2033	65.5043
Prob>F =	<.0001	0.1541	<.0001
AVG Predicted Flow	181.68	112.24	64.61
AVG Observed Flow	237.99	106.07	131.92

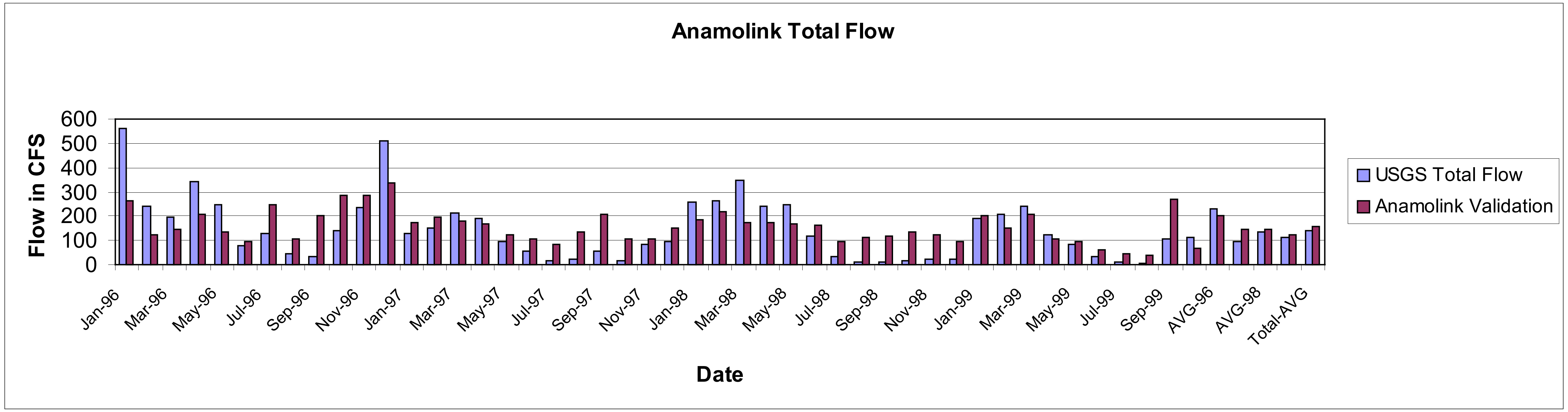
Table 26: Monthly Validation Statistics For Minisink Subbasin, Winter Months

	Total Flow	Base Flow	Surface Flow
R^2 =	0.7504	0.0985	0.7700
RMSE =	274.8587	257.6848	260.2765
Prob>F =	<.0001	0.1908	<.0001
AVG Predicted Flow	678.95	405.06	239.47
AVG Observed Flow	927.40	257.68	669.72

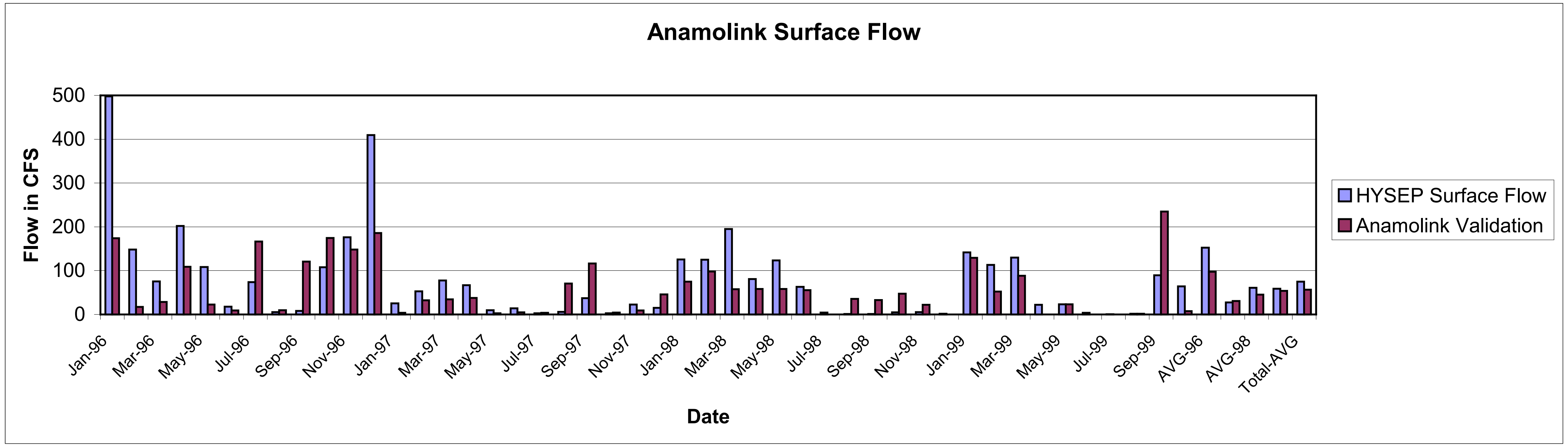
Based on the Probability > F, it is likely there is a strong correlation between the model predicted flows and the observed flows for monthly validation, excluding base flow for winter months. Based on R^2, surface flow and total flow appeared to be predicted fairly well over the validation period while base flow seemed to show poor results when compared to how it tested in calibration comparisons.

To determine if SWAT accurately predicted monthly total flow surface flow, and base flow, the residuals were averaged on a yearly basis over the course of the validation period for the three separate time frames. An average difference of less than 20% was viewed as a successful model. Graphs were made on a monthly time step for total flow, surface flow, and base flow for both the Anamolink and Minisink subbasin for use in visual comparison. The graphs and the average difference can be viewed on the fold out graphs of Figures 18 through 23. The tables the graphs and averages were calculated from can be viewed in appendices V through AD.

Figure 18: Results of Anamolink Monthly Validation, Total Flow



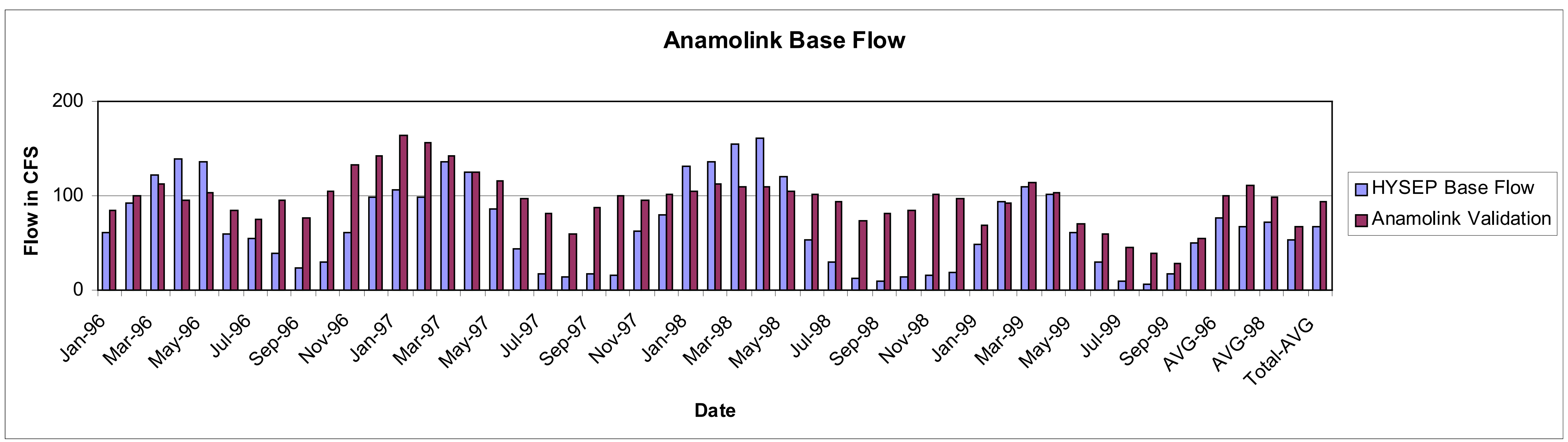
	Average Difference of Total Flow for All Months	Average Difference of Total Flow for Non-Winter Months	Average Difference of Total Flow for Winter Months
AVG-96	98.05	139.36	41.94
AVG-97	161.57	256.23	23.97
AVG-98	301.98	443.93	36.71
AVG-99	150.03	174.21	91.01
Total-AVG	177.91	253.43	48.41



	Average Difference of Surface Flow for All Months	Average Difference of Surface Flow for Non-Winter Months	Average Difference of Surface Flow for Winter Months
AVG-96	178.50	260.87	65.32
AVG-97	165.97	223.53	55.54
AVG-98	639.85	1059.59	72.97
AVG-99	75.04	76.16	58.69
Total-AVG	264.84	405.04	63.13

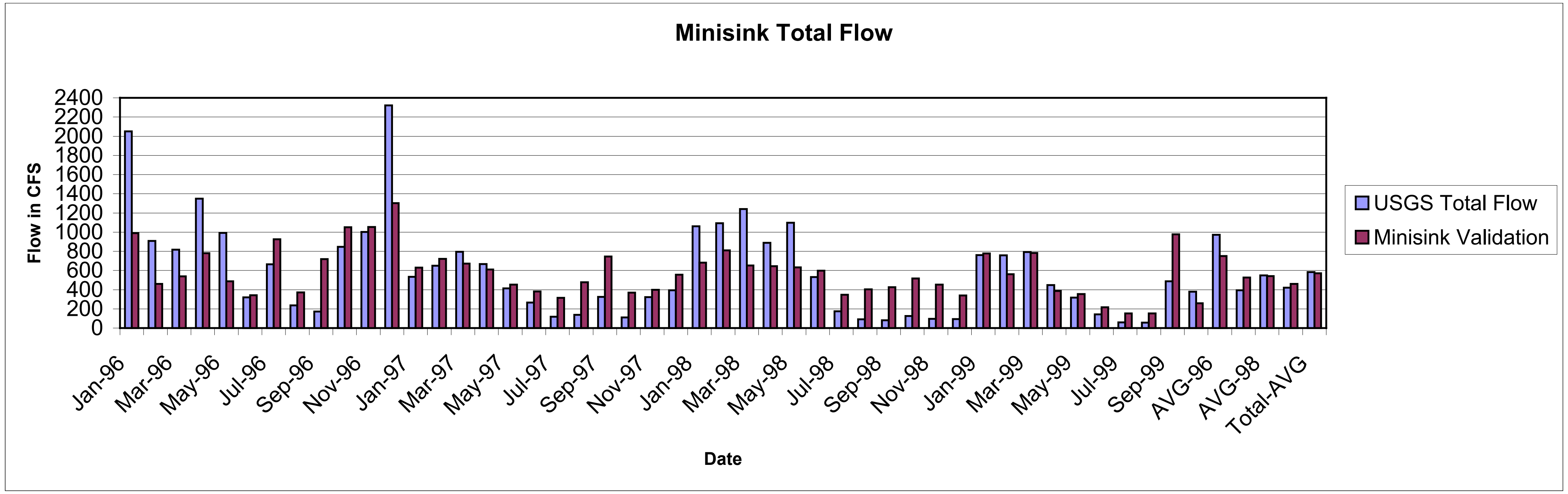
Figure 19: Results of Anamolink Monthly Validation, Surface Flow

Figure 20: Results of Anamolink Monthly Validation, Base Flow



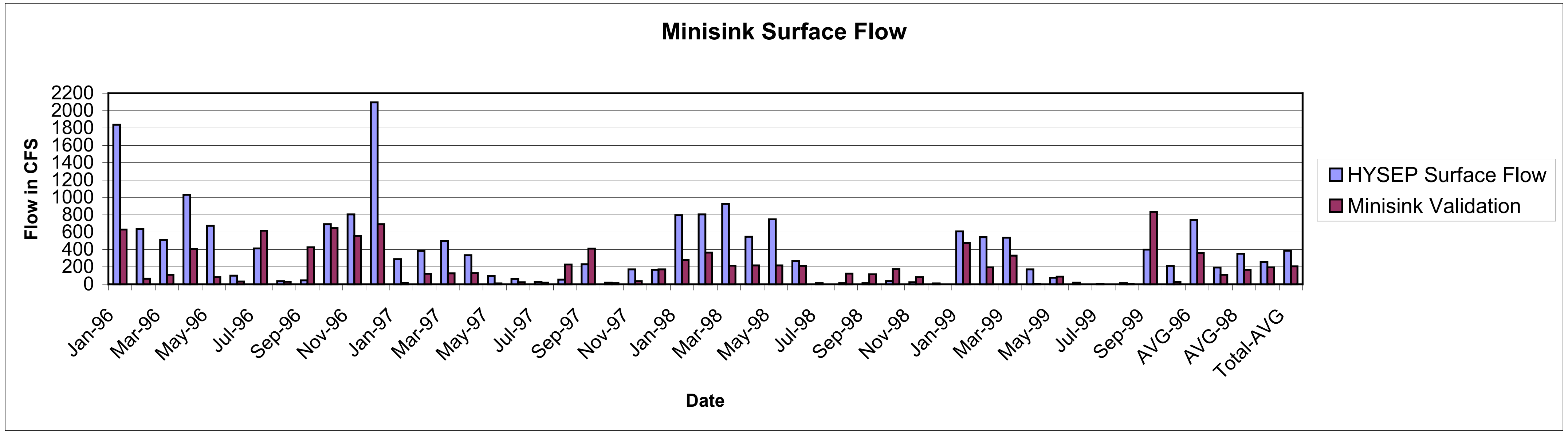
	Average Difference of Base Flow for All Months	Average Difference of Base Flow for Non-Winter Months	Average Difference of Base Flow for Winter Months
AVG-96	80.72	119.98	20.94
AVG-97	165.61	263.25	32.52
AVG-98	263.19	376.04	25.20
AVG-99	153.69	176.38	95.73
Total-AVG	165.80	233.91	43.60

Figure 21: Results of Minisink Monthly Validation, Total Flow



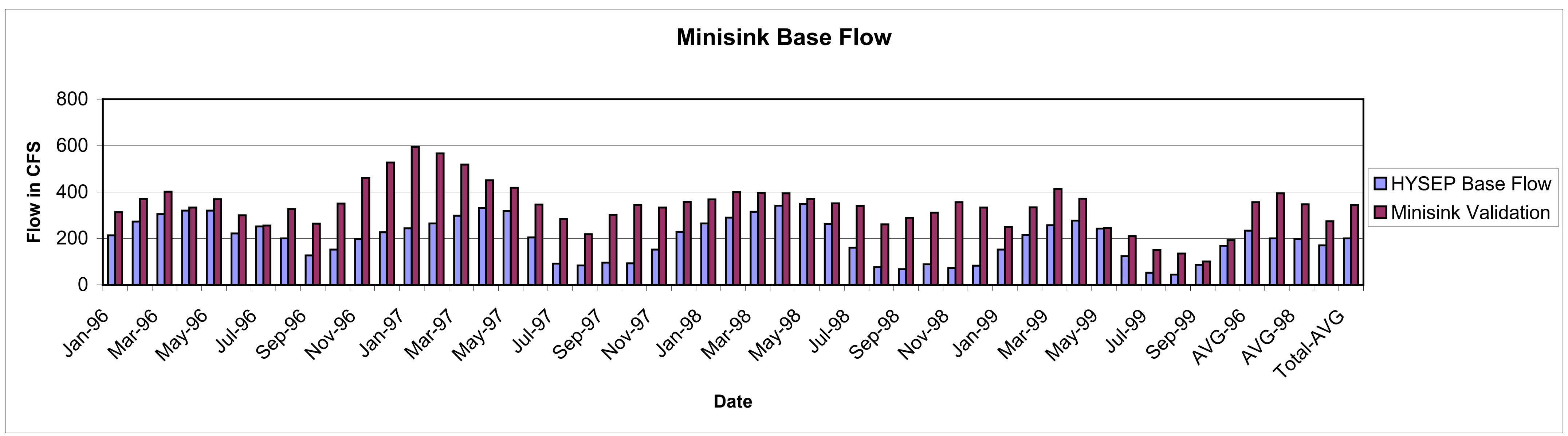
	Average Difference of Total Flow for All Months	Average Difference of Total Flow for Non-Winter Months	Average Difference of Total Flow for Winter Months
AVG-96	60.24	71.69	44.27
AVG-97	78.97	121.98	19.39
AVG-98	167.00	228.96	35.46
AVG-99	82.98	87.02	61.53
Total-AVG	97.30	127.41	40.16

Figure 22: Results of Minisink Monthly Validation, Surface Flow



	Average Difference of Surface Flow for All Months	Average Difference of Surface Flow for Non-Winter Months	Average Difference of Surface Flow for Winter Months
AVG-96	122.62	158.62	73.55
AVG-97	82.61	98.54	73.19
AVG-98	220.84	327.62	51.85
AVG-99	79.57	78.79	64.59
Total-AVG	126.41	165.89	65.79

Figure 23: Results of Minisink Monthly Validation, Base Flow



	Average Difference of Base Flow for All Months	Average Difference of Base Flow for Non-Winter Months	Average Difference of Base Flow for Winter Months
AVG-96	61.38	69.26	29.60
AVG-97	125.23	153.94	100.33
AVG-98	148.86	195.01	35.11
AVG-99	100.85	81.74	103.61
Total-AVG	109.08	124.99	67.16

Monthly surface flow proved to be incredibly difficult to predict. The model tended to drastically under predict run-off amounts during spring snowmelt events, indicating a problem with the snowmelt rates, and drastically over predict during periods of heavy precipitation, indicating a problem with runoff rates associated with curve number values. Due to these mispredictions, none of the comparisons for total flow or surface flow for either subbasin were within 20% of the observed flow. Differences ranged from roughly 70% to over 1000% off in the case of surface flow comparisons, which resulted in a poor prediction of total flow. Base flow consistently overestimated and could probably be corrected if an effort was made to detect the relationship of the overestimated predicted base flow to the observed base flow.

Conclusion

The SWAT model predicted annual flow reasonably well. Base flow was consistently over predicted, which could be corrected for using an adjustment factor rather than continuing to calibrate the model settings. Excluding the extremely high runoff year of 1996, validation of surface flow was predicted within reason and could probably be used as a good predictor given more data for calibration.

Excluding the winter months, predicted flow and observed flow appear to have significant linear relationship, as indicated by the p-values. However, low R^2 values show that there is little correlation between the two.

Discussion and Recommendations

DEWA was looking for a model they could use to help predict the effects of changes in land use. The first step in this process was to set up a model that will accurately predict stream flow. This project has produced a model that reasonably predicted flow on an annual basis. Unfortunately, monthly flow could not be calibrated to produce accurate results. However, based on the results of other applications of SWAT, the model of the Broadhead has the potential to be greatly improved. Perkins and Sophocleous (1999) reported good results, $r^2 = 0.85$, when comparing predicted and observed stream flow on a monthly time step for a basin in North-Central Kansas. Arnold and Allen (1996) achieved r^2 results ranging from 0.63 to 0.95 when comparing predicted and observed flow on a monthly time step in three Illinois watersheds. Manguerra and Engel (1998) showed an increase in monthly correlation by updating curve number values for the model in response to management practices in an agricultural watershed. The r^2 value increased from 0.69 to 0.77 with the updated curve number values. Given more site-specific data, DEWA should be able to achieve acceptable monthly results.

The following discussion and recommendations will attempt to explain what can be done in the future to help DEWA meet their goals.

Several steps must be taken in order to achieve more accurate results for both annual and monthly prediction of flow. First, a land use/ land cover map that corresponds to the dates of the weather data must be used. The land use/ land cover map used for this project was from the early 1980's, which is 15 years older then the weather and flow data used to calibrate the model. The ramifications of this alone are enough to skew the results. Second, the USGS gage data should be checked for inaccuracies. The Broadhead basin is located in an area that can have potentially harsh winters producing large errors in the gage recordings. Third, the HYSEP results should be checked, as there was no data for validation. Fourth, STATSGO soil data does not come with a common attribute to connect the sequence number in the soils map. Therefore, the model utilized the first common MUID it found rather than getting the more specific sequence number. Casson Stallings found in his SAVI project for DEWA that a more detailed soils map is important and could result in significant improvements in model outputs (Stallings, 1998). An attempt was made to use SSURGO soil data, 1:24,000 scale, but was unsuccessful. Lastly, more data should have been used in the calibration process. There were only seven years of data with which to calibrate and validate the model. This posed a problem when testing the results of annual model predictions. Statistical analysis of the results was severely limited due to the lack of observations. Also, common practice in modeling says that two thirds of the data available for modeling should be used for calibration while the remainder should be used for validation (Johnson, T. verbal communication, November 2001). Due to extreme events in the weather it was decided to abandon that practice and calibrate with less than half of the total data. This may have altered the overall outcome.

Predicting flow on an annual basis is much less complex than predicting flow on a monthly time step. There are no extreme variations in temperature or precipitation, which make the model's task of predicting flow easier. The results produced by the SWAT model gave reasonable enough results to be considered for use in DEWA's watershed modeling projects. Given more data for calibration and the rest of the criteria listed above, it is likely that SWAT could accurately predict flow allowing DEWA to move forward and calibrate the model for the prediction of sediment and nutrient loading.

To prepare for the future use of hydrologic modeling, DEWA should start collecting site-specific data with regard to storm flow. Special attention should be placed on recording sediment and nutrient levels during run-off events.

Bibliography

Arnold, J.G., Allen, P.M., and Bernhardt, G., 1993. A comprehensive surface-groundwater flow model. Journal of Hydrology. vol 142: 47-69

Arnold, J.G. and Allen, P.M., 1996. Estimating hydrologic budgets for three Illinois watersheds. Journal of Hydrology. Vol 176: 57-77

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Allen, P.M., 1999. Continental Scale Simulation of the Hydrologic Balance. Journal of the American Water Resources Association,Vol 35(5): 1037-1051

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R., 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. Journal of the American Water Resources Association. Vol 34(1): 73-89

Arnold, J.G., Williams J.R., Nicks, A.D., and Sammons, N.B., 1990. SWRRB: A basin scale simulation model for soil and water resources management. Texas A&M Univ. Press, College Station, TX

Arnold, J.G., Williams, J.R., Srinivasan, R., King, K.W., 1999B. Version 99.2. SWAT: Soil Water Assessment Tool. Manual for Model Theory.

Arnold, Jeffrey G., Allen, Peter M., and Morgan, David S., 2001. Hydrologic Model for Design and Constructed Wetlands. Wetlands, Vol 21(2): 167-178

Bagnold, R.A., 1977. Bedload trasport in natural rivers. Water Rescources Res. Vol 13(2): 303-312

Becker, H., Laflen, J., Nearing, M., Flanagan, D., Meyer, C., 1997. WEPP: Spilling the Secrets of Water Erosion. Agricultural Research, Vol 45(4)

Bouraoui, Faycal and Dillaha III, Theo A., 1994. Development of a Continuous, Physically-Based, Distributed Parameter, Nonpoint Source Model. Masters Thesis. Virginia Polytechnical Institute. Blacksburg, VA

Bouraoui, Faycal and Dillaha, Theo A., 2000. ANSWERS-2000: Nonpoint Source Nutrient Planning Model. Virginia Polytechnical Institute. Blacksburg, VA

Cho, Sung-Min, 1995. The Inegration of Water Quality Models and Geographic Information Systems (GIS) for Water Quality Modeling at Delaware Water Gap National Recreation Area. Doctoral Thesis. North Carolina State University. Raleigh, NC

DHI. MIKE SHE/ MIKE 11. [On-Line]. Available WWW. http://www.dhi.dk/index.htm (December, 2001)

Flynn, K.M., Hummel, P.R., Lumb, A.M., and Kittle, J.L., Jr., 1995. User's manual for ANNIE. version 2. a computer program for interactive hydrologic data management: U.S. Geological Survey Water-Resources Investigations Report 95-4085, 211. [Online] Available WWW. http://water.usgs.gov/cgi-bin/man_wrdapp?hspf (October, 2001)

Grayson, R.B., Moore, J.D. and McMahon, T.A., 1992. Physically based hydrologic modeling. 2. Is the concept realistic? Water Resour. Res., 26(10): 2659-2666.

GMS/WMS/SMS Group, WMS: Watershed Modeling System. [On-Line]. Available WWW. http://www.scisoft-gms.com/html/wms_details.html (October, 2001)

Hargreaves, G.H. and Samani, Z.A., 1985. Reference crop evapotranspiration form temperature. Applied Engineering Agriculture. 1:96-99

Johnson, Thomas. NCSU Professor of Agricultural Resource Economics and Statistics. Raleigh, NC. Personal communication, Oct 30, 2001. email: tom_Johnson@ncsu.edu

Kinsel, W.G., 1980. CREAMS, A field scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Department of Agricultural Conservation Resources. Report No. 26

Leonard, R.A., Kinsel W.G., and Still, D.A., 1987. GLEAMS: Groundwater loading effects on agricultural management systems. Trans. ASAE 30(5): 1403-1428

Manguerra, H.B. and Engel, B.A., 1998. Hydrologic Parameterization of Watersheds for Runoff Prediction Using SWAT. Journal of the American Water Resources Association. Vol 34(5): 1149-1162

McElroy, A.D., Chiu, S.Y., Nebgen, J.W., and others, 1976. Loading functions for assessment of water pollution from nonpoint sources. Environmental Protection Service, EPA 600/2-76-151

Monteith, 1965. Found in Arnold, J.G., Williams, J.R., Srinivasan, R., King, K.W., 1999B. Version 99.2. SWAT: Soil Water Assessment Tool. Manual for Model Theory.

Muszik, I, 1996, Chapter 10. Lumped Modeling and GIS in Flood Prediction, In Singh, Vijay P., and Fiorentino, M., Geographical Information Systems in Hydrology. Kluwer Academic Publishers, 1996

Nicks, A.D., 1974. Stochastic generation of the occurrence, pattern, and location of maximum amount of daily rainfall, pp 154-171 In Proc. Symp. Statistical Hydrology, Aug- Sept. 1971, Tucson, AZ, U.S. Department of Agriculture, Misc. Publ. No. 1275.

Perkins, S.P., and Sophocleous, M., 1999. Development of a Comprehensive Watershed Model Applied to Study Stream Yield under Drought Conditions. Ground Water 37(3): 418-426

Priestly, C.H.B. and Taylor, R.J., 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Mon. Weather Rev. 100:81-92

Ritchie, J.T. 1972. A model for predicting evaporation from a row crop with incomplete cover. Water Resources Res. Vol 17 (1), pg 182-190

Robbins, Jeanne C. U.S. Geological Survey. Raleigh, NC office. Personal communication, Oct 30, 2001

Sloto, Ronald and Crouse, Michele Y., 1996. HYSEP: A Computer Program For Streamflow Hydrograph Separation and Analysis. U.S. Geological Survey Water Resources Report 96-4040

Sophocleous, M.A., Koelliker, J.K., Govindaraju, R.S., Birdie, T., Ramireddygari, S.R. and Perkins, S.P., 1999. Integrated numerical modeling for basin-wide water management: The case of the Rattlesnake Creek basin in south-central Kansas. Journal of Hydrology, vol. 214: 179-196

Stallings, Casson, 1998. The Integration of Water Quality Models and GIS for Special Protection Management. North Carolina State University Center for Earth Observation

U.S. Department of Agriculture, Soil Conservation Service, 1972. National Engineering Handbook, Hydrology Section 4, Chapters 4 - 10

U.S. Department of Agriculture, Soil Conservation Service, 1983. National Engineering Handbook, Hydrology Section 4, Chapter 19.

U.S. Environmental Protection Agency. BASINS: Better Assessment Science Integrating Point and Non-Point Sources. [Online] Available WWW. http://www.epa.gov/OST/BASINS (October, 2001)

USGS. Data Users Guide. [On-Line]. Available WWW. http://mapping.usgs.gov/pub/ti/LULC/lulcguide/dug4lulc.txt (December, 2001)

van Griensven, A., ESWAT: Extended Soil Water Assessment Tool. [On-Line]. Available WWW. http://homepages.vub.ac.be/~avgriens/research/eswat.html

Williams, J.R., 1969. Flood routing with variable travel time or variable storage coefficients. Trans. ASAE, Vol 12(1), 100-103

Williams, J.R. and Hann, R.W., 1978. Optimal operation of large agricultural watersheds with water quality constraints,.Texas Water Resource Institute. Texas A&M University. Technical Report No. 96

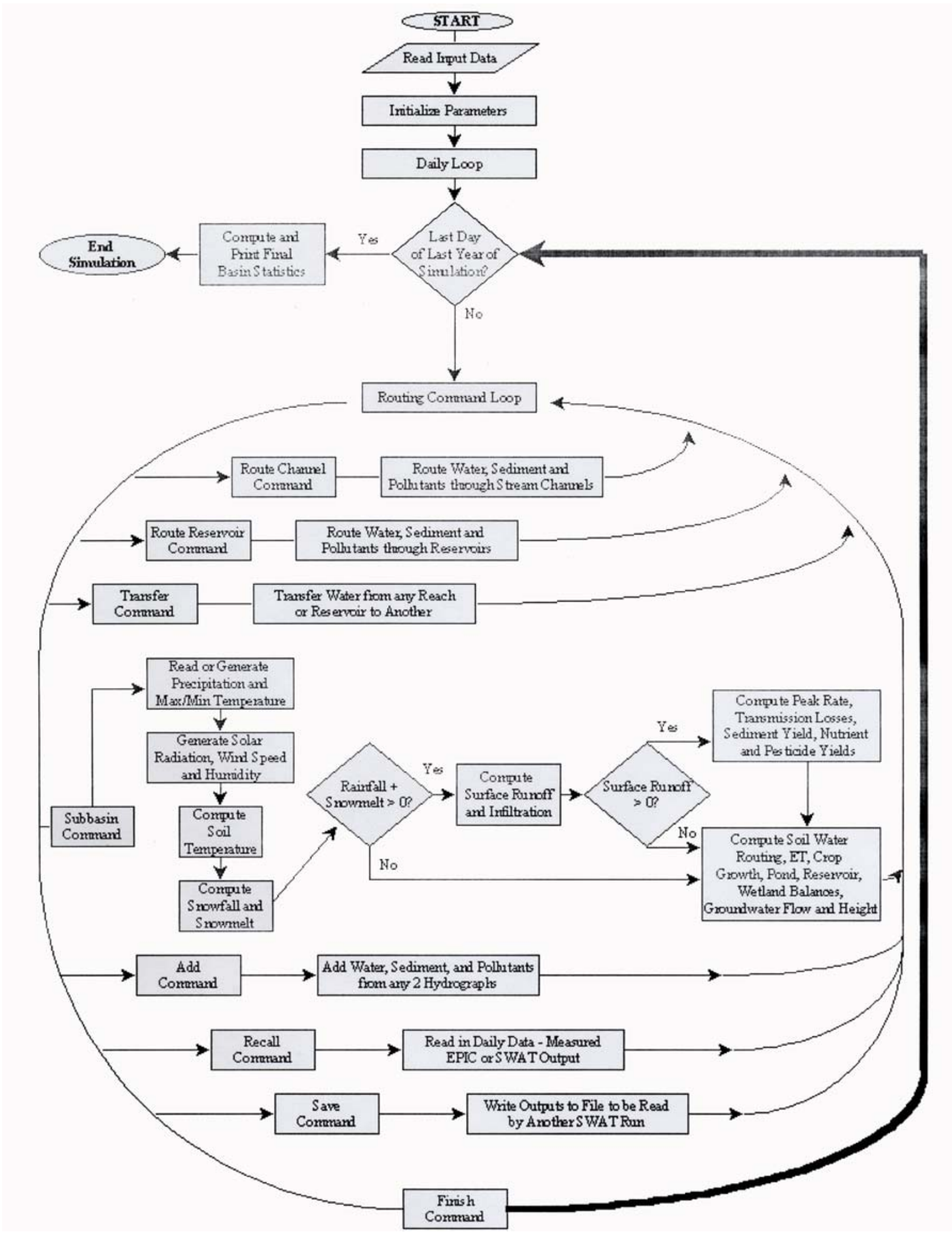
Williams, J.R., 1980. SPNM, A model for predicting sediment, phosphorus, and nitrogen from agricultural basins. Water Resources Bulletin Vol 16(5): 843-848

Williams, J.R., Jones, C.A. and Dyke, P.T., 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE 27(1):129-14.

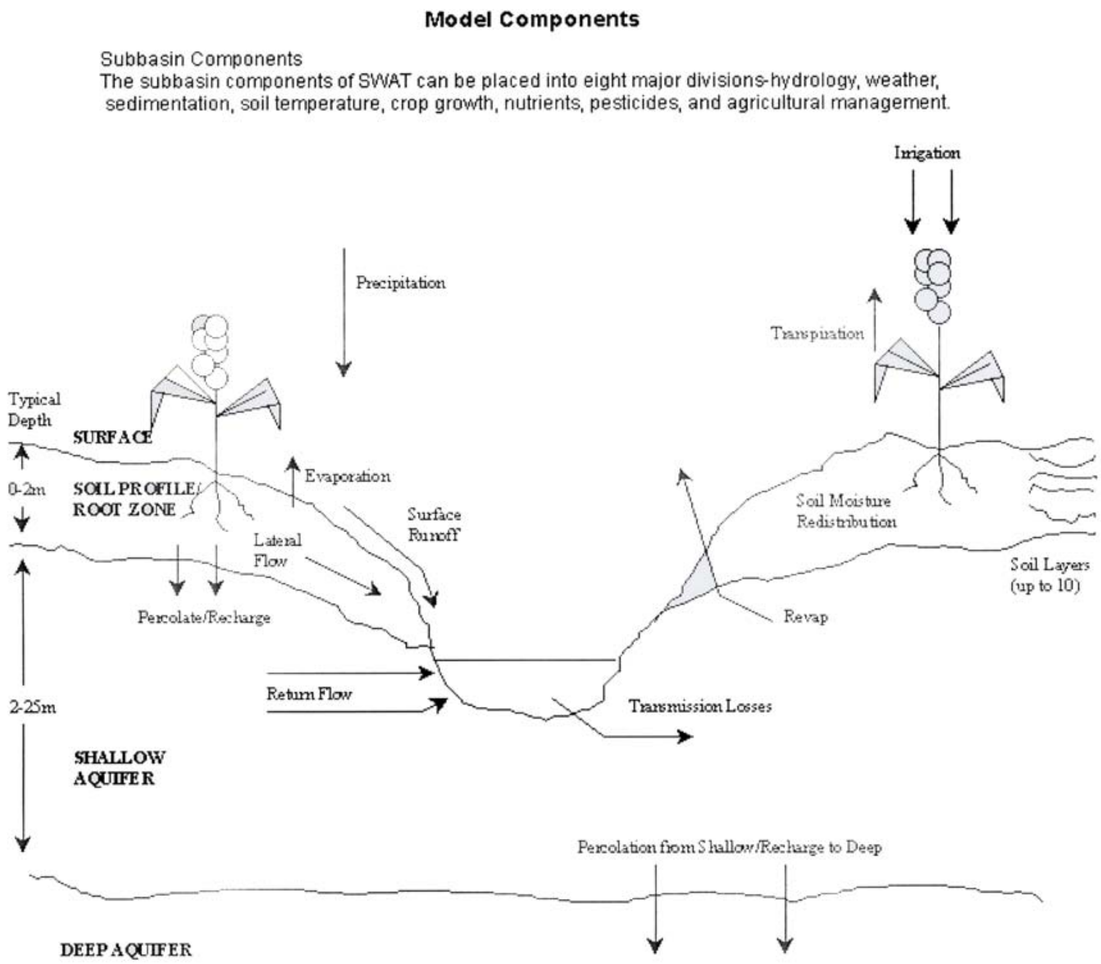
Williams, O.O., 1975. Daily values data entry and computation (program H475)- section A of chapter IV of WATSTORE user's guide: U.S. Geological Survey Open-File Report 75-426

Appendix

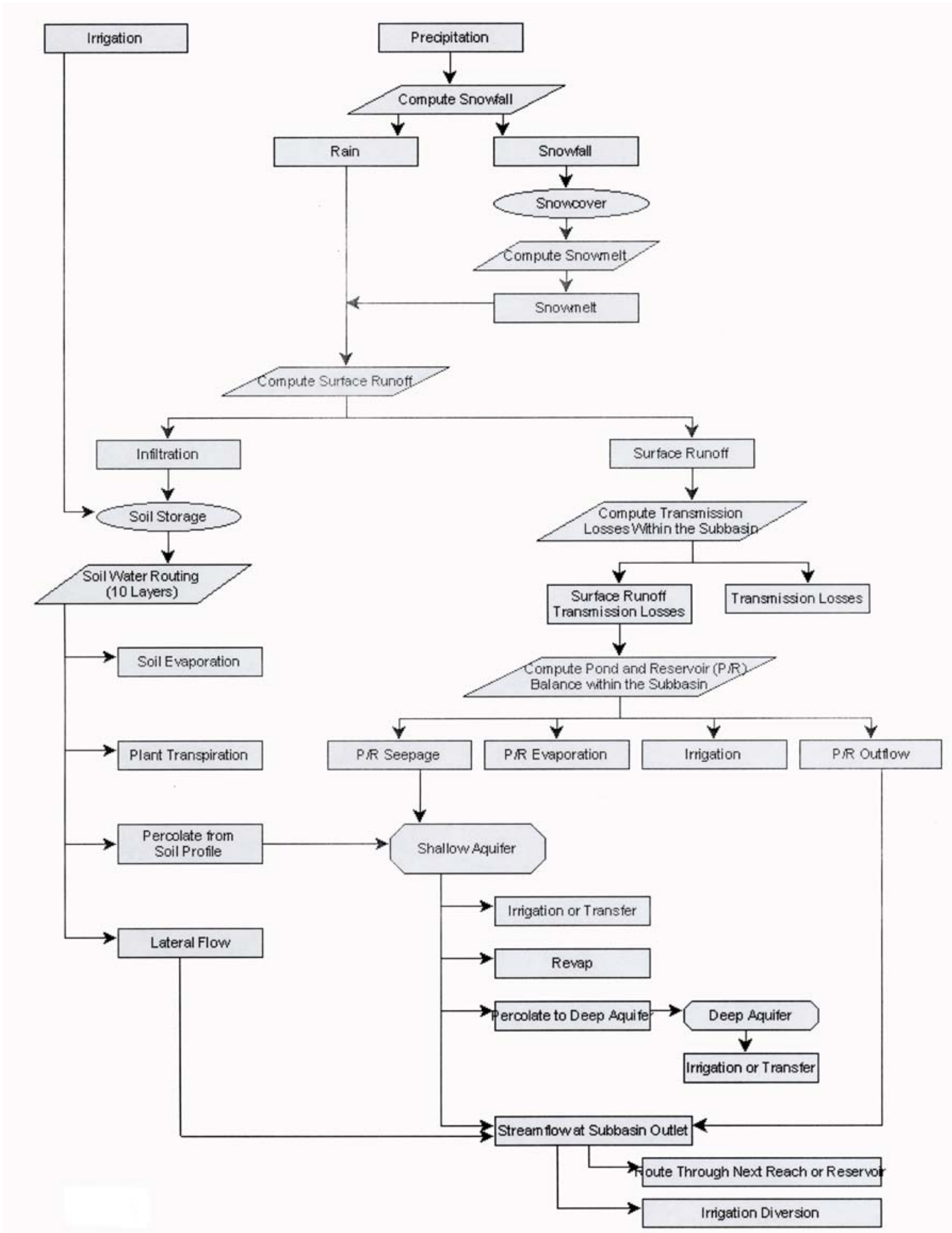
Appendix A: Command structure for SWAT. Direct Excerpt from SWAT Model Theory manual, pg 3



Appendix B: Model components for SWAT. Direct Excerpt from SWAT Model Theory manual, pg 4



Appendix C: Subbasin components for SWAT. Direct Excerpt from SWAT Model Theory manual, pg 5



Appendix D: Directions for the Creation of Broadhead watershed boundary

1- Load SWAT in ArcView and create a new temporary project (you are only using this to delineate the Broadhead watershed, so it can be done in a temp space of your choosing)
2- Use the "Watershed Delineation" tab located under the Watershed menu if the “Watershed, Subbasins, and Stream definition” GUI does not automatically load when you create a new project.
3- Load the 30 meter DEM in the "DEM grid" space
4- Make sure the "Z resolution" = 30 meters and "X-Y resolution" equals 30 meters and click "OK".
5- Click "Custom Projection" then change "Category" to "UTM- 1983" and "Type" to "Zone 18"
6- Click "Apply" next to "Processing of the DEM"
7- Once the DEM has been processed enter a "Threshold Area" of 500 ha and click "Apply" (this is only to get the watershed delineated so it doesn't need to be high definition)
8- Use the "Remove" to delete all the outlets created by the Stream Definition builder except for the Broadhead outlet.
9- Use the "Select" tool to select the Broadhead outlet as the only stream outlet then click "OK" on the "Outlet Selection” window. Click "Yes" on the window letting you know that you have selected one outlet.
10- A theme called "watershed" is created, make it active in the table of contents and then export it as a shapefile to the folder that contains all of your other spatial data.
11- Using the geoprocessing wizard in ArcView, add an additional 500m buffer to the watershed polygon.
12- Convert the shapefile to a grid.

Appendix E: Creation of the STATSGO soil tables for use in SWAT

1- Bring layer table and comp table into ArcView.
2- In layer table properties turn off all fields except MUID, seqnum, MUIDseqnum, s5id, layernum, kffact, layerdeph, layerdepl, Bdh, Bdl, AWCH, AWCL, permh, perml, omh, oml, clayh, clayl, No10h, No10l, No200h, No200l, inch3h, and inch3l.
3- In comp table properties turn off all fields except MUIDseqnum, compname, comppct, and hydgrp.
4- Combine the tables using MUIDseqnum.
5- Export the table as a .dbf file.
6- Import the table in Microsoft Access.
7- In the table make sure layernum, kffact, layerdeph, layerdepl, Bdh, Bdl, AWCH, AWCL, permh, perml, omh, oml, clayh, clayl, No10h, No10l, No200h, No200l, inch3h, inch3l, and comppct are designated as numbers.
8- Query the table and average layerdeph with layerdepl, Bdh with Bdl, AWCH with AWCL, permh with perml, omh with oml, calyh with clayl, No10h with No10l, No200h with No200l and inch3h with inch3l.
9- Save the table and export it as a .xls file.
10- Bring the table into Microsoft Excel and put the fields in this order: MUID, Seqnum, MUIDSeqnum, compname, s5id, comppct, layernum, hydgrp, kffact, layerdep, Bd, AWC, perm, om, cly, No10, No200, and inch3.
11- To calculate % sand, add a new column to the spreadsheet called % sand and write an equation to populate the records that subtracts No200 from No10 and is then divided by No10. This separates sand from the rest of the soil peds and effectively recenters the numbers so the % sand, silt, and clay add up to 100%
12- To calculate % silt, add a new column to the spreadsheet called % silt and write an equation to populate the records that subtracts Clay from No200 and is then divided by No10. This separates clay from silt and effectively recenters % sand, silt, and clay so that they add up to 100%- (note the sieve No200 only filters soil particles down to 0.075 mm. This leads to a slight over estimation of silt since silt is defined as soil particles that are < 0.02 mm and greater than 0.002 mm. However, since that is the closest STATSGO soil data comes to measuring silt, it is all there is to use.)
13- To calculate % clay, add a new column to the spreadsheet called % clay and write and equation to populate the records that divides Clay from No10. This will recenter % Clay so that % sand, silt, and clay add up to 100%.
14- The fields No10, No200 and clay need to be deleted.
15- The following field headings need to be converted: sequm to SEQN, compname to SNAME, comppct to CMPPCT, layernum to NLAYERS, kffact to USLEK, layerdep to Z, bd to BD, perm, K, om to CBN, % Clay to CLAY, % Silt to Silt, and inch3 to ROCK.
16- The following fields need to have their units converted: Z from inches to mm, BD from g/cm3 to Mg/m3, K from inches to mm.

17- Make sure the fields are in the following order: MUID, SEQN, MUIDSEQN, SNAME, S5ID, CMPPCT, NLAYERS, HYDGRP, USLEK, Z, BD, AWC K CBN, CLAY, SILT, SAND, ROCK
18- Insert the following fields: ALB between HYDGRP and USLEK, CRK between USLEK and Z, and NO3 just after ROCK.
19- Give values to the following records: every record for ALB should = 0.05, every record for CRK should = 0.00, and every record for NO31 should = 0.00. This is done because values for these fields are not given in STATSGO data but they are needed for SWAT. ALB is soil reflectance, generally speaking PA soils have a low reflectance so it was given a value of .05. The values for CRK and NO3 aren't necessary for SWAT but the columns need to be in for SWAT to run so a value of 0.00 is given.
20- The following fields should be in this form: MUID as a character, SEQN as an integer, SNAME as a character, CMPPCT as a float with 5 decimal places, NLAYERS as an integer, HYDGRP as a character, ALB as a float with 2 decimal places, USLEK as a float with 2 decimal places, CRK as a float with 2 decimal places, Z as a float with 2 decimal places, BD as a float with 2 decimal places, AWC as a float with 2 decimal places, K as a float with 2 decimal places, CBN as a float with 2 decimal places, CLAY as a float with 2 decimal places, SILT as a float with 2 decimal places, SAND as a float with 2 decimal places, ROCK as a float with 2 decimal places, NO3 as a float with 2 decimal places.
21- Save the file as a .xls file, then save it as a .dbf file- if you do not take these two steps chances are there will be formatting problems later.
22- Bring the .dbf file into ArcView.
23- Separate the layers by querying the NLAYRES field for each individual layer.
24- Export each query as an individual .dbf file and open them in Excel.
25- For the query of soil layer 1 leave all field headings the same change the following headings Z to Z1, BD to BD1, AWC to AWC1, K to K1, CBN to CBN1, CLAY to CLAY1, SILT to SILT1, SAND to SAND1, ROCK to ROCK1, and NO3 to NO31; For the query of soil layer 2 change the same field headings you changed in the previous step but instead of following with a value of 1, use a value of 2 (eg Z2, BD2, AWC2...) also change NLAYERS to NLAYERS2, For the query of soil layer 3, change the same field headings you changed in the previous step but instead of following with a value of 1, use a value of 3 (eg Z3, BD3, AWC3...) also change NLAYERS to NLAYERS3, For the query of soil layer 4 change the same field headings you changed in the previous step but instead of following with a value of 1, use a value of 4 (eg Z4, BD4, AWC4...) also change NLAYERS to NLAYERS4.
26- Save each file and bring them into ArcView.
27- For the files containing layers 2, 3, and 4 open the table properties and hide MUID, SEQN, SNAME, S5ID, CMPPCT, HYDGRP, ALB, USLEK, and CRK.
28- Join the table containing soil layer2 data to soil layer1 using the MUIDSeqnum, Join the tables containing soil layers3 and soil layers4 in the same manner then export the table as a .dbf file.
29- Bring the table into Excel and make sure the fields are in the following order from left to right: MUID SEQN, MUIDSeqnum, SNAME, S5ID, CMPPCT,

NLAYERS, NLAYERS2, NLAYERS3, NLAYERS4, HYDGRP, ALB, USLEK CRK Z1, BD1, AWC1, K1, CBN1, CLAY1, SILT1, SAND1 ROCK1, NO31, Z2, BD2, AWC2, K2, CBN2, CLAY2, SILT2, SAND2, ROCK2, NO32, Z3, BD3, AWC3, K3, CBN3, CLAY3, SILT3, SAND3, ROCK3, NO33, Z4, BD4, AWC4, K4, CBN4, CLAY4, SILT4, SAND4, ROCK4, NO34.

30- Change the field heading NLAYERS to NLAYERS 1 and add a field NLAYERS to the right of NLAYERS4.
31- Use the following equation in the NLAYERS' field's 1st record: =if(sum(NLAYERS1..NLAYERS4)=1,1,if(sum(NLAYERS1..NLAYERS4)=3,2,if(sum(NLAYERS1..NLAYERS4)=6,3,if(sum(NLAYERS1..NLAYERS4)=10,4))))

    where NLAYERS1..NLAYERS4 corresponds to the columns in which they are located and the record number should be 1(eg a1..d1).
32- Copy the equation to all records in the file.
33- Cut the entire NLAYERS field and paste it in the same place as values.
34- Delete NLAYERS1, NLAYERS2, NLAYERS3, NLAYERS4, and MUIDSeqnum.
35- Complete the table by adding fields to represent a total of 10 soil layers- the final table should have the following fields: MUID SEQN, MUIDSeqnum, SNAME, S5ID, CMPPCT, NLAYERS, NLAYERS2, NLAYERS3, NLAYERS4, HYDGRP, ALB, USLEK CRK Z1, BD1, AWC1, K1, CBN1, CLAY1, SILT1, SAND1 ROCK1, NO31, Z2, BD2, AWC2, K2, CBN2, CLAY2, SILT2, SAND2, ROCK2, NO32, Z3, BD3, AWC3, K3, CBN3, CLAY3, SILT3, SAND3, ROCK3, NO33, Z4, BD4, AWC4, K4, CBN4, CLAY4, SILT4, SAND4, ROCK4, NO34, Z5, BD5, AWC5, K5, CBN5, CLAY5, SILT5, SAND5 ROCK5, NO35, Z6, BD6, AWC6, K6, CBN6, CLAY6, SILT6, SAND6, ROCK6, NO36, Z7, BD7, AWC7, K7, CBN7, CLAY7, SILT7, SAND7, ROCK7, NO37, Z8, BD8, AWC8, K8, CBN8, CLAY8, SILT8, SAND8, ROCK8, NO38, Z9, BD9, AWC9, K9, CBN9, CLAY9, SILT9, SAND9, ROCK9, NO39, Z10, BD10, AWC10, K10, CBN10, CLAY10, SILT10, SAND10, ROCK10, NO310.
36- For every a soil characteristic that does not have a value, give it the value 0.00.
37- Save the table as an .xls file, then save it as a .dbf file.
38- Bring the table into ArcView and query for each individual MUID, exporting each query as its own .dbf file- Save the file as the name of the MUID.
39- Put all files in a folder named PA.
40- Add the folder to the AvSwat/AvSwatDB/AllUS/Statsgo.

Appendix F: Example of the STATSGO Look Up Table

VALUE	STMUID
1	42030
2	42024
3	42031
4	42026
5	42027
6	42022
7	42037
8	42025
9	42029
10	42033

Appendix G: Example of a Precipitation Look Up Table

ID	NAME	XPR	YPR
1	pcpful	498658	4547909

Appendix H: Example of a Temperature Look Up Table

ID	NAME	XPR	YPR
1	tmpful	498658	4547909

Appendix I: Directions for Creating Input Files for HYSEP

The HYSEP program accepts daily mean stream discharge as input in either of two formats: (1) the standard USGS National Water Data Storage and Retrieval System (WATSTORE) daily values, 80-character record American Standard Code for Information (ASCII) format (table) (Williams, 1975, p. A21 –A23) or (2) the binary, direct access Watershed Data Management (WDM) file format (Flynn and others, 1995, p. 12-14).

Table for U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) daily values 80-character record ASCII format (Excerpted from Sloto, Ronald and Crouse, Michele Y., 1996).

[Columns 1-24 are integers; columns 25-80 are decimal numbers]

column	numeric code
1	Format number—Daily values are designated by the number 3.
2-16	Station-identification number.
17-20	Calendar year—A four-digit number representing the calendar year.
21-22	Month—A two digit number representing the month.
23-24	Record number—A two-digit number representing the days of the month for the data. The record number is coded as follows:
Number	Days
01	1-8
02	9-16
03	17-24
04	25-31
25-80	Daily values—Eight, seven-column fields (25-31, 32-38, 39-45, 46-52, 53-59, 60-66, 67-73, 74-80) in which daily values are coded for the days designated. Blank fields are read as zero values.

For this project, a WATSTORE ASCII file was made from the daily flow data for both Anamolink and Minisink. These files were created using several steps in Excel and ArcView. The input files for both Anamolink and Minisink were created the same way. First, the daily values were copied and pasted so that they corresponded to the order listed in Table 1, however “Calendar Year”, “Month”, and “Record number” were added to the same column. There should be a total of 11 columns: 1 for Format # (all lines with attribute data should have a format number of three), 1 for Station ID #, 1 for Calendar Year, Month and Record number, and 8 different columns for daily flow data. The file was then saved as a .dbf and brought into ArcView where the following new fields were created with appropriate column widths: 1st field = “1” for Format Number was designated as numeric and contained a column width of 1
2nd field = “Station ID” for Station Identification Number was designated as a string and contained a column width of 15
3rd field = Date” for Calendar Year, Month, and Record Number was designated as a string and contained a column width of 8

4th field = “DV1” for Daily Value 1 was designated as numeric and contained a column width of 7 with 1 decimal place
5th field = “DV2” for Daily Value 2 was designated as numeric and contained a column width of 7 with 1 decimal place
6th field =”DV3” for Daily Value 3 was designated as numeric and contained a column width of 7 with 1 decimal place
7th field =”DV4” for Daily Value 4 was designated as numeric and contained a column width of 7 with 1 decimal place
8th field =”DV5” for Daily Value 5 was designated as numeric and contained a column width of 7 with 1 decimal place
9th field =”DV6” for Daily Value 6 was designated as numeric and contained a column width of 7 with 1 decimal place
10th field =”DV7” for Daily Value 7 was designated as numeric and contained a column width of 7 with 1 decimal place
11th field =”DV8” for Daily Value 8 was designated as numeric and contained a column width of 7 with 1 decimal place
Then using the calculate function in ArcView all the created columns were populated with the data from their corresponding original fields. This step was done to give the proper spacing to each column. The .dbf file was saved and reopened in Excel and the original fields were deleted leaving only the 11 fields created during the ArcView step. The first row was then deleted so that there were no headings for each column. The file was then saved as a space delimited .prn file and reopened as text document in a notepad. Header information was added to the file (as shown in example of Anamolink file below), the file was saved, and the extension was changed to .GSD.

Below is a subset of the Anamolink.GSD file for use as a guide.

```
201440400     # USGS 01440400 BRODHEAD CREEK NEAR ANALOMINK, PA.
301440400     1993 1 1  355.0  267.0  223.0  204.0  398.0  340.0  277.0  240.0
301440400     1993 1 2  208.0  181.0  167.0  165.0  226.0  220.0  182.0  164.0
301440400     1993 1 3  152.0  137.0  123.0  117.0  110.0  100.0   98.0  150.0
301440400     1993 1 4  200.0  180.0  167.0  156.0  147.0  133.0  128.0
301440400     1993 2 1  110.0  100.0   96.0   88.0   84.0   80.0   76.0   74.0
301440400     1993 2 2   86.0   73.0   73.0   72.0   84.0   76.0   70.0   66.0
301440400     1993 2 3   62.0   58.0   56.0   54.0   52.0   52.0   50.0   70.0
301440400     1993 2 4   90.0   86.0   80.0   81.0
```

Appendix J: Instructions on Running the HYSEP Model

Separately, the Anamolink.GSD file and the Minisink.GSD file were run through HYSEP. This is done by:
1st- Selecting the “Specifying the Card, or WATSTORE input file” so the GSD file can be brought into the model
2nd -In the Output section, specifying the print file options needs to be set as starting in January, Units need to be set to cubic feet per second/ per mile squared, and the data output options need to be changed so that both Surface runoff and Base flow are set to yes
3rd- The Method needs to be set to Local Minimum
4th- Finally the file can be executed
This will produce to output files, an SRO file for Surface runoff and BSF for Base flow. These files are in the form of ASCII text, the same as the input data. These files were opened in a spreadsheet as tab delimited text and copy and pasted back into two columns next to total flow. The final table should contain four columns, one for date, one for Total Flow, one for Surface Flow, and one for Base Flow.

Appendix K: U.S. Geological Survey LULC Classification System for Level I. and II.

Excerpted from USGS data users guide, 2001

Table for U.S. Geological Survey Land Use and Land Cover Classification System for Use with Remote Sensor Data

LEVEL 1 LEVEL II

1 Urban or Built-up Land
- 11 Residential
- 12 Commercial and Services
- 13 Industrial
- 14 Transportation, Communications and Utilities
- 15 Industrial and Commercial Complexes
- 16 Mixed Urban or Built-up Land
- 17 Other Urban or Built-up Land

2 Agricultural Land
- 21 Cropland and Pasture
- 22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Areas
- 23 Confined Feeding Operations
- 24 Other Agricultural Land

3 Rangeland
- 31 Herbaceous Rangeland
- 32 Shrub and Brush Rangeland
- 33 Mixed Rangeland

4 Forest Land
- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Mixed Forest Land

5 Water
- 51 Streams and Canals
- 52 Lakes
- 53 Reservoirs
- 54 Bays and Estuaries

6 Wetland
- 61 Forested Wetland
- 62 Nonforested Wetland

7 Barren Land
- 71 Dry Salt Flats
- 72 Beaches
- 73 Sandy Areas Other than Beaches
- 74 Bare Exposed Rock
- 75 Strip Mines, Quarries, and Gravel Pit
- 76 Transitional Areas
- 77 Mixed Barren Land

8 Tundra
- 81 Shrub and Brush Tundra
- 82 Herbaceous Tundra
- 83 Bare Ground
- 84 Wet Tundra
- 85 Mixed Tundra

9 Perennial Snow or Ice
- 91 Perennial Snowfields
- 92 Glaciers

Appendix L: HRU Distribution Report

WATERSHED: Basin AREA: 744.608 [Km²] MULTIPLE HRUs LandUse/Soil OPTION
THRESHOLDS : 5 / 5 [%] ELABORATED SUBBASINS COMPOSITION: Number of HRUs: 98

HRU

SUBBASIN NUMBER: 1 AREA: 120.929 [016.24%]

LANDUSE: URBN AREA: [009.61%]
SOIL: PA024 AREA: [070.22%] 1
SOIL: PA026 AREA: [029.78%] 2
LANDUSE: FRSD AREA: [081.48%]
SOIL: PA030 AREA: [026.79%] 3
SOIL: PA024 AREA: [052.55%] 4
SOIL: PA026 AREA: [020.67%] 5
LANDUSE: FRSE AREA: [008.91%]
SOIL: PA030 AREA: [019.32%] 6
SOIL: PA024 AREA: [067.53%] 7
SOIL: PA026 AREA: [013.15%] 8

SUBBASIN NUMBER: 2 AREA: 54.3631 [007.30%]

LANDUSE: FRSD AREA: [100.00%]
SOIL: PA030 AREA: [020.11%] 9
SOIL: PA024 AREA: [042.52%] 10
SOIL: PA026 AREA: [029.18%] 11
SOIL: PA027 AREA: [008.19%] 12

SUBBASIN NUMBER: 3 AREA: 119.663 [016.07%]

LANDUSE: URBN AREA: [018.49%]
SOIL: PA030 AREA: [011.14%] 13
SOIL: PA024 AREA: [056.68%] 14
SOIL: PA031 AREA: [027.14%] 15
SOIL: PA027 AREA: [005.03%] 16
LANDUSE: FRSD AREA: [074.66%]
SOIL: PA030 AREA: [011.76%] 17
SOIL: PA024 AREA: [065.39%] 18
SOIL: PA026 AREA: [012.04%] 19
SOIL: PA027 AREA: [010.81%] 20
LANDUSE: AGRL AREA: [006.85%]
SOIL: PA024 AREA: [052.43%] 21
SOIL: PA026 AREA: [006.34%] 22
SOIL: PA027 AREA: [041.23%] 23

SUBBASIN NUMBER: 4 AREA: 129.658 [017.41%]

LANDUSE: URBN AREA: [016.89%]
SOIL: PA024 AREA: [012.94%] 24
SOIL: PA031 AREA: [020.03%] 25
SOIL: PA026 AREA: [008.00%] 26
SOIL: PA027 AREA: [046.14%] 27
SOIL: PA025 AREA: [012.90%] 28
LANDUSE: FRSD AREA: [065.32%]
SOIL: PA024 AREA: [039.47%] 29
SOIL: PA031 AREA: [014.59%] 30

SOIL: PA026 AREA: [028.79%] 31
SOIL: PA027 AREA: [006.19%] 32
SOIL: PA025 AREA: [010.95%] 33
LANDUSE: FRSE AREA: [006.83%]
SOIL: PA024 AREA: [024.31%] 34
SOIL: PA026 AREA: [005.84%] 35
SOIL: PA027 AREA: [048.00%] 36
SOIL: PA025 AREA: [021.84%] 37
LANDUSE: AGRL AREA: [010.95%]
SOIL: PA024 AREA: [050.82%] 38
SOIL: PA026 AREA: [010.56%] 39
SOIL: PA027 AREA: [032.07%] 40
SOIL: PA025 AREA: [006.54%] 41

SUBBASIN NUMBER: 5 AREA: 160.663 [021.58%]

LANDUSE: FRSD AREA: [049.02%]
SOIL: PA024 AREA: [019.66%] 42
SOIL: PA027 AREA: [015.99%] 43
SOIL: PA022 AREA: [015.72%] 44
SOIL: PA037 AREA: [015.68%] 45
SOIL: PA025 AREA: [032.95%] 46
LANDUSE: FRSE AREA: [011.10%]
SOIL: PA024 AREA: [027.87%] 47
SOIL: PA027 AREA: [020.46%] 48
SOIL: PA022 AREA: [017.70%] 49
SOIL: PA025 AREA: [023.52%] 50
SOIL: PA033 AREA: [010.44%] 51
LANDUSE: AGRL AREA: [039.88%]
SOIL: PA024 AREA: [022.85%] 52
SOIL: PA027 AREA: [036.04%] 53
SOIL: PA022 AREA: [008.75%] 54
SOIL: PA025 AREA: [027.13%] 55
SOIL: PA033 AREA: [005.23%] 56

SUBBASIN NUMBER: 6 AREA: 1.60254 [000.22%]

LANDUSE: URBN AREA: [069.40%]
SOIL: PA027 AREA: [072.57%] 57
SOIL: PA022 AREA: [027.43%] 58
LANDUSE: FRSD AREA: [030.60%]
SOIL: PA027 AREA: [036.88%] 59
SOIL: PA022 AREA: [063.12%] 60

SUBBASIN NUMBER: 7 AREA: 79.5754 [010.69%]

LANDUSE: URBN AREA: [015.53%]
SOIL: PA024 AREA: [012.56%] 61
SOIL: PA027 AREA: [047.03%] 62
SOIL: PA022 AREA: [033.40%] 63
SOIL: PA025 AREA: [007.01%] 64
LANDUSE: FRSD AREA: [078.26%]
SOIL: PA030 AREA: [024.62%] 65
SOIL: PA024 AREA: [021.10%] 66
SOIL: PA026 AREA: [025.18%] 67
SOIL: PA027 AREA: [019.87%] 68

SOIL: PA022 AREA: [009.23%] 69
LANDUSE: AGRL AREA: [006.21%]
SOIL: PA030 AREA: [007.42%] 70
SOIL: PA024 AREA: [007.54%] 71
SOIL: PA026 AREA: [017.51%] 72
SOIL: PA027 AREA: [022.77%] 73
SOIL: PA022 AREA: [044.77%] 74

SUBBASIN NUMBER: 8 AREA: 7.47012 [001.00%]

LANDUSE: URBN AREA: [021.90%]
SOIL: PA027 AREA: [007.54%] 75
SOIL: PA022 AREA: [092.46%] 76
LANDUSE: FRSD AREA: [067.60%]
SOIL: PA027 AREA: [028.67%] 77
SOIL: PA022 AREA: [071.33%] 78
LANDUSE: AGRL AREA: [010.50%]
SOIL: PA022 AREA: [100.00%] 79

SUBBASIN NUMBER: 9 AREA: 70.1113 [009.42%]

LANDUSE: URBN AREA: [010.23%]
SOIL: PA030 AREA: [030.73%] 80
SOIL: PA024 AREA: [013.35%] 81
SOIL: PA026 AREA: [032.89%] 82
SOIL: PA027 AREA: [012.03%] 83
SOIL: PA022 AREA: [011.00%] 84
LANDUSE: FRSD AREA: [077.67%]
SOIL: PA030 AREA: [022.61%] 85
SOIL: PA024 AREA: [015.65%] 86
SOIL: PA026 AREA: [031.98%] 87
SOIL: PA027 AREA: [012.18%] 88
SOIL: PA022 AREA: [017.58%] 89
LANDUSE: FRSE AREA: [006.03%]
SOIL: PA024 AREA: [011.87%] 90
SOIL: PA026 AREA: [036.34%] 91
SOIL: PA022 AREA: [051.79%] 92
LANDUSE: AGRL AREA: [006.07%]
SOIL: PA026 AREA: [005.86%] 93
SOIL: PA027 AREA: [034.78%] 94
SOIL: PA022 AREA: [059.36%] 95

SUBBASIN NUMBER: 10 AREA: 0.572271 [000.08%]

LANDUSE: URBN AREA: [026.57%]
SOIL: PA027 AREA: [100.00%] 96
LANDUSE: FRSD AREA: [064.62%]
SOIL: PA027 AREA: [100.00%] 97
LANDUSE: AGRL AREA: [008.81%]
SOIL: PA027 AREA: [100.00%] 98

Appendix M: Tables for Monthly Surface Flow Calibration Comparisons of Anamolink and Minisink Subbasins, All Months

Table 27: Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, All Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
1/1/93	80.19	25.18	24.40	22.84	20.96	27.52	29.08	30.98	28.78	29.70	23.90	18.32
2/1/93	9.07	40.47	38.93	35.81	32.10	45.05	48.00	51.41	14.70	16.93	26.65	37.31
3/1/93	144.73	140.09	135.38	125.92	114.58	154.15	163.45	174.51	93.11	94.80	103.87	122.45
4/1/93	405.47	155.32	149.08	137.05	123.41	175.02	188.95	206.57	123.41	123.41	123.40	123.42
5/1/93	17.40	0.12	0.08	0.04	0.01	0.47	0.98	1.93	0.01	0.01	0.01	0.01
6/1/93	6.03	15.38	13.63	10.50	7.42	21.43	26.16	32.70	7.41	7.41	7.41	7.42
7/1/93	1.85	4.07	3.52	2.54	1.58	5.97	7.47	9.51	1.58	1.58	1.58	1.58
8/1/93	2.05	5.91	5.32	4.26	3.24	7.93	9.50	11.70	3.23	3.23	3.23	3.24
9/1/93	6.40	98.57	93.52	83.93	73.32	114.54	126.14	140.89	73.30	73.31	73.32	73.32
10/1/93	18.43	64.67	61.17	54.54	47.20	75.98	84.20	94.84	47.20	47.19	47.20	47.21
11/1/93	86.42	117.25	114.30	108.55	101.92	126.43	132.83	140.85	101.92	101.92	101.92	101.92
12/1/93	138.42	89.86	87.11	81.75	75.53	98.52	104.63	112.32	75.53	75.53	75.53	75.53
1/1/94	21.55	275.78	272.44	265.60	257.07	285.44	291.63	298.79	193.81	202.27	237.75	275.23
2/1/94	75.01	213.50	208.07	197.38	184.87	230.21	241.64	255.64	143.30	165.67	191.50	169.37
3/1/94	290.58	176.23	170.30	158.61	144.91	195.67	207.88	222.89	145.28	134.12	144.91	145.30
4/1/94	273.94	26.98	24.94	21.20	17.27	33.84	39.17	46.52	17.27	17.27	17.27	17.27
5/1/94	27.53	35.86	33.58	29.27	24.56	43.29	48.76	55.94	24.55	24.55	24.55	24.56
6/1/94	28.49	163.79	157.38	144.91	130.66	183.91	198.06	215.80	130.62	130.63	130.65	130.66
7/1/94	13.85	46.69	44.60	40.66	36.39	53.58	58.77	65.80	36.38	36.38	36.38	36.39
8/1/94	84.96	219.53	213.85	202.74	189.80	237.20	249.66	265.44	189.76	189.77	189.78	189.80
9/1/94	96.37	171.79	168.02	160.64	152.05	183.20	191.06	200.59	152.03	152.03	152.04	152.04
10/1/94	44.98	1.45	1.17	0.72	0.36	2.53	3.47	4.91	0.35	0.36	0.36	0.35
11/1/94	82.75	90.28	86.84	80.18	72.56	101.04	108.54	117.80	72.56	72.56	72.56	72.56
12/1/94	129.94	35.32	33.16	29.07	24.56	42.32	47.40	53.98	24.56	24.57	24.56	24.56
1/1/95	86.08	44.82	42.57	38.28	33.49	51.98	57.16	63.89	33.49	33.49	33.49	33.49
2/1/95	6.13	22.75	21.48	18.99	16.13	26.62	29.25	32.55	22.79	21.63	17.76	17.46
3/1/95	84.89	146.64	143.44	137.01	129.24	156.17	162.49	170.08	118.65	118.88	124.80	132.81
4/1/95	10.68	24.63	22.97	19.86	16.47	30.93	34.84	39.93	16.47	16.47	16.47	16.48
5/1/95	10.08	7.38	6.44	4.82	3.30	10.74	13.56	17.72	3.29	3.29	3.30	3.30
6/1/95	6.39	9.97	9.07	7.41	5.66	12.95	15.22	18.29	5.66	5.65	5.66	5.66
7/1/95	0.33	12.27	10.76	8.12	5.59	17.57	21.83	27.82	5.59	5.59	5.59	5.60
8/1/95	0.52	0.01	0.00	0.00	0.00	0.06	0.21	0.56	0.00	0.00	0.00	0.00
9/1/95	1.57	28.61	26.52	22.67	18.58	35.67	41.06	48.17	18.57	18.57	18.58	18.58
10/1/95	91.31	348.94	341.16	325.87	307.95	372.74	389.01	408.96	307.94	307.95	307.95	307.96
11/1/95	176.77	126.68	122.88	115.47	106.83	138.36	146.45	156.49	106.08	107.97	107.33	106.37
12/1/95	12.42	7.28	6.71	5.65	4.46	9.14	10.51	12.26	1.20	1.57	3.35	5.58

Table 28: Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, All Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
1/1/93	467.13	103.94	100.77	94.39	86.68	113.35	119.52	126.91	119.13	122.45	99.05	71.58
2/1/93	63.14	150.45	144.66	133.08	119.31	167.63	178.78	191.88	54.85	63.11	99.11	138.64
3/1/93	792.67	524.50	506.53	470.55	427.48	578.44	614.24	657.03	344.22	350.13	388.87	454.69
4/1/93	1846.33	584.42	560.76	515.24	463.65	659.02	711.87	778.75	463.63	463.62	463.62	463.66
5/1/93	193.81	0.69	0.45	0.17	0.02	2.29	4.39	8.19	0.02	0.02	0.02	0.02
6/1/93	34.00	61.44	54.70	42.69	30.72	84.81	103.24	129.02	30.68	30.68	30.71	30.73
7/1/93	10.85	13.38	11.51	8.24	5.12	20.00	25.42	33.12	5.12	5.12	5.12	5.12
8/1/93	13.69	15.60	13.66	10.34	7.29	22.61	28.33	36.42	7.28	7.29	7.29	7.30
9/1/93	52.94	335.34	317.32	283.31	245.82	392.92	434.43	488.06	245.74	245.76	245.81	245.84
10/1/93	154.00	241.92	228.83	204.01	176.45	284.18	314.89	354.58	176.44	176.44	176.46	176.47
11/1/93	370.11	442.79	431.56	409.67	384.39	477.73	502.11	532.58	384.37	384.38	384.39	384.39
12/1/93	762.71	337.71	327.15	306.67	282.93	370.86	394.23	423.69	282.93	282.93	282.93	282.92
1/1/94	114.70	1043.32	1030.17	1003.15	969.49	1081.45	1105.84	1134.09	731.40	763.16	896.68	1038.03
2/1/94	327.33	800.23	778.89	736.99	687.94	865.68	910.42	965.28	525.32	606.92	705.64	631.89
3/1/94	1349.23	668.41	646.45	603.28	552.86	737.08	783.15	840.02	538.14	496.35	543.67	557.16
4/1/94	1084.17	100.10	92.44	78.43	63.80	126.14	146.54	174.75	63.79	63.78	63.80	63.80
5/1/94	191.19	134.95	126.32	110.06	92.31	163.06	183.81	210.96	92.28	92.28	92.30	92.32
6/1/94	147.25	636.07	612.05	565.24	511.67	711.33	763.78	829.48	511.74	511.73	511.66	511.66
7/1/94	83.44	156.18	148.50	134.14	118.66	181.53	200.83	226.49	118.67	118.66	118.65	118.66
8/1/94	298.16	776.45	755.05	712.94	664.08	843.49	890.55	949.60	664.28	664.25	664.09	664.06
9/1/94	254.64	651.46	637.38	609.41	576.57	693.69	722.40	755.91	576.52	576.52	576.55	576.56
10/1/94	123.58	6.20	5.09	3.29	1.78	10.45	14.21	19.76	1.77	1.77	1.78	1.78
11/1/94	292.84	338.80	325.74	300.50	271.64	379.62	408.23	443.72	271.61	271.62	271.63	271.64
12/1/94	531.94	132.42	124.30	108.94	92.09	158.75	177.92	202.81	92.08	92.10	92.10	92.09
1/1/95	439.68	168.56	160.09	144.00	126.06	195.57	215.18	240.69	126.08	126.07	126.07	126.07
2/1/95	51.69	83.76	79.05	69.83	59.27	98.43	108.59	121.34	84.46	80.08	65.47	63.94
3/1/95	435.23	551.29	538.97	514.25	484.50	588.09	612.57	642.12	442.46	444.34	467.53	497.84
4/1/95	64.73	94.07	87.87	76.21	63.56	115.12	129.50	148.98	63.74	63.69	63.56	63.57
5/1/95	38.95	28.80	25.19	18.95	13.06	41.89	52.85	68.87	13.04	13.04	13.06	13.07
6/1/95	31.02	41.31	37.85	31.45	24.65	52.75	61.40	72.96	24.64	24.63	24.65	24.66
7/1/95	65.21	42.92	37.62	28.37	19.66	61.90	77.37	99.67	19.63	19.63	19.66	19.66
8/1/95	8.67	0.01	0.00	0.00	0.00	0.10	0.34	1.04	0.00	0.00	0.00	0.00
9/1/95	11.37	86.81	79.90	67.34	54.22	110.40	128.68	153.49	54.18	54.19	54.22	54.23
10/1/95	395.89	1297.06	1267.84	1210.30	1142.47	1386.58	1447.71	1522.20	1142.39	1142.40	1142.46	1142.48
11/1/95	767.97	483.78	469.19	440.63	408.24	528.68	559.75	598.22	405.45	412.79	410.23	406.39
12/1/95	128.94	25.84	23.76	19.89	15.67	32.72	37.88	44.61	4.45	5.69	11.81	19.62

Appendix N: Tables for Monthly Surface Flow Calibration Comparisons of Anamolink and Minisink Subbasins, Non-Winter Months

Table 29: Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, Non-Winter Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
5/1/93	17.40	0.12	0.08	0.04	0.01	0.47	0.98	1.93	0.01	0.01	0.01	0.01
6/1/93	6.03	15.38	13.63	10.50	7.42	21.43	26.16	32.70	7.41	7.41	7.41	7.42
7/1/93	1.85	4.07	3.52	2.54	1.58	5.97	7.47	9.51	1.58	1.58	1.58	1.58
8/1/93	2.05	5.91	5.32	4.26	3.24	7.93	9.50	11.70	3.23	3.23	3.23	3.24
9/1/93	6.40	98.57	93.52	83.93	73.32	114.54	126.14	140.89	73.30	73.31	73.32	73.32
10/1/93	18.43	64.67	61.17	54.54	47.20	75.98	84.20	94.84	47.20	47.19	47.20	47.21
11/1/93	86.42	117.25	114.30	108.55	101.92	126.43	132.83	140.85	101.92	101.92	101.92	101.92
5/1/94	27.53	35.86	33.58	29.27	24.56	43.29	48.76	55.94	24.55	24.55	24.55	24.56
6/1/94	28.49	163.79	157.38	144.91	130.66	183.91	198.06	215.80	130.62	130.63	130.65	130.66
7/1/94	13.85	46.69	44.60	40.66	36.39	53.58	58.77	65.80	36.38	36.38	36.38	36.39
8/1/94	84.96	219.53	213.85	202.74	189.80	237.20	249.66	265.44	189.76	189.77	189.78	189.80
9/1/94	96.37	171.79	168.02	160.64	152.05	183.20	191.06	200.59	152.03	152.03	152.04	152.04
10/1/94	44.98	1.45	1.17	0.72	0.36	2.53	3.47	4.91	0.35	0.36	0.36	0.35
11/1/94	82.75	90.28	86.84	80.18	72.56	101.04	108.54	117.80	72.56	72.56	72.56	72.56
5/1/95	10.08	7.38	6.44	4.82	3.30	10.74	13.56	17.72	3.29	3.29	3.30	3.30
6/1/95	6.39	9.97	9.07	7.41	5.66	12.95	15.22	18.29	5.66	5.65	5.66	5.66
7/1/95	0.33	12.27	10.76	8.12	5.59	17.57	21.83	27.82	5.59	5.59	5.59	5.60
8/1/95	0.52	0.01	0.00	0.00	0.00	0.06	0.21	0.56	0.00	0.00	0.00	0.00
9/1/95	1.57	28.61	26.52	22.67	18.58	35.67	41.06	48.17	18.57	18.57	18.58	18.58
10/1/95	91.31	348.94	341.16	325.87	307.95	372.74	389.01	408.96	307.94	307.95	307.95	307.96
11/1/95	176.77	126.68	122.88	115.47	106.83	138.36	146.45	156.49	106.08	107.97	107.33	106.37

Table 30: Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, Non-Winter Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
5/1/93	193.81	0.69	0.45	0.17	0.02	2.29	4.39	8.19	0.02	0.02	0.02	0.02
6/1/93	34.00	61.44	54.70	42.69	30.72	84.81	103.24	129.02	30.68	30.68	30.71	30.73
7/1/93	10.85	13.38	11.51	8.24	5.12	20.00	25.42	33.12	5.12	5.12	5.12	5.12
8/1/93	13.69	15.60	13.66	10.34	7.29	22.61	28.33	36.42	7.28	7.29	7.29	7.30
9/1/93	52.94	335.34	317.32	283.31	245.82	392.92	434.43	488.06	245.74	245.76	245.81	245.84
10/1/93	154.00	241.92	228.83	204.01	176.45	284.18	314.89	354.58	176.44	176.44	176.46	176.47
11/1/93	370.11	442.79	431.56	409.67	384.39	477.73	502.11	532.58	384.37	384.38	384.39	384.39
5/1/94	191.19	134.95	126.32	110.06	92.31	163.06	183.81	210.96	92.28	92.28	92.30	92.32
6/1/94	147.25	636.07	612.05	565.24	511.67	711.33	763.78	829.48	511.74	511.73	511.66	511.66
7/1/94	83.44	156.18	148.50	134.14	118.66	181.53	200.83	226.49	118.67	118.66	118.65	118.66
8/1/94	298.16	776.45	755.05	712.94	664.08	843.49	890.55	949.60	664.28	664.25	664.09	664.06
9/1/94	254.64	651.46	637.38	609.41	576.57	693.69	722.40	755.91	576.52	576.52	576.55	576.56
10/1/94	123.58	6.20	5.09	3.29	1.78	10.45	14.21	19.76	1.77	1.77	1.78	1.78
11/1/94	292.84	338.80	325.74	300.50	271.64	379.62	408.23	443.72	271.61	271.62	271.63	271.64
5/1/95	38.95	28.80	25.19	18.95	13.06	41.89	52.85	68.87	13.04	13.04	13.06	13.07
6/1/95	31.02	41.31	37.85	31.45	24.65	52.75	61.40	72.96	24.64	24.63	24.65	24.66
7/1/95	65.21	42.92	37.62	28.37	19.66	61.90	77.37	99.67	19.63	19.63	19.66	19.66
8/1/95	8.67	0.01	0.00	0.00	0.00	0.10	0.34	1.04	0.00	0.00	0.00	0.00
9/1/95	11.37	86.81	79.90	67.34	54.22	110.40	128.68	153.49	54.18	54.19	54.22	54.23
10/1/95	395.89	1297.06	1267.84	1210.30	1142.47	1386.58	1447.71	1522.20	1142.39	1142.40	1142.46	1142.48
11/1/95	767.97	483.78	469.19	440.63	408.24	528.68	559.75	598.22	405.45	412.79	410.23	406.39

Appendix O: Tables for Monthly Surface Flow Calibration Comparisons of Anamolink and Minisink Subbasins, Winter Months

Table 31: Monthly Surface Flow Calibration Comparisons of Anamolink Subbasin, Winter Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
1/1/93	80.19	25.18	24.40	22.84	20.96	27.52	29.08	30.98	28.78	29.70	23.90	18.32
2/1/93	9.07	40.47	38.93	35.81	32.10	45.05	48.00	51.41	14.70	16.93	26.65	37.31
3/1/93	144.73	140.09	135.38	125.92	114.58	154.15	163.45	174.51	93.11	94.80	103.87	122.45
4/1/93	405.47	155.32	149.08	137.05	123.41	175.02	188.95	206.57	123.41	123.41	123.40	123.42
12/1/93	138.42	89.86	87.11	81.75	75.53	98.52	104.63	112.32	75.53	75.53	75.53	75.53
1/1/94	21.55	275.78	272.44	265.60	257.07	285.44	291.63	298.79	193.81	202.27	237.75	275.23
2/1/94	75.01	213.50	208.07	197.38	184.87	230.21	241.64	255.64	143.30	165.67	191.50	169.37
3/1/94	290.58	176.23	170.30	158.61	144.91	195.67	207.88	222.89	145.28	134.12	144.91	145.30
4/1/94	273.94	26.98	24.94	21.20	17.27	33.84	39.17	46.52	17.27	17.27	17.27	17.27
12/1/94	129.94	35.32	33.16	29.07	24.56	42.32	47.40	53.98	24.56	24.57	24.56	24.56
1/1/95	86.08	44.82	42.57	38.28	33.49	51.98	57.16	63.89	33.49	33.49	33.49	33.49
2/1/95	6.13	22.75	21.48	18.99	16.13	26.62	29.25	32.55	22.79	21.63	17.76	17.46
3/1/95	84.89	146.64	143.44	137.01	129.24	156.17	162.49	170.08	118.65	118.88	124.80	132.81
4/1/95	10.68	24.63	22.97	19.86	16.47	30.93	34.84	39.93	16.47	16.47	16.47	16.48
12/1/95	12.42	7.28	6.71	5.65	4.46	9.14	10.51	12.26	1.20	1.57	3.35	5.58

Table 32: Monthly Surface Flow Calibration Comparisons of Minisink Subbasin, Winter Months

Date	Observed Surface Flow	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Run11
1/1/93	467.13	103.94	100.77	94.39	86.68	113.35	119.52	126.91	119.13	122.45	99.05	71.58
2/1/93	63.14	150.45	144.66	133.08	119.31	167.63	178.78	191.88	54.85	63.11	99.11	138.64
3/1/93	792.67	524.50	506.53	470.55	427.48	578.44	614.24	657.03	344.22	350.13	388.87	454.69
4/1/93	1846.33	584.42	560.76	515.24	463.65	659.02	711.87	778.75	463.63	463.62	463.62	463.66
12/1/93	762.71	337.71	327.15	306.67	282.93	370.86	394.23	423.69	282.93	282.93	282.93	282.92
1/1/94	114.70	1043.32	1030.17	1003.15	969.49	1081.45	1105.84	1134.09	731.40	763.16	896.68	1038.03
2/1/94	327.33	800.23	778.89	736.99	687.94	865.68	910.42	965.28	525.32	606.92	705.64	631.89
3/1/94	1349.23	668.41	646.45	603.28	552.86	737.08	783.15	840.02	538.14	496.35	543.67	557.16
4/1/94	1084.17	100.10	92.44	78.43	63.80	126.14	146.54	174.75	63.79	63.78	63.80	63.80
12/1/94	531.94	132.42	124.30	108.94	92.09	158.75	177.92	202.81	92.08	92.10	92.10	92.09
1/1/95	439.68	168.56	160.09	144.00	126.06	195.57	215.18	240.69	126.08	126.07	126.07	126.07
2/1/95	51.69	83.76	79.05	69.83	59.27	98.43	108.59	121.34	84.46	80.08	65.47	63.94
3/1/95	435.23	551.29	538.97	514.25	484.50	588.09	612.57	642.12	442.46	444.34	467.53	497.84
4/1/95	64.73	94.07	87.87	76.21	63.56	115.12	129.50	148.98	63.74	63.69	63.56	63.57
12/1/95	128.94	25.84	23.76	19.89	15.67	32.72	37.88	44.61	4.45	5.69	11.81	19.62

Appendix P: Tables for Monthly Base Flow Calibration Comparisons of Anamolink and Minisink Subbasins, All Months

Table 33: Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, All Months

Date	Observed Base Flow	Run12	Run13	Run14
1/1/93	110.61	91.74	91.85	94.07
2/1/93	65.89	78.22	75.12	75.40
3/1/93	68.33	59.76	57.66	55.64
4/1/93	135.33	70.99	62.46	57.94
5/1/93	89.53	71.16	63.82	57.54
6/1/93	29.07	52.64	43.33	36.99
7/1/93	15.29	41.47	31.68	25.36
8/1/93	8.43	34.84	27.22	22.37
9/1/93	10.76	39.07	33.19	27.76
10/1/93	29.51	68.06	63.32	60.67
11/1/93	50.11	87.07	87.48	88.09
12/1/93	73.87	99.21	90.41	91.51
1/1/94	61.35	103.61	100.04	102.02
2/1/94	77.45	95.78	96.71	90.22
3/1/94	109.68	113.75	109.34	103.92
4/1/94	128.33	124.01	114.76	115.72
5/1/94	99.83	116.55	105.19	98.75
6/1/94	37.98	92.69	81.49	75.41
7/1/94	37.09	89.75	78.25	72.45
8/1/94	36.94	87.89	78.26	71.95
9/1/94	44.80	105.14	98.36	95.13
10/1/94	57.89	111.76	112.63	108.52
11/1/94	68.22	113.04	109.63	105.91
12/1/94	87.16	119.52	118.23	110.58
1/1/95	109.38	126.47	118.80	121.51
2/1/95	79.66	121.15	119.76	114.80
3/1/95	105.63	89.68	86.28	82.25
4/1/95	79.99	95.91	86.40	78.28
5/1/95	66.01	73.51	65.31	59.97
6/1/95	41.25	55.27	44.98	38.71
7/1/95	29.84	44.53	34.85	28.28
8/1/95	17.08	40.89	32.96	27.82
9/1/95	8.94	37.47	31.36	27.45
10/1/95	31.89	57.63	55.99	53.66
11/1/95	75.67	93.82	89.81	89.28
12/1/95	75.87	107.89	104.19	102.71

Table 34: Monthly Base Flow Calibration Comparisons of Minisink Subbasin, All Months

Date	Observed Base Flow	Run12	Run13	Run14
1/1/93	281.94	324.36	307.63	290.93
2/1/93	255.61	278.73	254.14	246.72
3/1/93	279.27	209.10	195.79	196.10
4/1/93	290.00	251.77	213.85	198.65
5/1/93	265.13	255.42	214.04	190.99
6/1/93	143.53	183.62	146.32	124.31
7/1/93	101.06	141.23	104.79	84.13
8/1/93	73.53	119.47	90.54	73.89
9/1/93	80.80	121.96	100.93	86.80
10/1/93	173.88	236.55	216.17	206.78
11/1/93	249.92	314.26	295.28	288.14
12/1/93	268.39	351.98	314.25	308.78
1/1/94	263.36	371.72	354.94	343.08
2/1/94	299.92	330.27	332.39	309.99
3/1/94	316.45	406.50	392.86	356.39
4/1/94	328.00	477.56	435.13	401.36
5/1/94	307.13	433.26	378.98	359.79
6/1/94	195.22	326.30	285.15	258.76
7/1/94	171.94	328.37	281.87	254.92
8/1/94	147.84	309.53	273.70	251.72
9/1/94	168.39	367.75	339.03	319.29
10/1/94	216.16	390.78	385.57	364.68
11/1/94	256.19	408.55	393.33	382.26
12/1/94	310.00	430.67	416.73	396.15
1/1/95	318.39	453.54	435.10	426.52
2/1/95	294.42	440.87	433.43	417.33
3/1/95	311.29	308.95	304.93	289.82
4/1/95	310.87	347.65	310.56	290.41
5/1/95	255.28	266.47	229.74	208.29
6/1/95	189.21	192.65	154.42	131.05
7/1/95	153.50	152.05	117.74	96.41
8/1/95	95.91	140.75	110.10	92.68
9/1/95	67.83	130.52	107.83	92.99
10/1/95	124.86	190.83	178.57	169.71
11/1/95	170.00	328.04	314.22	303.67
12/1/95	197.42	381.97	370.91	359.84

Appendix Q: Tables for Monthly Base Flow Calibration Comparisons of Anamolink and Minisink Subbasins, Non-Winter Months

Table 35: Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, Non-Winter Months

Date	Observed Base Flow	Run12	Run13	Run14
5/1/93	89.53	71.16	63.82	57.54
6/1/93	29.07	52.64	43.33	36.99
7/1/93	15.29	41.47	31.68	25.36
8/1/93	8.43	34.84	27.22	22.37
9/1/93	10.76	39.07	33.19	27.76
10/1/93	29.51	68.06	63.32	60.67
11/1/93	50.11	87.07	87.48	88.09
5/1/94	99.83	116.55	105.19	98.75
6/1/94	37.98	92.69	81.49	75.41
7/1/94	37.09	89.75	78.25	72.45
8/1/94	36.94	87.89	78.26	71.95
9/1/94	44.80	105.14	98.36	95.13
10/1/94	57.89	111.76	112.63	108.52
11/1/94	68.22	113.04	109.63	105.91
5/1/95	66.01	73.51	65.31	59.97
6/1/95	41.25	55.27	44.98	38.71
7/1/95	29.84	44.53	34.85	28.28
8/1/95	17.08	40.89	32.96	27.82
9/1/95	8.94	37.47	31.36	27.45
10/1/95	31.89	57.63	55.99	53.66
11/1/95	75.67	93.82	89.81	89.28

Table 36: Monthly Base Flow Calibration Comparisons of Minisink Subbasin, Non-Winter Months

Date	Observed Base Flow	Run12	Run13	Run14
5/1/93	265.13	255.42	214.04	190.99
6/1/93	143.53	183.62	146.32	124.31
7/1/93	101.06	141.23	104.79	84.13
8/1/93	73.53	119.47	90.54	73.89
9/1/93	80.80	121.96	100.93	86.80
10/1/93	173.88	236.55	216.17	206.78
11/1/93	249.92	314.26	295.28	288.14
5/1/94	307.13	433.26	378.98	359.79
6/1/94	195.22	326.30	285.15	258.76
7/1/94	171.94	328.37	281.87	254.92
8/1/94	147.84	309.53	273.70	251.72
9/1/94	168.39	367.75	339.03	319.29
10/1/94	216.16	390.78	385.57	364.68
11/1/94	256.19	408.55	393.33	382.26
5/1/95	255.28	266.47	229.74	208.29
6/1/95	189.21	192.65	154.42	131.05
7/1/95	153.50	152.05	117.74	96.41
8/1/95	95.91	140.75	110.10	92.68
9/1/95	67.83	130.52	107.83	92.99
10/1/95	124.86	190.83	178.57	169.71
11/1/95	170.00	328.04	314.22	303.67

Appendix R: Table for Monthly Base Flow Calibration Comparisons of Anamolink and Minisink Subbasins, Winter Months

Table 37: Monthly Base Flow Calibration Comparisons of Anamolink Subbasin, Winter Months

Date	Observed Base Flow	Run12	Run13	Run14
1/1/93	110.61	91.74	91.85	94.07
2/1/93	65.89	78.22	75.12	75.40
3/1/93	68.33	59.76	57.66	55.64
4/1/93	135.33	70.99	62.46	57.94
12/1/93	73.87	99.21	90.41	91.51
1/1/94	61.35	103.61	100.04	102.02
2/1/94	77.45	95.78	96.71	90.22
3/1/94	109.68	113.75	109.34	103.92
4/1/94	128.33	124.01	114.76	115.72
12/1/94	87.16	119.52	118.23	110.58
1/1/95	109.38	126.47	118.80	121.51
2/1/95	79.66	121.15	119.76	114.80
3/1/95	105.63	89.68	86.28	82.25
4/1/95	79.99	95.91	86.40	78.28
12/1/95	75.87	107.89	104.19	102.71

Table 38: Monthly Base Flow Calibration Comparisons of Minisink Subbasin, Winter Months

Date	Observed Base Flow	Run12	Run13	Run14
1/1/93	281.94	324.36	307.63	290.93
2/1/93	255.61	278.73	254.14	246.72
3/1/93	279.27	209.10	195.79	196.10
4/1/93	290.00	251.77	213.85	198.65
12/1/93	268.39	351.98	314.25	308.78
1/1/94	263.36	371.72	354.94	343.08
2/1/94	299.92	330.27	332.39	309.99
3/1/94	316.45	406.50	392.86	356.39
4/1/94	328.00	477.56	435.13	401.36
12/1/94	310.00	430.67	416.73	396.15
1/1/95	318.39	453.54	435.10	426.52
2/1/95	294.42	440.87	433.43	417.33
3/1/95	311.29	308.95	304.93	289.82
4/1/95	310.87	347.65	310.56	290.41
12/1/95	197.42	381.97	370.91	359.84

Appendix S: Annual Validation Comparisons for Anamolink and Minisink Subbasins, Total Flow

Table 39: Annual Validation Comparison for Anamolink Subbasin, Total Flow

Year	USGS Total Flow	Validation	Residuals	% Difference
1996	228.86	194.24	34.61	15.12
1997	94.63	132.09	37.45	39.58
1998	132.26	135.55	3.29	2.49
1999	105.93	118.33	12.40	11.70
AVG	140.42	145.05	21.94	15.62

Table 40: Annual Validation Comparison for Minisink Subbasin, Total Flow

Year	USGS Total Flow	Validation	Residuals	% Difference
1996	973.38	712.13	261.26	26.84
1997	394.32	478.27	83.96	21.29
1998	548.04	497.58	50.45	9.21
1999	403.27	436.50	33.23	8.24
AVG	579.75	531.12	107.22	18.49

Appendix T: Annual Validation Comparisons for Anamolink and Minisink Subbasins, Surface Flow

Table 41: Annual Validation Comparison for Anamolink Subbasin, Surface Flow

Year	HYSEP Surface Flow	Validation	Residuals	% Difference
1996	152.50	105.86	46.64	30.58
1997	27.75	35.91	8.16	29.42
1998	60.94	52.14	8.80	14.44
1999	54.33	65.65	11.33	20.85
AVG	73.88	64.89	18.73	25.36

Table 42: Annual Validation Comparison for Minisink Subbasin, Surface Flow

Year	HYSEP Surface Flow	Validation	Residuals	% Difference
1996	739.44	391.07	348.37	47.11
1997	194.07	129.07	64.99	33.49
1998	350.46	193.47	156.99	44.79
1999	244.99	242.40	2.59	1.06
AVG	382.24	239.01	143.23	37.47

Appendix U: Annual Validation Comparisons for Anamolink and Minisink Subbasins, Surface Flow

Table 43: Annual Validation Comparison for Anamolink Subbasin, Base Flow

Year	HYSEP Base Flow	Validation	Residuals	% Difference
1996	76.35	83.23	6.88	9.01
1997	66.89	92.59	25.70	38.43
1998	71.32	79.43	8.11	11.37
1999	51.60	49.41	2.20	4.26
AVG	66.54	76.16	10.72	16.11

Table 44: Annual Validation Comparison for Minisink Subbasin, Base Flow

Year	HYSEP Base Flow	Validation	Residuals	% Difference
1996	233.94	284.78	50.84	21.73
1997	200.25	325.96	125.71	62.78
1998	197.58	277.77	80.19	40.59
1999	158.28	171.53	13.25	8.37
AVG	197.51	265.01	67.50	34.17

Appendix V: Validation Tables of Comparisons for Total Flow of Anamolink and Minisink Subbasins, All Months

Table 45: Monthly Validation Comparisons for Total Flow of Anamolink Subbasin, All Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
Jan-96	559.19	262.41	296.78	53.07
Feb-96	241.10	121.77	119.33	49.49
Mar-96	197.81	145.52	52.29	26.44
Apr-96	341.63	209.25	132.38	38.75
May-96	244.42	132.00	112.42	46.00
Jun-96	76.23	94.95	18.71	24.55
Jul-96	127.68	248.69	121.02	94.78
Aug-96	44.74	108.27	63.53	141.99
Sep-96	31.33	200.37	169.03	539.47
Oct-96	137.52	286.30	148.78	108.19
Nov-96	236.93	285.56	48.63	20.52
Dec-96	507.68	338.64	169.04	33.30
Jan-97	131.42	171.30	39.88	30.35
Feb-97	151.79	194.03	42.24	27.83
Mar-97	213.58	180.08	33.50	15.68
Apr-97	192.20	167.80	24.40	12.69
May-97	95.65	121.37	25.72	26.89
Jun-97	57.20	104.13	46.93	82.04
Jul-97	19.48	86.66	67.17	344.77
Aug-97	20.31	135.05	114.74	564.86
Sep-97	53.83	208.88	155.04	288.01
Oct-97	18.94	106.15	87.22	460.60
Nov-97	85.97	108.69	22.72	26.43
Dec-97	95.23	151.11	55.88	58.68
Jan-98	256.19	184.42	71.78	28.02
Feb-98	261.39	215.93	45.46	17.39
Mar-98	349.74	173.81	175.93	50.30
Apr-98	242.17	171.59	70.58	29.15
May-98	244.23	170.26	73.97	30.29
Jun-98	116.17	162.12	45.96	39.56
Jul-98	33.84	95.41	61.57	181.95
Aug-98	13.77	111.65	97.87	710.54
Sep-98	10.81	118.51	107.70	995.97
Oct-98	18.48	136.00	117.52	636.01
Nov-98	20.47	125.50	105.03	513.19
Dec-98	19.84	97.49	77.65	391.41
Jan-99	189.32	203.63	14.31	7.56
Feb-99	207.00	149.61	57.39	27.73
Mar-99	239.97	207.34	32.63	13.60
Apr-99	124.53	106.13	18.40	14.77
May-99	83.77	96.24	12.47	14.88
Jun-99	34.17	60.45	26.28	76.93
Jul-99	10.55	45.70	35.14	333.06
Aug-99	7.91	41.92	34.01	429.97
Sep-99	107.42	268.53	161.10	149.97
Oct-99	114.40	68.13	46.27	40.45
AVG-96	228.86	202.81	121.00	98.05
AVG-97	94.63	144.60	59.62	161.57
AVG-98	132.26	146.89	87.58	301.98
AVG-99	111.90	124.77	51.57	150.03

Table 46: Monthly Validation Comparisons for Total Flow of Minisink Subbasin, All Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
Jan-96	2051.29	990.27	1061.02	51.72
Feb-96	907.28	461.39	445.89	49.15
Mar-96	816.94	538.58	278.35	34.07
Apr-96	1350.10	781.23	568.87	42.14
May-96	993.06	487.06	506.00	50.95
Jun-96	319.20	342.63	23.43	7.34
Jul-96	665.68	925.49	259.82	39.03
Aug-96	236.39	371.38	134.99	57.11
Sep-96	171.90	718.77	546.87	318.13
Oct-96	845.58	1050.05	204.47	24.18
Nov-96	1002.17	1053.37	51.20	5.11
Dec-96	2321.03	1301.19	1019.84	43.94
Jan-97	533.58	631.00	97.42	18.26
Feb-97	649.43	721.21	71.78	11.05
Mar-97	794.03	671.02	123.01	15.49
Apr-97	666.20	611.56	54.64	8.20
May-97	412.68	452.21	39.53	9.58
Jun-97	266.90	381.43	114.53	42.91
Jul-97	118.32	315.08	196.75	166.29
Aug-97	137.23	478.43	341.20	248.64
Sep-97	326.07	745.31	419.24	128.57
Oct-97	110.26	368.53	258.27	234.25
Nov-97	322.53	398.65	76.12	23.60
Dec-97	394.58	555.58	161.00	40.80
Jan-98	1062.00	680.91	381.09	35.88
Feb-98	1093.50	810.07	283.43	25.92
Mar-98	1240.00	653.06	586.94	47.33
Apr-98	888.60	645.30	243.30	27.38
May-98	1098.61	633.63	464.98	42.32
Jun-98	532.67	598.33	65.66	12.33
Jul-98	174.10	347.77	173.67	99.76
Aug-98	90.42	403.48	313.06	346.23
Sep-98	81.77	424.72	342.95	419.42
Oct-98	125.68	516.10	390.42	310.65
Nov-98	96.03	453.30	357.26	372.02
Dec-98	93.06	339.40	246.33	264.69
Jan-99	760.32	777.00	16.68	2.19
Feb-99	757.07	560.68	196.39	25.94
Mar-99	793.48	782.91	10.57	1.33
Apr-99	448.10	387.63	60.47	13.49
May-99	316.77	354.40	37.63	11.88
Jun-99	142.13	215.63	73.50	51.71
Jul-99	58.13	151.57	93.44	160.74
Aug-99	57.19	151.58	94.38	165.03
Sep-99	486.27	976.10	489.83	100.73
Oct-99	378.65	257.38	121.27	32.03
AVG-96	973.38	751.78	425.06	60.24
AVG-97	394.32	527.50	162.79	78.97
AVG-98	548.04	542.17	320.76	167.00
AVG-99	419.81	461.49	144.05	82.98

Appendix W: Validation Tables of Comparisons for Total Flow of Anamolink and Minisink Subbasins, Non-Winter Months

Table 47: Monthly Validation Comparisons for Total Flow of Anamolink Subbasin, Non-Winter Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
May-96	244.42	132.00	112.42	46.00
Jun-96	76.23	94.95	18.71	24.55
Jul-96	127.68	248.69	121.02	94.78
Aug-96	44.74	108.27	63.53	141.99
Sep-96	31.33	200.37	169.03	539.47
Oct-96	137.52	286.30	148.78	108.19
Nov-96	236.93	285.56	48.63	20.52
May-97	95.65	121.37	25.72	26.89
Jun-97	57.20	104.13	46.93	82.04
Jul-97	19.48	86.66	67.17	344.77
Aug-97	20.31	135.05	114.74	564.86
Sep-97	53.83	208.88	155.04	288.01
Oct-97	18.94	106.15	87.22	460.60
Nov-97	85.97	108.69	22.72	26.43
May-98	244.23	170.26	73.97	30.29
Jun-98	116.17	162.12	45.96	39.56
Jul-98	33.84	95.41	61.57	181.95
Aug-98	13.77	111.65	97.87	710.54
Sep-98	10.81	118.51	107.70	995.97
Oct-98	18.48	136.00	117.52	636.01
Nov-98	20.47	125.50	105.03	513.19
May-99	83.77	96.24	12.47	14.88
Jun-99	34.17	60.45	26.28	76.93
Jul-99	10.55	45.70	35.14	333.06
Aug-99	7.91	41.92	34.01	429.97
Sep-99	107.42	268.53	161.10	149.97
Oct-99	114.40	68.13	46.27	40.45
AVG-96	128.41	193.73	97.45	139.36
AVG-97	50.20	124.42	74.22	256.23
AVG-98	65.39	131.35	87.09	443.93
AVG-99	59.70	96.83	52.55	174.21

Table 48: Monthly Validation Comparisons for Total Flow of Minisink Subbasin, Non-Winter Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
May-96	993.06	487.06	506.00	50.95
Jun-96	319.20	342.63	23.43	7.34
Jul-96	665.68	925.49	259.82	39.03
Aug-96	236.39	371.38	134.99	57.11
Sep-96	171.90	718.77	546.87	318.13
Oct-96	845.58	1050.05	204.47	24.18
Nov-96	1002.17	1053.37	51.20	5.11
May-97	412.68	452.21	39.53	9.58
Jun-97	266.90	381.43	114.53	42.91
Jul-97	118.32	315.08	196.75	166.29
Aug-97	137.23	478.43	341.20	248.64
Sep-97	326.07	745.31	419.24	128.57
Oct-97	110.26	368.53	258.27	234.25
Nov-97	322.53	398.65	76.12	23.60
May-98	1098.61	633.63	464.98	42.32
Jun-98	532.67	598.33	65.66	12.33
Jul-98	174.10	347.77	173.67	99.76
Aug-98	90.42	403.48	313.06	346.23
Sep-98	81.77	424.72	342.95	419.42
Oct-98	125.68	516.10	390.42	310.65
Nov-98	96.03	453.30	357.26	372.02
May-99	316.77	354.40	37.63	11.88
Jun-99	142.13	215.63	73.50	51.71
Jul-99	58.13	151.57	93.44	160.74
Aug-99	57.19	151.58	94.38	165.03
Sep-99	486.27	976.10	489.83	100.73
Oct-99	378.65	257.38	121.27	32.03
AVG-96	604.85	706.96	246.68	71.69
AVG-97	242.00	448.52	206.52	121.98
AVG-98	314.18	482.47	301.14	228.96
AVG-99	239.86	351.11	151.68	87.02

Appendix X: Validation Tables of Comparisons for Total Flow of Anamolink and Minisink Subbasins,, Winter Months

Table 49: Monthly Validation Comparisons for Total Flow of Anamolink Subbasin, Winter Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
Jan-96	559.19	262.41	296.78	53.07
Feb-96	241.10	121.77	119.33	49.49
Mar-96	197.81	145.52	52.29	26.44
Apr-96	341.63	209.25	132.38	38.75
Dec-96	507.68	338.64	169.04	33.30
Jan-97	131.42	171.30	39.88	30.35
Feb-97	151.79	194.03	42.24	27.83
Mar-97	213.58	180.08	33.50	15.68
Apr-97	192.20	167.80	24.40	12.69
Dec-97	95.23	151.11	55.88	58.68
Jan-98	256.19	184.42	71.78	28.02
Feb-98	261.39	215.93	45.46	17.39
Mar-98	349.74	173.81	175.93	50.30
Apr-98	242.17	171.59	70.58	29.15
Dec-98	19.84	97.49	77.65	391.41
Jan-99	189.32	203.63	14.31	7.56
Feb-99	207.00	149.61	57.39	27.73
Mar-99	239.97	207.34	32.63	13.60
Apr-99	124.53	106.13	18.40	14.77
AVG-96	334.93	184.74	150.20	41.94
AVG-97	239.33	210.37	61.81	23.97
AVG-98	240.94	179.37	83.93	36.71
AVG-99	156.13	152.84	40.08	91.01

Table 50: Monthly Validation Comparisons for Total Flow of Minisink Subbasin, Winter Months

Date	USGS Gage Total_Flow	Validation Total Flow	Residuals	% Difference
Jan-96	2051.29	990.27	1061.02	51.72
Feb-96	907.28	461.39	445.89	49.15
Mar-96	816.94	538.58	278.35	34.07
Apr-96	1350.10	781.23	568.87	42.14
Dec-96	2321.03	1301.19	1019.84	43.94
Jan-97	533.58	631.00	97.42	18.26
Feb-97	649.43	721.21	71.78	11.05
Mar-97	794.03	671.02	123.01	15.49
Apr-97	666.20	611.56	54.64	8.20
Dec-97	394.58	555.58	161.00	40.80
Jan-98	1062.00	680.91	381.09	35.88
Feb-98	1093.50	810.07	283.43	25.92
Mar-98	1240.00	653.06	586.94	47.33
Apr-98	888.60	645.30	243.30	27.38
Dec-98	93.06	339.40	246.33	264.69
Jan-99	760.32	777.00	16.68	2.19
Feb-99	757.07	560.68	196.39	25.94
Mar-99	793.48	782.91	10.57	1.33
Apr-99	448.10	387.63	60.47	13.49
AVG-96	1281.40	692.87	588.53	44.27
AVG-97	992.85	787.20	273.34	19.39
AVG-98	935.74	668.98	331.15	35.46
AVG-99	570.41	569.52	106.09	61.53

Appendix Y: Validation Tables of Comparisons for Surface Flow of Anamolink and Minisink Subbasins, All Months

Table 51: Monthly Validation Comparisons for Surface Flow of Anamolink Subbasin, All Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
Jan-96	497.88	174.17	323.70	65.02
Feb-96	148.38	17.37	131.00	88.29
Mar-96	75.55	28.75	46.80	61.94
Apr-96	201.97	109.01	92.96	46.03
May-96	108.17	22.80	85.38	78.93
Jun-96	17.53	9.34	8.19	46.73
Jul-96	73.67	166.30	92.63	125.73
Aug-96	5.48	9.94	4.46	81.39
Sep-96	7.96	120.65	112.69	1415.62
Oct-96	107.89	174.79	66.90	62.01
Nov-96	175.93	148.37	27.57	15.67
Dec-96	409.61	185.90	223.71	54.61
Jan-97	25.40	3.98	21.42	84.33
Feb-97	52.91	32.10	20.80	39.32
Mar-97	77.84	34.51	43.33	55.66
Apr-97	66.87	37.61	29.26	43.75
May-97	9.77	2.51	7.26	74.28
Jun-97	13.94	5.03	8.90	63.87
Jul-97	2.51	3.96	1.45	57.88
Aug-97	6.15	70.35	64.20	1044.77
Sep-97	36.99	116.39	79.40	214.65
Oct-97	2.72	4.09	1.36	50.09
Nov-97	22.76	9.29	13.47	59.17
Dec-97	15.12	45.94	30.82	203.79
Jan-98	125.53	74.78	50.75	40.43
Feb-98	125.10	97.82	27.27	21.80
Mar-98	194.90	57.67	137.23	70.41
Apr-98	81.08	58.03	23.05	28.43
May-98	123.15	58.18	64.98	52.76
Jun-98	63.04	55.50	7.54	11.96
Jul-98	4.32	0.00	4.32	100.00
Aug-98	1.23	35.43	34.19	2774.10
Sep-98	0.96	32.94	31.98	3321.70
Oct-98	5.06	47.50	42.44	838.92
Nov-98	5.33	22.25	16.92	317.66
Dec-98	1.60	0.00	1.60	100.00
Jan-99	141.54	129.06	12.49	8.82
Feb-99	113.07	52.35	60.72	53.70
Mar-99	129.97	88.19	41.78	32.14
Apr-99	22.23	0.27	21.96	98.79
May-99	23.08	23.02	0.06	0.26
Jun-99	3.70	0.00	3.70	100.00
Jul-99	0.54	0.00	0.54	100.00
Aug-99	1.79	1.68	0.11	6.37
Sep-99	89.55	234.70	145.15	162.08
Oct-99	63.90	7.50	56.40	88.26
AVG-96	152.50	97.28	101.33	178.50
AVG-97	27.75	30.48	26.81	165.97
AVG-98	60.94	45.01	36.86	639.85
AVG-99	58.94	53.68	34.45	75.04

Table 52: Monthly Validation Comparisons for Surface Flow of Minisink Subbasin, All Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
Jan-96	1837.98	629.61	1208.37	65.74
Feb-96	634.86	65.67	569.20	89.66
Mar-96	511.77	111.25	400.52	78.26
Apr-96	1030.10	406.44	623.66	60.54
May-96	673.14	83.68	589.46	87.57
Jun-96	98.27	32.81	65.46	66.61
Jul-96	414.18	616.86	202.68	48.93
Aug-96	35.68	29.20	6.48	18.17
Sep-96	44.87	427.01	382.14	851.63
Oct-96	693.34	646.27	47.07	6.79
Nov-96	804.17	557.80	246.36	30.64
Dec-96	2094.90	692.71	1402.19	66.93
Jan-97	290.03	15.69	274.35	94.59
Feb-97	384.43	120.50	263.92	68.65
Mar-97	496.29	126.35	369.94	74.54
Apr-97	335.53	130.09	205.44	61.23
May-97	94.99	10.69	84.30	88.75
Jun-97	62.16	22.86	39.30	63.22
Jul-97	27.20	18.04	9.16	33.68
Aug-97	53.25	227.90	174.65	327.97
Sep-97	230.19	411.69	181.51	78.85
Oct-97	17.46	14.24	3.22	18.43
Nov-97	170.75	36.04	134.71	78.89
Dec-97	166.52	170.70	4.18	2.51
Jan-98	797.48	278.09	519.40	65.13
Feb-98	803.86	366.00	437.85	54.47
Mar-98	924.84	214.55	710.29	76.80
Apr-98	547.27	217.08	330.18	60.33
May-98	749.51	216.36	533.15	71.13
Jun-98	269.59	212.65	56.94	21.12
Jul-98	13.75	0.06	13.69	99.56
Aug-98	13.98	122.64	108.66	777.38
Sep-98	14.50	115.61	101.10	697.04
Oct-98	36.64	174.86	138.22	377.28
Nov-98	23.86	83.48	59.62	249.85
Dec-98	10.24	0.00	10.24	100.00
Jan-99	608.66	476.10	132.56	21.78
Feb-99	541.36	196.78	344.57	63.65
Mar-99	537.03	330.67	206.36	38.43
Apr-99	171.43	1.56	169.87	99.09
May-99	74.00	89.30	15.30	20.68
Jun-99	18.03	0.00	18.03	100.00
Jul-99	5.44	0.00	5.44	100.00
Aug-99	13.24	5.82	7.41	56.01
Sep-99	399.30	835.58	436.28	109.26
Oct-99	210.65	27.83	182.82	86.79
AVG-96	739.44	358.28	478.63	122.62
AVG-97	194.07	108.73	145.39	82.61
AVG-98	350.46	166.78	251.61	220.84
AVG-99	257.91	196.36	152.89	79.57

Appendix Z: Validation Tables of Comparisons for Surface Flow of Anamolink and Minisink Subbasins, Non-Winter Months

Table 53: Monthly Validation Comparisons for Surface Flow of Anamolink Subbasin, Non-Winter Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
May-96	108.17	22.80	85.38	78.93
Jun-96	17.53	9.34	8.19	46.73
Jul-96	73.67	166.30	92.63	125.73
Aug-96	5.48	9.94	4.46	81.39
Sep-96	7.96	120.65	112.69	1415.62
Oct-96	107.89	174.79	66.90	62.01
Nov-96	175.93	148.37	27.57	15.67
May-97	9.77	2.51	7.26	74.28
Jun-97	13.94	5.03	8.90	63.87
Jul-97	2.51	3.96	1.45	57.88
Aug-97	6.15	70.35	64.20	1044.77
Sep-97	36.99	116.39	79.40	214.65
Oct-97	2.72	4.09	1.36	50.09
Nov-97	22.76	9.29	13.47	59.17
May-98	123.15	58.18	64.98	52.76
Jun-98	63.04	55.50	7.54	11.96
Jul-98	4.32	0.00	4.32	100.00
Aug-98	1.23	35.43	34.19	2774.10
Sep-98	0.96	32.94	31.98	3321.70
Oct-98	5.06	47.50	42.44	838.92
Nov-98	5.33	22.25	16.92	317.66
May-99	23.08	23.02	0.06	0.26
Jun-99	3.70	0.00	3.70	100.00
Jul-99	0.54	0.00	0.54	100.00
Aug-99	1.79	1.68	0.11	6.37
Sep-99	89.55	234.70	145.15	162.08
Oct-99	63.90	7.50	56.40	88.26
AVG-96	70.95	93.17	56.83	260.87
AVG-97	13.55	30.23	25.15	223.53
AVG-98	29.01	35.97	28.91	1059.59
AVG-99	30.43	44.48	34.33	76.16

Table 54: Monthly Validation Comparisons for Surface Flow of Minisink Subbasin, Non-Winter Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
May-96	673.14	83.68	589.46	87.57
Jun-96	98.27	32.81	65.46	66.61
Jul-96	414.18	616.86	202.68	48.93
Aug-96	35.68	29.20	6.48	18.17
Sep-96	44.87	427.01	382.14	851.63
Oct-96	693.34	646.27	47.07	6.79
Nov-96	804.17	557.80	246.36	30.64
May-97	94.99	10.69	84.30	88.75
Jun-97	62.16	22.86	39.30	63.22
Jul-97	27.20	18.04	9.16	33.68
Aug-97	53.25	227.90	174.65	327.97
Sep-97	230.19	411.69	181.51	78.85
Oct-97	17.46	14.24	3.22	18.43
Nov-97	170.75	36.04	134.71	78.89
May-98	749.51	216.36	533.15	71.13
Jun-98	269.59	212.65	56.94	21.12
Jul-98	13.75	0.06	13.69	99.56
Aug-98	13.98	122.64	108.66	777.38
Sep-98	14.50	115.61	101.10	697.04
Oct-98	36.64	174.86	138.22	377.28
Nov-98	23.86	83.48	59.62	249.85
May-99	74.00	89.30	15.30	20.68
Jun-99	18.03	0.00	18.03	100.00
Jul-99	5.44	0.00	5.44	100.00
Aug-99	13.24	5.82	7.41	56.01
Sep-99	399.30	835.58	436.28	109.26
Oct-99	210.65	27.83	182.82	86.79
AVG-96	394.81	341.95	219.95	158.62
AVG-97	93.71	105.92	89.55	98.54
AVG-98	160.26	132.24	144.48	327.62
AVG-99	120.11	159.76	110.88	78.79

Appendix AA: Validation Tables of Comparisons for Surface Flow of Anamolink and Minisink Subbasins, Winter Months

Table 55: Monthly Validation Comparisons for Surface Flow of Anamolink Subbasin, Winter Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
Jan-96	497.88	174.17	323.70	65.02
Feb-96	148.38	17.37	131.00	88.29
Mar-96	75.55	28.75	46.80	61.94
Apr-96	201.97	109.01	92.96	46.03
Dec-96	409.61	185.90	223.71	54.61
Jan-97	25.40	3.98	21.42	84.33
Feb-97	52.91	32.10	20.80	39.32
Mar-97	77.84	34.51	43.33	55.66
Apr-97	66.87	37.61	29.26	43.75
Dec-97	15.12	45.94	30.82	203.79
Jan-98	125.53	74.78	50.75	40.43
Feb-98	125.10	97.82	27.27	21.80
Mar-98	194.90	57.67	137.23	70.41
Apr-98	81.08	58.03	23.05	28.43
Dec-98	1.60	0.00	1.60	100.00
Jan-99	141.54	129.06	12.49	8.82
Feb-99	113.07	52.35	60.72	53.70
Mar-99	129.97	88.19	41.78	32.14
Apr-99	22.23	0.27	21.96	98.79
AVG-96	230.94	82.33	148.62	65.32
AVG-97	126.52	58.82	67.70	55.54
AVG-98	108.35	66.85	53.82	72.97
AVG-99	81.68	53.97	27.71	58.69

Table 56: Monthly Validation Comparisons for Surface Flow of Minisink Subbasin, Winter Months

Date	HYSEP Surface Flow	Validation Surface Flow	Residuals	% Difference
Jan-96	1837.98	629.61	1208.37	65.74
Feb-96	634.86	65.67	569.20	89.66
Mar-96	511.77	111.25	400.52	78.26
Apr-96	1030.10	406.44	623.66	60.54
Dec-96	2094.90	692.71	1402.19	66.93
Jan-97	290.03	15.69	274.35	94.59
Feb-97	384.43	120.50	263.92	68.65
Mar-97	496.29	126.35	369.94	74.54
Apr-97	335.53	130.09	205.44	61.23
Dec-97	166.52	170.70	4.18	2.51
Jan-98	797.48	278.09	519.40	65.13
Feb-98	803.86	366.00	437.85	54.47
Mar-98	924.84	214.55	710.29	76.80
Apr-98	547.27	217.08	330.18	60.33
Dec-98	10.24	0.00	10.24	100.00
Jan-99	608.66	476.10	132.56	21.78
Feb-99	541.36	196.78	344.57	63.65
Mar-99	537.03	330.67	206.36	38.43
Apr-99	171.43	1.56	169.87	99.09
AVG-96	1003.68	303.24	700.44	73.55
AVG-97	720.24	217.07	503.17	73.19
AVG-98	647.99	249.29	400.38	51.85
AVG-99	373.74	201.02	172.72	64.59

Appendix AB: Validation Tables of Comparisons for Base Flow of Anamolink and Minisink Subbasins, All Months

Table 57: Monthly Validation Comparisons for Base Flow of Anamolink Subbasin, All Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
Jan-96	61.32	83.61	22.29	36.36
Feb-96	92.72	99.67	6.95	7.50
Mar-96	122.26	112.98	9.27	7.59
Apr-96	139.67	94.54	45.13	32.31
May-96	136.25	103.43	32.82	24.09
Jun-96	58.70	83.61	24.91	42.43
Jul-96	54.00	74.85	20.85	38.60
Aug-96	39.26	94.77	55.51	141.36
Sep-96	23.37	76.08	52.70	225.49
Oct-96	29.63	104.09	74.46	251.32
Nov-96	61.00	132.11	71.11	116.58
Dec-96	98.06	142.19	44.12	44.99
Jan-97	106.02	163.63	57.61	54.34
Feb-97	98.88	156.75	57.87	58.52
Mar-97	135.74	142.02	6.28	4.63
Apr-97	125.33	125.47	0.14	0.11
May-97	85.88	114.94	29.06	33.84
Jun-97	43.27	96.62	53.36	123.33
Jul-97	16.97	80.54	63.57	374.50
Aug-97	14.17	59.93	45.76	323.02
Sep-97	16.84	87.46	70.62	419.25
Oct-97	16.21	100.26	84.05	518.39
Nov-97	63.20	95.08	31.88	50.44
Dec-97	80.10	101.69	21.59	26.95
Jan-98	130.67	104.68	25.98	19.88
Feb-98	136.30	112.42	23.88	17.52
Mar-98	154.84	109.82	45.02	29.07
Apr-98	161.09	108.62	52.47	32.57
May-98	121.07	105.04	16.03	13.24
Jun-98	53.13	101.25	48.12	90.57
Jul-98	29.51	93.67	64.16	217.39
Aug-98	12.54	73.45	60.91	485.68
Sep-98	9.85	81.96	72.11	732.01
Oct-98	13.42	83.94	70.52	525.57
Nov-98	15.14	101.11	85.97	567.83
Dec-98	18.24	96.12	77.88	426.91
Jan-99	47.78	69.37	21.59	45.20
Feb-99	93.93	91.93	2.00	2.13
Mar-99	110.00	113.88	3.88	3.52
Apr-99	102.31	103.20	0.90	0.88
May-99	60.69	70.24	9.55	15.74
Jun-99	30.47	58.89	28.42	93.29
Jul-99	10.01	45.28	35.27	352.34
Aug-99	6.12	38.48	32.37	529.30
Sep-99	17.87	28.58	10.71	59.96
Oct-99	50.50	54.35	3.85	7.63
AVG-96	76.35	100.16	38.34	80.72
AVG-97	66.89	110.37	43.48	165.61
AVG-98	71.32	97.67	53.59	263.19
AVG-99	52.97	67.42	22.64	153.69

Table 58: Monthly Validation Comparisons for Base Flow of Minisink Subbasin, All Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
Jan-96	213.31	313.42	100.11	46.93
Feb-96	272.41	370.39	97.97	35.96
Mar-96	305.16	401.46	96.30	31.56
Apr-96	320.00	332.65	12.65	3.95
May-96	319.92	369.51	49.59	15.50
Jun-96	220.93	299.45	78.51	35.54
Jul-96	251.49	255.66	4.17	1.66
Aug-96	200.70	325.82	125.12	62.34
Sep-96	127.03	263.52	136.49	107.45
Oct-96	152.24	349.72	197.48	129.71
Nov-96	198.00	460.63	262.63	132.64
Dec-96	226.13	527.53	301.40	133.29
Jan-97	243.55	594.80	351.25	144.22
Feb-97	265.00	566.21	301.21	113.66
Mar-97	297.74	518.16	220.42	74.03
Apr-97	330.67	451.25	120.58	36.47
May-97	317.69	418.62	100.94	31.77
Jun-97	204.74	345.80	141.07	68.90
Jul-97	91.12	284.12	193.00	211.81
Aug-97	83.97	218.24	134.26	159.89
Sep-97	95.88	301.98	206.09	214.95
Oct-97	92.80	343.81	251.02	270.50
Nov-97	151.78	333.54	181.75	119.75
Dec-97	228.06	357.57	129.50	56.78
Jan-98	264.52	368.65	104.13	39.37
Feb-98	289.64	400.00	110.35	38.10
Mar-98	315.16	396.14	80.98	25.69
Apr-98	341.33	394.55	53.22	15.59
May-98	349.11	370.69	21.58	6.18
Jun-98	263.07	351.31	88.23	33.54
Jul-98	160.35	340.24	179.89	112.19
Aug-98	76.44	260.95	184.51	241.37
Sep-98	67.26	289.13	221.87	329.86
Oct-98	89.04	310.79	221.75	249.04
Nov-98	72.17	355.74	283.57	392.91
Dec-98	82.82	333.33	250.51	302.46
Jan-99	151.67	250.05	98.38	64.87
Feb-99	215.71	334.32	118.60	54.98
Mar-99	256.45	413.84	157.38	61.37
Apr-99	276.67	371.79	95.12	34.38
May-99	242.78	244.14	1.36	0.56
Jun-99	124.10	209.67	85.57	68.95
Jul-99	52.69	149.69	97.00	184.12
Aug-99	43.96	135.02	91.07	207.18
Sep-99	86.97	100.41	13.44	15.45
Oct-99	168.00	191.81	23.81	14.18
AVG-96	233.94	355.81	121.87	61.38
AVG-97	200.25	394.51	194.26	125.23
AVG-98	197.58	347.63	150.05	148.86
AVG-99	170.18	273.41	103.23	100.85

Appendix AC: Validation Tables of Comparisons for Base Flow of Anamolink and Minisink Subbasins, Non-Winter Months

Table 59: Monthly Validation Comparisons for Base Flow of Anamolink Subbasin, Non-Winter Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
May-96	136.25	103.43	32.82	24.09
Jun-96	58.70	83.61	24.91	42.43
Jul-96	54.00	74.85	20.85	38.60
Aug-96	39.26	94.77	55.51	141.36
Sep-96	23.37	76.08	52.70	225.49
Oct-96	29.63	104.09	74.46	251.32
Nov-96	61.00	132.11	71.11	116.58
May-97	85.88	114.94	29.06	33.84
Jun-97	43.27	96.62	53.36	123.33
Jul-97	16.97	80.54	63.57	374.50
Aug-97	14.17	59.93	45.76	323.02
Sep-97	16.84	87.46	70.62	419.25
Oct-97	16.21	100.26	84.05	518.39
Nov-97	63.20	95.08	31.88	50.44
May-98	121.07	105.04	16.03	13.24
Jun-98	53.13	101.25	48.12	90.57
Jul-98	29.51	93.67	64.16	217.39
Aug-98	12.54	73.45	60.91	485.68
Sep-98	9.85	81.96	72.11	732.01
Oct-98	13.42	83.94	70.52	525.57
Nov-98	15.14	101.11	85.97	567.83
May-99	60.69	70.24	9.55	15.74
Jun-99	30.47	58.89	28.42	93.29
Jul-99	10.01	45.28	35.27	352.34
Aug-99	6.12	38.48	32.37	529.30
Sep-99	17.87	28.58	10.71	59.96
Oct-99	50.50	54.35	3.85	7.63
AVG-96	57.46	95.56	47.48	119.98
AVG-97	36.65	90.69	54.04	263.25
AVG-98	36.38	91.49	59.69	376.04
AVG-99	29.28	49.31	20.03	176.38

Table 60: Monthly Validation Comparisons for Base Flow of Minisink Subbasin, Non-Winter Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
May-96	319.92	369.51	49.59	15.50
Jun-96	220.93	299.45	78.51	35.54
Jul-96	251.49	255.66	4.17	1.66
Aug-96	200.70	325.82	125.12	62.34
Sep-96	127.03	263.52	136.49	107.45
Oct-96	152.24	349.72	197.48	129.71
Nov-96	198.00	460.63	262.63	132.64
May-97	317.69	418.62	100.94	31.77
Jun-97	204.74	345.80	141.07	68.90
Jul-97	91.12	284.12	193.00	211.81
Aug-97	83.97	218.24	134.26	159.89
Sep-97	95.88	301.98	206.09	214.95
Oct-97	92.80	343.81	251.02	270.50
Nov-97	151.78	333.54	181.75	119.75
May-98	349.11	370.69	21.58	6.18
Jun-98	263.07	351.31	88.23	33.54
Jul-98	160.35	340.24	179.89	112.19
Aug-98	76.44	260.95	184.51	241.37
Sep-98	67.26	289.13	221.87	329.86
Oct-98	89.04	310.79	221.75	249.04
Nov-98	72.17	355.74	283.57	392.91
May-99	242.78	244.14	1.36	0.56
Jun-99	124.10	209.67	85.57	68.95
Jul-99	52.69	149.69	97.00	184.12
Aug-99	43.96	135.02	91.07	207.18
Sep-99	86.97	100.41	13.44	15.45
Oct-99	168.00	191.81	23.81	14.18
AVG-96	210.05	332.04	122.00	69.26
AVG-97	148.28	320.87	172.59	153.94
AVG-98	153.92	325.55	171.63	195.01
AVG-99	119.75	171.79	52.04	81.74

Appendix AD: Validation Tables of Comparisons for Base Flow of Anamolink and Minisink Subbasins, Winter Months

Table 61: Monthly Validation Comparisons for Base Flow of Anamolink Subbasin, Winter Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
Jan-96	61.32	83.61	22.29	36.36
Feb-96	92.72	99.67	6.95	7.50
Mar-96	122.26	112.98	9.27	7.59
Apr-96	139.67	94.54	45.13	32.31
Dec-96	98.06	142.19	44.12	44.99
Jan-97	106.02	163.63	57.61	54.34
Feb-97	98.88	156.75	57.87	58.52
Mar-97	135.74	142.02	6.28	4.63
Apr-97	125.33	125.47	0.14	0.11
Dec-97	80.10	101.69	21.59	26.95
Jan-98	130.67	104.68	25.98	19.88
Feb-98	136.30	112.42	23.88	17.52
Mar-98	154.84	109.82	45.02	29.07
Apr-98	161.09	108.62	52.47	32.57
Dec-98	18.24	96.12	77.88	426.91
Jan-99	47.78	69.37	21.59	45.20
Feb-99	93.93	91.93	2.00	2.13
Mar-99	110.00	113.88	3.88	3.52
Apr-99	102.31	103.20	0.90	0.88
AVG-96	103.99	97.70	20.91	20.94
AVG-97	112.81	146.01	33.20	32.52
AVG-98	132.60	107.45	33.79	25.20
AVG-99	74.45	94.90	21.25	95.73

Table 62: Monthly Validation Comparisons for Base Flow of Minisink Subbasin, Winter Months

Date	HYSEP Base Flow	Validation Base Flow	Residuals	% Difference
Jan-96	213.31	313.42	100.11	46.93
Feb-96	272.41	370.39	97.97	35.96
Mar-96	305.16	401.46	96.30	31.56
Apr-96	320.00	332.65	12.65	3.95
Dec-96	226.13	527.53	301.40	133.29
Jan-97	243.55	594.80	351.25	144.22
Feb-97	265.00	566.21	301.21	113.66
Mar-97	297.74	518.16	220.42	74.03
Apr-97	330.67	451.25	120.58	36.47
Dec-97	228.06	357.57	129.50	56.78
Jan-98	264.52	368.65	104.13	39.37
Feb-98	289.64	400.00	110.35	38.10
Mar-98	315.16	396.14	80.98	25.69
Apr-98	341.33	394.55	53.22	15.59
Dec-98	82.82	333.33	250.51	302.46
Jan-99	151.67	250.05	98.38	64.87
Feb-99	215.71	334.32	118.60	54.98
Mar-99	256.45	413.84	157.38	61.37
Apr-99	276.67	371.79	95.12	34.38
AVG-96	277.72	354.48	76.76	29.60
AVG-97	272.62	531.59	258.97	100.33
AVG-98	287.74	383.38	95.64	35.11
AVG-99	196.66	340.66	144.00	103.61