1997

Computer Modeling of the North Fork of the Kentucky River Using SWAT and BASINS

T. Bischoff
Kentucky Water Resources Research Institute

S. Yost
Kentucky Water Resources Research Institute

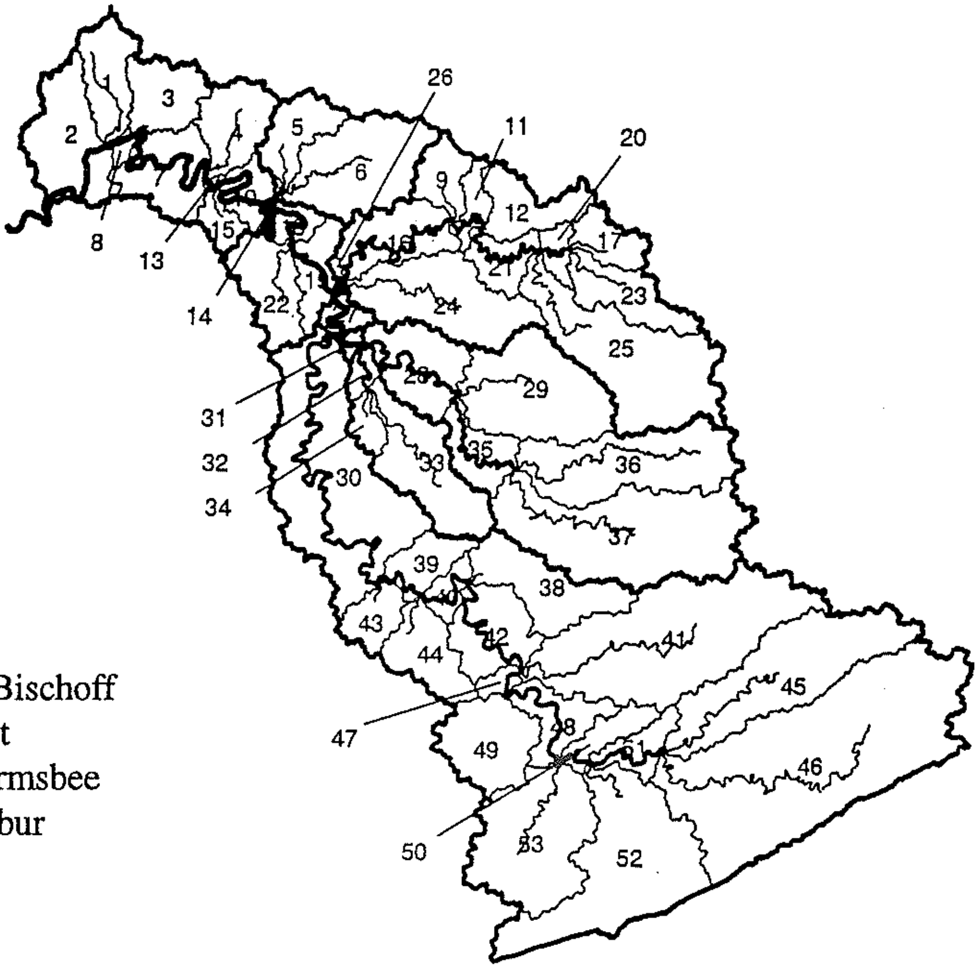
L. Ormsbee
Kentucky Water Resources Research Institute

T. Stumbur
Kentucky Water Resources Research Institute

Repository Citation

Bischoff, T.; Yost, S.; Ormsbee, L.; and Stumbur, T., "Computer Modeling of the North Fork of the Kentucky River Using SWAT and BASINS" (1997). *KWRRI Research Reports*. 254.
https://uknowledge.uky.edu/kwrri_reports/254

COMPUTER MODELING OF THE NORTH FORK OF THE KENTUCKY RIVER USING SWAT AND BASINS



Anthony Bischoff
Scott Yost
Lindell Ormsbee
Ted Stumbur

Prepared for:
The Kentucky Division of Water

Prepared By:
The University of Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky 40506

March 1997
KWRRI 9703

ABSTRACT

The purpose of this study was to investigate possible watershed models for use in the State of Kentucky's new watershed framework initiative and to apply the selected model(s) to the North Fork of the Kentucky River as part of an initial pilot project. As a result of an initial screening of over 30 models, two models were selected for a more detailed examination. These models included 1) the Soil and Water Assessment Tool (SWAT) and 2) the Better Assessment Science Integrating Point and Nonpoint Sources model (BASINS). Initial project objectives, which included both water quantity and water quality applications, were subsequently reduced to include water quantity simulations only. This modified project objective was necessitated as a result of several algorithmic problems that were identified with each model and that resulted in significant project delays as the research team was forced to interact with the initial model developers in an attempt to resolve these issues. A subsequent study will extended the hydrologic results generated in this study to include water quality impacts.

The results of this study indicate that the SWAT model can be calibrated to produce realistic results for the various watersheds modeled in this project. Subsequent validation runs revealed that the model is also able to predict the hydrologic response from the modeled watersheds with reasonable accuracy. Application of the BASINS model to the same watersheds was limited by the restriction of its application to 8-digit watersheds. Comparison of the BASINS results to the SWAT results revealed significant differences. Attempts to resolve these differences revealed the possibility of significant mass-balance problems with the BASINS model.

Although the BASINS modeling environment is superior to the SWAT environment, it would appear that the existing restriction of an 8-digit watershed application scale along with possible mass-balance inaccuracies clearly limit its general applicability in the development of detailed watershed management plans. It is our understanding that EPA is currently planning to update BASINS in order to expand its applicability to smaller basin areas as well as to improve its hydrologic modeling components. Should this be the case, it is possible that BASINS may surface as the model of choice. Until that time, however, it would appear that SWAT would be the preferable model of choice, at least for the development of detailed management plans.

Table of Contents

1.0 Introduction

As part of a national Environmental Protection Agency (EPA) focus, the Kentucky Division of Water (DOW) has embarked on the development of a comprehensive watershed framework for use in managing and preserving the water resources of Kentucky. Throughout this effort, computer modeling is expected to be a major tool in assessing the conditions of the watershed and evaluating the impacts of future changes in landuse and management practices. Thus, it is necessary to develop a watershed modeling protocol for the future modeling needs of the DOW. This project focuses on evaluation of potential models to be used in this process. The associated GIS work done in cooperation with this project can be found in detail in an accompanying report.

The purpose of this project is to evaluate different models and their applicability to Kentucky's future modeling needs. Several models were examined, including Agricultural Non-Point Source Pollution Model (AGNPS), Hydrological Simulation Program-FORTRAN (HSPF), Decision Support system for Evaluation River basin sTrategies (DESERT), Soil and Water Assessment Tool (SWAT), and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). Based on the need for a continuous-simulation watershed streamflow and water quality model that operates on a maximum of a daily time step, SWAT and BASINS were chosen as the focus of this project. SWAT is used to model the North Fork of the Kentucky River on United States Geological Survey (USGS) 11-digit and 14-digit watershed scales, and BASINS is used to model the same watershed on an 8-digit scale. A Geographic Information System (GIS) is used to gather and organize the associated geographic input data. GIS is a powerful tool for analyzing landuse, soil characteristics, subbasin elevations, watershed delineation, subbasin areas, routing structure, channel slope, land slope, channel length, and data station locations. For SWAT, GIS is used to collect much of the input data, and in BASINS, an ArcView environment is linked directly with the Nonpoint Source Model (NPSM) and provides all the input data. After the data was input into the model, a hydrologic calibration and sensitivity process was conducted. This project was limited to a streamflow analysis and general water balance using 1970 to 1975 historical climate and streamflow data. An analysis for the time period of 1980 to 1990 is completed for verification.

This study compares and contrasts the performances of SWAT for different watershed scales and SWAT versus BASINS. SWAT was run for Troublesome Creek, a subwatershed of the North Fork of the Kentucky River, at both the 14-digit and 11-digit scales. These two outputs were compared to each other and to the actual streamflow data on both a daily and monthly basis. The 11-digit SWAT evaluation of the North Fork was then compared to actual streamflow data and to an 8-digit evaluation of the North Fork using BASINS.

2.0 Model Evaluation

In searching the local libraries and the Internet for previous efforts in watershed modeling, many models were identified and subsequently evaluated as part of this study. In a 1989 study, El-Kadi (1989) developed a comprehensive evaluation of approximately 30 watershed models. Due to the overwhelming number of existing models and in order to limit the focus of this project, only five models were finally considered on the basis of the selected criteria. These included Agricultural Non-Point Source Model (AGNPS), Hydrological Simulation Program-FORTRAN (HSPF), Decision Support system for Evaluation River basin sTrategies (DESERT), Soil and Water Assessment Tool (SWAT), and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). First and foremost, this project required a continuous-simulation model with the ability to simulate streamflow and water quality. The model must have the ability to handle very large watersheds. Other considerations were vector versus raster-based data sets, modeling of groundwater, sediment, nutrient, and pesticide transport, dissolved oxygen, evapotranspiration, snow melt, point sources, and reservoirs. In addition, linkage with GIS and ease of use were considered. Table 1.1 gives a summary of the important criteria used for selecting a model. The following entails a description of the models considered and their strengths and weaknesses.

Criteria	AGNPS	HSPF	DESERT	SWAT	BASINS
Continuous vs. event-based	Event	Cont.	Cont.	Cont.	Cont.
Large watershed area	Yes	Yes	Yes	Yes	Yes
14-digit scale	Yes	Yes	Yes	Yes	No
Evapotranspiration	No	Yes	No	Yes	Yes
Snow melt	No	Yes	No	Yes	Yes
Point source	Yes	Yes	Yes	Yes	Yes
Reservoir	No	Yes	Yes	Yes	No
Groundwater	No	Yes	No	Yes	Yes
Sediment	Yes	Yes	No	Yes	Yes
Nutrients	Yes	Yes	Yes	Yes	Yes
Pesticides	Yes	Yes	Yes	Yes	No
Dissolved oxygen	No	Yes	Yes	No	Yes
Ease of use	Yes	No	Yes	Yes	Yes
User assistance	Yes	Yes	No	Yes	Yes
GIS linkage	GRASS	No	No	GRASS	Yes
Vector versus raster-based	Raster	Vect.	Vector	Vector	Vector

Table 1.1: Model criteria.

2.1 Agricultural Non-Point Source Pollution Model (AGNPS)

AGNPS was developed by the Agricultural Research Service scientists and engineers (Young et al., 1989). The event-based model has the capabilities to simulate soil erosion, nutrient (nitrogen and phosphorus) transport, and chemical oxygen demand (COD) in an agricultural watershed. It can simulate watersheds ranging from only a couple of hectares to 50,000 acres. AGNPS is a raster-based model, meaning that the model divides the watershed into many interconnected cells. The size of these cells then determines the accuracy of the model and the amount of time it takes to set up and run the model. This model does not meet the continuous-modeling capabilities necessary for this study. It also lacks the ability to model subsurface conditions.

2.2 Hydrologic Simulation Program-FORTRAN (HSPF)

HSPF is an Environmental Protection Agency (EPA) continuous watershed computer model, with the ability to simulate water quantity and water quality aspects (Bicknell et al., 1993). The model can handle pervious and impervious land segments, along with streams and well-mixed impoundments. The hydrological processes of HSPF are based on the "Stanford Watershed Model" (Viessman et al., 1977). HSPF can model both conventional and toxic organic pollutants, such as sediment loadings and nutrient and pesticide concentrations. Three types of sediment, sand, silt, and clay, are modeled, along with one organic chemical and the transformation products of that chemical. Transfer and reaction processes such as hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption are simulated. A first-order kinetic method is used to model sorption, where the user must input the desorption rate and an equilibrium partition coefficient for each of the three soil types. HSPF accounts for settling and resuspension of silts and clays as it relates to the shear stress at the sediment water interface. The transport of sand at a particular flow rate is also modeled. Sorption/desorption and deposition/scour with surficial benthic sediments are used to simulate the benthic exchange. To operate all the aspects of HSPF an enormous amount of input data and operator skill is necessary. Due to the model's vast complexity and lack of user-friendliness, HSPF was not selected for this project.

2.3 Decision Support system for Evaluation River basin Strategies (DESERT)

The DESERT computer model is a continuous-simulation model and was developed as a result of the cooperation of the Water Resources Project of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria and the Institute for Water and Environmental Problems of the Siberian Branch of Russian Academy of Sciences in Barnaul, Russia (Ivanov et al., 1995). DESERT allows the user the capabilities of water quality assessment and decision making in emission control, such as wastewater treatment methods. The model has the ability to evaluate least-cost strategies for optimal watershed planning. While this model has many advantages, technical support is difficult to receive because this model was developed in Europe. Therefore, this model was not used in this study.

2.4 Soil and Water Assessment Tool (SWAT)

The SWAT model was developed by J. G. Arnold, J. R. Williams, R. Srinivasan, and K. W. King at the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Arnold et al., 1996). SWAT is a vector-based, continuous-simulation model and operates on a daily time step. SWAT can model at most any watershed scale designated by the model operator. It was designed to model the water management, sediment, and agricultural chemical yields, such as nitrogen, phosphorus, and pesticides, in large ungaged basins. Flows can be routed through well-mixed streams and reservoirs. Along with its non-point source modeling capabilities, SWAT can handle measured point source inputs. SWAT also incorporates actual rainfall and temperature data to accurately predict long term yields, but it is not designed to model detailed, single event flood routing. SWAT's water quality modeling capabilities are limited to conservative simulations. It has a Windows Interface which makes it easy to enter data and adjust the model's controls. Two major limitations of the Windows Interface is that it only allows a maximum of 30 subbasins, and it operates in only one direction. Namely, data can be entered in the Windows 3.1 environment and converted to the ASCII format, but not vice versa. The SWAT Windows Interface must be used in a Windows 3.1 environment, it cannot yet function properly in the Windows 95 environment.

2.5 Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

BASINS was recently released by the Environmental Protection Agency (EPA) and was designed by Tetra Tech, Inc. (Lahlou et al., 1996). BASINS runs out of the ArcView 2.1 environment. In addition to the program's ability to assist in locating and assessing poor water quality areas of a watershed, it includes 3 modeling features: Nonpoint Source Model (NPSM), QUAL2E, and TOXIROUTE. NPSM is a simplified HSPF model, used to model the nonpoint source loadings for streamflow, dissolved oxygen levels, and pollutant concentrations at the cataloging unit scale of a watershed. The QUAL2E model allows for a detailed prediction of pollutant fate and transport through selected stream reaches using the nonpoint source loadings calculated by NPSM. TOXIROUTE models the mean and low flow dilution and decay aspects of the watershed at the cataloging unit scale. The model can take the loadings predicted by NPSM and the loadings from Permit Compliance System (PCS) data and apply them to the mean or low flow conditions for analysis. BASINS shows much promise, but its accuracy depends on the detail of the GIS coverage of the study area. The current resolution of BASINS is limited to the USGS watershed 8-digit scale, an hourly time step, and does not contain any routing routines. BASINS gives an overall assessment of the watershed, but it cannot be used for detailed modeling within the watershed.

2.6 Summary

Each model was evaluated using the criteria listed in Table 1.1. None of the models met all of the criteria, but those which performed the best were SWAT and BASINS. SWAT was selected because it met all but two of the requirements: dissolved oxygen modeling and appropriate GIS linkage with ARCINFO. Although BASINS failed three of the criteria, it was selected primarily because of its sophisticated linkages between ArcView and its three modeling modules. It is also a new model, making an investigation appropriate. AGNPS and DESERT failed to meet many of the criteria and were not chosen for this study. HSPF was very qualified in its mechanics, but it failed a major requirement in being extremely difficult to use.

3.0 Detailed Description of SWAT

The SWAT model was selected as the most qualified model for this project based on the criteria listed previously. The following section gives a brief description of the methods used by SWAT to simulate a watershed. For an in-depth examination of SWAT, reference the SWAT User's Manual (Arnold et al., 1996).

There are nine major components of SWAT that should be discussed to give the reader an understanding of the basic mechanics of the SWAT model. These components include hydrology, weather, sedimentation, crop growth, nutrients, pesticides, agricultural management, channel routing, and reservoir routing. Each of these major components are discussed below.

3.1 Hydrology

The major factors affecting hydrology are surface runoff, percolation, lateral subsurface flow, groundwater flow, evapotranspiration, snow melt, transmission losses, and ponds. Surface runoff is calculated using a modified version of the SCS curve number where the curve number is allowed to vary non-linearly from the dry condition to the wet condition of the soil. This method also accounts for periods of time when the soil is frozen by allowing no percolation through the frozen soil.

The peak runoff flowrate is found by a modification of the Rational Formula, where a runoff coefficient, rainfall intensity, and time of concentration are estimated for each storm. The runoff coefficient is equal to the fraction of outflow volume divided by the rainfall volume. The rainfall intensity of each storm is found using a stochastic technique. Using overland and channel flow, Manning's formula is used to predict the time of concentration of each subbasin.

The water that does not flow as surface runoff percolates into the soil. Percolation is simulated through each soil layer and is dependent upon the field capacity of the soil layer and its temperature. When the field capacity of a soil layer is surpassed and the layer below is not saturated, percolation will occur at a rate controlled by the soil's saturated conductivity. If the soil freezes in a layer, then no percolation is allowed to or from that layer. When a lower layer exceeds field capacity, upward flow through the soil layers is possible.

Some of the water that infiltrates into the soil becomes lateral subsurface flow, or interflow. Interflow is predicted by a kinematic storage model as it flows through the soil layers to the channel. Major factors affecting the interflow are hydraulic conductivity, land slope, and soil water content. Upward flow to an adjacent layer or the surface is possible when a lower layer exceeds field capacity.

Water that flows through the soil layers reaches the shallow aquifer storage. From here, the water can flow to the channel as baseflow, it can escape by evaporation, or some may be lost to the deep aquifer. A simple groundwater flow model, dependent on a recession constant, determines how much of the shallow aquifer is discharged to the streamflow.

Some infiltrated water may be lost to the atmosphere through evapotranspiration. Evapotranspiration can be calculated by three different methods: Hargreaves, Priestly-Taylor, and Penman-Monteith. The Hargreaves method requires only air temperature data. Priestly-Taylor method needs solar radiation and air temperature information. The Penman-Monteith method uses solar radiation, air temperature, wind speed, and relative humidity data. When data is limited, the Hargreaves and Priestly-Taylor methods tend to give accurate results in most cases.

Moisture is lost to the atmosphere by simple evaporation from the soil and plant surfaces. Potential soil water evaporation depends on the potential evapotranspiration and leaf area index. The actual soil evaporation is calculated as an exponential function of the soil depth and water content. Plant water evaporation is dependent linearly on the potential evapotranspiration and leaf area index.

When snow is present, it is allowed to melt when the temperature is above 0°C. As snow melts, it is treated just like rainfall in determining the runoff and the percolation, except the energy of the rainfall is set to zero. When the rainfall energy is zero, the erosion caused by the impact of rainfall on the soil is not considered. For snow melt, a uniformly distributed 24 hour rainfall is assumed in order to calculate the peak runoff rate.

As water flows through the channels of the watershed, some is lost through the channel bed. Lane's method is used to calculate these transmission losses. They are dependent on the channel dimensions and flow duration.

Some of the surface flow is retained in surface impoundments such as small farm ponds. Outflow from these ponds are simulated assuming the properties of an emergency spillway. Storage is a function of pond capacity, daily inflows and outflows, seepage, and evaporation. When the pond is below capacity, its surface area is estimated non-linearly from the storage.

3.2 Weather

The five major factors controlling climate in SWAT are precipitation, air temperature, solar radiation, wind speed, and relative humidity. Daily precipitation and air temperature data can input directly into the model if data is available. SWAT also allows different weather data to be used for individual subbasins. If no data is available, SWAT can generate precipitation and air temperature values, along with values for solar radiation, wind speed, and relative humidity.

When no actual rainfall data is available, SWAT generates precipitation based on a first-order Markov chain model. The input of the monthly probability of rainfall occurring on a certain day depends on whether or not the previous day was wet or dry. As the model runs it uses the wet/dry state to determine stochastically the days when rainfall occurs. The amount of rainfall that occurs is then determined by a skewed normal daily precipitation distribution. Air temperature determines the precipitation to be rain or snow.

A normal distribution is used to calculate the air temperature and solar radiation with a correction for days when the weather is changing or is raining. Daily wind speed and daily humidity are found from their average monthly values based on a modified exponential equation and triangular distribution, respectively. Humidity is also corrected for rainy days.

3.3 Sedimentation

As flow occurs, so does erosion, which leads to sediment transport. Sediment loss is a function of runoff volume, peak runoff rates, above-ground biomass, crop residue on the surface, and the minimum crop management factor for the crop.

The hydrology and residue decay are affected by the temperature of the soil layers. Soil temperature of each layer is found independently and is a function of the damping depth of each layer and air temperature.

3.4 Crop Growth Model

SWAT simulates the growth of different crops on an annual rotation. The amount of energy absorbed by the crop depends on the solar radiation and the leaf area index of that particular crop. Growth of the crop depends on each crop's ability to convert the energy to biomass. As the crop grows, the leaf area index increases according to the heat units attained. Harvesting the crop is simulated by the harvest index which increases nonlinearly from zero at planting to a mature heat unit level at maturity.

3.5 Nutrients

Nitrogen can be found in the soil layers and it can be applied to the soil for agricultural purposes. It is present in the surface runoff, interflow, and percolation. The nitrogen loading is calculated as the product of the volume of water and the average concentration in the water. The organic nitrogen lost is based on the organic nitrogen concentration in the upper soil layer, the sediment yield, and the enrichment ratio.

Phosphorus is also found in the soil and can be added to the soil as fertilizer. Soluble phosphorus runoff is dependent on the amount of labile phosphorus in the top soil layer, runoff volume, and a partitioning factor. The sediment movement of phosphorus is estimated as a loading function just like organic nitrogen transport.

3.6 Pesticides

Many farming applications involve pesticides, so pesticide concentrations in the streamflow can become a serious problem and worthy of consideration in modeling. Pesticides can be applied at any depth in the soil or on the surface. Surface application efficiency depends on the leaf area index. The application efficiency determines the amount of pesticide that reaches the foliage, topsoil, and atmosphere. Not all of the pesticide that falls on the foliage and ground surface reaches the streamflow; some is lost to degradation and percolation. Pesticide degradation on plant foliage and in the soil is an exponential function of its half-life. Some pesticide is allowed to leach through the soil parallel to percolation.

3.7 Agricultural Management

A maximum of three crops per year can be simulated, with an unlimited number of crop rotations possible. The tillage component of SWAT controls the amount of biomass removed, tilled into the soil, and left as surface residue during times of harvest.

Dates and amounts of irrigation, nutrient applications, and pesticide applications can be specified. These can be applied by a trigger mechanism which activates when the soil reaches different threshold levels.

3.8 Channel Routing

The water that flows as surface runoff will flow into the channels. These channels must be routed to and from each other to create a stream network for the watershed. The channel flow is affected by reach length, channel slope, bankfull width and depth, channel side slope, flood plain slope, and Manning's n for both the channel and floodplain. Manning's equation is used to calculate the flowrate and average velocity. Travel time in the channel is important to the timeliness of the routing process and is found by dividing the channel length by the velocity. Adjustments to the channel flow are made as necessary for transmission losses, evaporation, diversions, and return flow.

Sediment routing in the channels has two components: deposition and degradation. Deposition deals with the rate at which the particle falls to the bottom of the channel as governed by Stokes Law. In Stokes Law, settling speed is a function of particle diameter. The major control of bed degradation, or erosion, is Bagnold's stream power concept. Stream power is the product of water density, flow rate, and water surface slope.

Nutrients and pesticides are treated as conservative constituents during channel simulation. Degradation of soluble chemicals is not modeled and chemicals attached to sediment settle to the bottom with the particle.

3.9 Reservoir Routing

Water that flows through a reservoir behaves quite differently from the streamflow and overland flow and requires unique treatment within the model. Water balance of reservoirs considers inputs from inflow, rainfall on the surface, and return flow. It also considers outputs from outflow, evaporation, seepage from the reservoir bottom, and diversions. Three methods are possible for modeling the outflow from the reservoir. First, the actual outflow data is read in as streamflow while all the other modeling components operate normally. The second method simulates small reservoirs to release flow at a specific rate when the storage level exceeds the principle storage. A third method handles large reservoirs where a monthly target release volume approach is utilized.

Sedimentation in a reservoir is also an important consideration. Sediment outflow is estimated as the product of the sediment concentration and the outflow volume. In between storms, the concentration is allowed to decrease over time where the median particle size decreases in the influent.

In simulating nutrients in the reservoir, the following assumptions are made: 1) completely mixed lake, 2) phosphorus limited, 3) total phosphorus can be a measure of trophic status. A completely mixed lake does not consider a stratification and the high level of phytoplankton in the epilimnon. A limited phosphorus condition would exist when nonpoint sources dominate. When total phosphorus is a measure of a lake's trophic status, then a relationship must exist between the total phosphorus and biomass. The phosphorus mass balance depends on the concentration in the lake, inflow, outflow, and an overall loss rate.

For pesticides, a well-mixed situation is assumed and a balance model is applied. This process involves a well-mixed surface water layer underlain by a well-mixed sediment layer. The pesticide is then separated into a soluble phase and particulate in the water and sediment layers. Major processes in the pesticide reservoir model include loading, outflow, reactions, volatilization, settling, diffusion, resuspension, and burial.

4.0 Methodology

4.1 Model Selection

Of the models identified earlier in this report, two were chosen for streamflow application in this study. Both Soil and Water Assessment Tool (SWAT) and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) meet many of the necessary modeling criteria. Although the models have different strengths and weaknesses, they are both applied to the North Fork of the Kentucky River for this study. SWAT is used to model both the entire North Fork watershed of 3416 km^2 and its Troublesome Creek tributary of 458 km^2. Each watershed is shown in Figure 4.1. Due to its limited 8-digit scale resolution, BASINS is used only to predict the streamflow out of the entire North Fork watershed; the Troublesome Creek tributary is too small of an area for BASINS to simulate. Because the input data for the BASINS model is generated automatically upon selection of a watershed and an associated rainfall station, the following discussion focuses on SWAT.

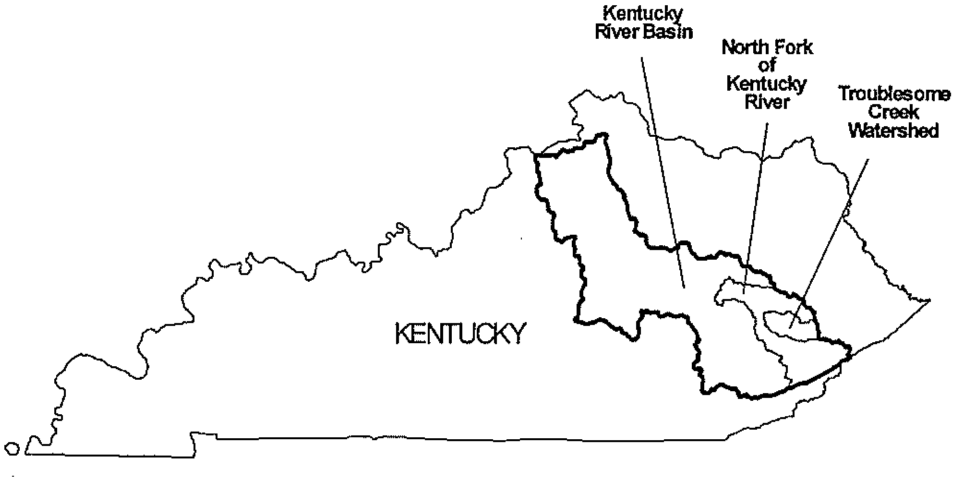


Figure 4.1: Location map of the North Fork of the Kentucky River and Troublesome Creek.

4.2 SWAT Input Data Requirements

SWAT is very data intensive and many parameters must be defined in order to use the model. There are nine types of input files per subbasin allowing the user to input well over 100 types of data per subbasin. Taking into account the number of subbasins in the model, this can result in an enormous amount of data that must be entered into SWAT. However, many of the parameters are given in tables provided by the User's Manual

(Arnold et al. 1996) and the help feature of the model. The physical data of the watershed can be determined from dependable survey data. Other data such as climate and streamflow data must be collected.

Because of the large amount of data to be acquired, special methods were used. GIS was used to collect and manage much of the physical data in the watershed, and Hydrosphere Data Products, Inc. data sets were used for the climate and streamflow data. The following physical data was collected using GIS: total watershed area, subbasin area, channel routing structure, distance to the furthest point in subbasin, mean subbasin elevation, mean subbasin slope, channel length, mean channel slope, landuse, climate gage and streamflow gage locations, and watershed delineation. Use of GIS significantly reduced the time in the data collection process and allowed the production of maps showing the layout of the study area in relation to the locations of the gaging stations.

All data was manually input into SWAT. The data input procedures assume that each subbasin contains homogeneous conditions. For example, one set of dominant soil properties are assumed constant over an entire subbasin area of several km^2. In reality, a wide range of soil properties exists throughout the subbasin and affects the runoff quite differently from the homogeneous situation. For the sake of simplicity and remaining within the limits of accuracy of the model, the assumption of a subbasin with homogeneous characteristics suffices. With proper calibration, the homogeneous characteristics input into the model can lead to an accurate simulation. Global settings of the model, such as the time period and time step, must also be defined.

4.3 Data Collection

Topography, soils, climate, streamflow, and water quality data are necessary for the SWAT model. Many sources of data were investigated, such as the Internet, United States Geological Survey (USGS), EPA STORET database, United States Department of Agriculture (USDA), Soil Conservation Service (SCS) Soil Surveys, University of Kentucky studies of Robinson Forest, National Climatic Data Center (NCDC), and the Midwestern Climate Center. For climate data, the NCDC and the Midwestern Climate Center were located at the Internet addresses in Table 4.1. Streamflow information was located at the USGS Internet address listed in Table 4.1, and locally within the University of Kentucky. The local information was found from a study conducted on Robinson Forest, an area which lies in the Troublesome Creek region of the North Fork. Water quality data was discovered at some USGS gaging stations, in the STORET EPA database, and locally within the University of Kentucky from the Robinson Forest study. After determining the data to be gathered and the means to acquire it, Hydrosphere Data Products, Inc. was selected as the source for climatic, streamflow, and water quality data. Hydrosphere provides a search engine to allow easy management of the data. The Hydrosphere software also allows the user to download the data in several formats, making it easier to convert to a usable form. A comparison of the data sources and their costs can be found in Table 4.2. The University of Kentucky library was used to collect soil surveys and topographical maps.

Description	**Internet Address**
NCDC	www.ncdc.noaa.gov
Midwestern Climate Center	http://mcc.sws.uiuc.edu
USGS	http://h2o.usgs.gov

Table 4.1: Internet addresses for data.

Source	**Description**	**Media**	**Cost**
NCDC	KY daily prec. and temp. data	CD	$120 per CD
Midwestern Climate Center	Daily prec. and temp. data	FTP	$2 per site
Hydrosphere	Subscription to daily prec. And temp. data	CD	$495 per CD
Hydrosphere	Subscription to daily streamflow	CD	$495 per CD
Hydrosphere	Subscription to STORET EPA Geoselect database	CD	$995 per CD
USGS	Daily streamflow for many stations	Diskettes	$250
Univ. of KY Forestry Dept.	Water quality and streamflow	Diskettes	free
STORET EPA	Water quality	FTP	free

Table 4.2: Data sources and applicable costs.

4.4 Determine General Guidelines of Simulation

Prior to running each model, some global modeling factors must be determined to focus the modeling effort. Organizing the geographical location and general descriptions of the available data is imperative to the project. GIS is very useful for learning about the spatial aspects of the available data.

By knowing locations of gaging stations and dates of the available climate and streamflow data, the user can determine the most appropriate time period and basin subdivision for modeling and subsequent calibration. This early step in the modeling process allows for strategic watershed delineations to align with the streamflow gaging station locations and for a realistic rain gage coverage to be assembled.

For this study, climatic data was found at a large number of stations, but the accuracy of the data was found to be suspect, especially in cases where many records of data were missing. The missing data was replaced by the record for that day from the nearest gaging station. Stations with a significant amount of missing data were omitted from the model. Climatic gaging stations used for the SWAT runs in this project are listed in

Table 4. In BASINS, all the climate data exists in the program, and the user must select from a list of five provided weather stations. These stations are DE Wilmington Airport, PA Philadelphia Airport, VA Richmond Airport, DC National Airport, and WV Charleston Airport. For this study, weather data from the WV Charleston Airport station was chosen. Although it is located 200 miles away, it remains the closest of the possible climate station choices for use in comparing the results of both SWAT and BASINS. When performing a direct comparison between SWAT and BASINS, the WV Charleston Airport climate data was converted to daily data for use in the SWAT model.

Title/Location of Climate Station	**Station ID Number**
Heidelberg	3741
Jackson	4196
Salyersville 2 SE	7134
Buckhorn Lake	1080
Hindman 11 NNE	3896
Hazard Water Works	3714
Jeremiah 1 S	4255
Pine Mountain 3 NW	6379
Cumberland	1964
Cumberland 2	1965

Table 4.3: Climatic gaging stations available for the SWAT model.

Streamflow stations used for model comparison were located at Noble (USGS # 03278500), Hazard (USGS # 03277500), Jackson (USGS # 03280000), and Clemon's Fork. The station at Noble is used to calibrate the outflow of Troublesome Creek. A streamflow comparison of Clemon's Fork, within Troublesome Creek, was also conducted. Unfortunately, streamflow data at the outlet of the North Fork could not be located, so streamflow data at Hazard and Jackson were used to calibrate the upper and lower runs of the entire North Fork. For a spatial representation of the climate and streamflow gages used during this study see Figure 4.2.

After examining the available streamflow data, the period from 1970 to 1975 was selected as a focus for the study because of the reliability and amount of data. This range of time allowed data from many of the streamflow and climate stations to overlap which led to dependable comparisons during the calibration phase of the project.

The process of assembling the rainfall and temperature input files for use in the SWAT model requires significant effort. Not only downloading data from the source, but converting it into proper units and format requires considerable preprocessing efforts. For example, precipitation data downloaded from the Hydrosphere database needs to be

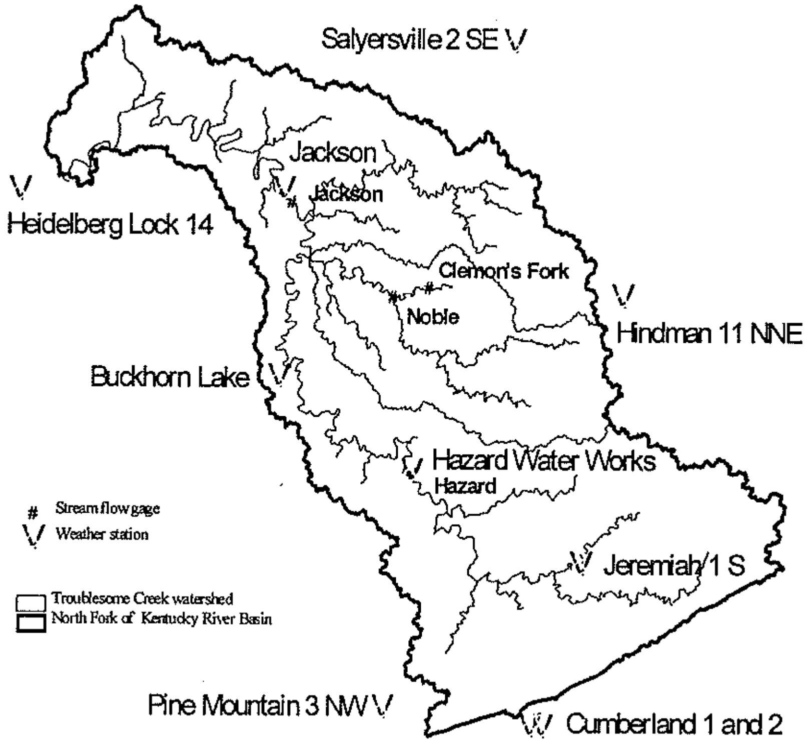


Figure 4.2: Map of climate and streamflow stations.

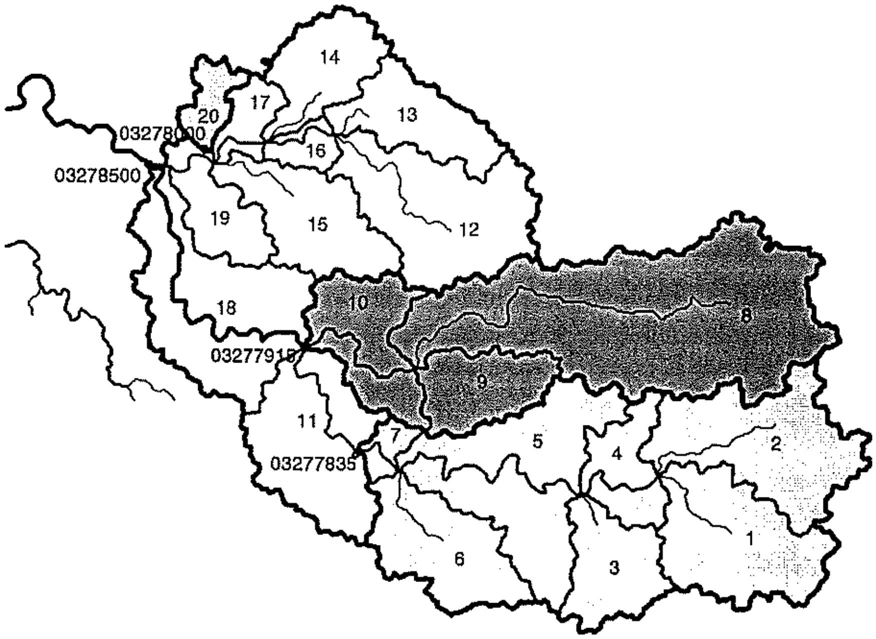


Figure 4.3: Troublesome Creek (14-digit watershed delineation).

Figure 4.4: Entire North Fork of the Kentucky River (11-digit watershed delineation).

converted from inches to millimeters. Then, the precipitation data must be converted to an ASCII file in a proper format for SWAT input. These two tasks are performed using a spreadsheet application and a FORTRAN data conversion program.

It is very important to delineate the number of subbasins in the watershed prior to applying a model. The entire North Fork of the Kentucky River watershed exists without any delineation at the USGS 8-digit scale. Troublesome Creek is subdivided into 19 subbasins at a 14-digit scale and 4 subbasins at the 11-digit scale. These delineations are shown in Figures 4.3 and 4.4. The entire North Fork was modeled at the 11-digit scale resulting in 53 subbasins. This creates a problem for the modeler because the SWAT Windows Interface maximum subbasin limit is 30. To address this problem, the watershed was split into two sections: an upper section and a lower section. The two sections were run sequentially separately and linked by the output hydrograph from the upper section. An 8-digit scale was used for the BASINS run of the entire North Fork because this scale is the only delineation BASINS can simulate.

4.5 Developing the Soil Input Parameters

The soil input parameters are dependent on the many different qualities of the dominant soil association within a particular subbasin. For each basin, the dominant soil association is determined, and the percentages of the major types of soils within the association are found. Next, each of the major types of soils is located in the SWAT soils database, and the values for each soil are recorded. Then, a weighted average using the soil values and the percentages of the soil association is calculated. This weighted average represents the average soil qualities for the entire subbasin, and its values are input manually into the soil file (.sol) of SWAT.

The development of the soil input files for SWAT could be an automated process through incorporation of GIS. By utilizing the STATSGO database as a coverage layer, GIS has the capabilities to determine the dominant soil coverages over individual subbasins and export the associated soil qualities to a table. This table can then be arranged into a format acceptable for a SWAT run. Future work in this area and others like it would prove very useful in assisting the SWAT modeler in completing a SWAT run.

4.6 Running the Model

SWAT can be controlled from a DOS environment or from the Windows Interface. By running SWAT from the DOS environment, much time can be conserved. The data input into the Windows environment is converted into ASCII file format by SWAT when it creates the run files in a preprocessing routine. Once the run files have been completed, some editing of them may be necessary. This project required some editing to link two watershed sections, known as the upper and lower, and some adjustments had to be made to the soil files (.sol).

To accomplish the watershed linkage, a SWAT run for each section is made. Logically, the upper, or higher elevation, section is run first because it feeds the lower section. The output hydrograph from the upper run is saved using the SAVE command in the routing structure file (.fig). The file is saved under the title listed in the second row of the first column of the input data file listing of the "file.cio" file. The hydrograph from the upper run is then read into the lower run at the location in the watershed where the upper section connects to the lower section. The read file command, RECDAY, is inserted into the proper location in the routing structure file (.fig), and it references the file name listed on the next line. Using the SAVE command again in the routing structure file (.fig) of the lower section, any designated hydrograph may be saved for analysis. For an example of these ".fig" and "file.cio" files see Appendix A. This entire process is accomplished from the DOS environment because these features cannot be controlled using the Windows Interface.

Another editing issue to be addressed involves editing the soil files (.sol). The Windows Interface does not create the soil files accurately. When the Windows Interface creates the run files, some of the data in the soil files are missing, and some are located in the wrong columns. This should be corrected in the DOS environment according to the soil files (.sol) shown in Appendix A.

After completing these changes, the model is run in the DOS mode using the command SWAT942. When the model stops running, either an error message or "Stop - Program terminated." will appear on the screen. If the message says "Stop - Program terminated.", then the run was successful. If a different message occurs, a problem was encountered, and it must be fixed before the run is successful.

4.7 Output Module

A successful run of SWAT will indicate that all the data is input correctly, and calibration becomes the next step. To obtain a decent calibration, the output of the model must be analyzed on a daily time step. Calibration efforts based on a monthly time step proved to be unsuccessful because the filtering process of taking the average monthly flows could lead to improved monthly results at the expense of daily accuracy. The monthly or annual time scale does not give the user accurate information about the peak flows, baseflows, and hydrograph lags being modeled. Also, the monthly and annual time scales do not show the user exactly how the hydrograph was affected by an adjustment of the input data. A daily time step will show these essential details making it very valuable to the calibration effort. **The SWAT model, however, does not come with a daily output comparison module.** A daily output comparison module was created for this project using the Microsoft Excel spreadsheet.

The output module imports the SWAT output hydrograph and presents daily and monthly streamflow comparison charts to the modeler. All necessary conversion calculations and data organization is accomplished by the output module "with the push of a button." The basic operational concept of the output module is shown in Figure 4.5.

The major components of the output module are the engine, actual streamflow data storage, charts, macros, and control pad. The engine is given its own worksheet and acts as the driving mechanism of the spreadsheet. It performs the necessary conversions to the SWAT output data. For the explicit purpose of comparing the two data sets in a graphical display, the engine acts as a temporary housing station for the actual and simulated streamflow data. For each station of actual streamflow data, a separate worksheet exists to keep the data organized. This is the permanent storage area for the actual streamflow data. When the data is needed for charting purposes, it is copied into the engine worksheet. The charts are also located within a separate worksheet for the sake of organization. Charts are created on both a daily and monthly basis to compare the simulated streamflow to the actual streamflow. The processes of copying the simulation output hydrograph and the actual hydrograph into the engine worksheet are recorded as separate macros. A separate macro is created to each station of actual streamflow data into the engine. Finally, a control pad is designed to contain multiple hotkeys which are assigned the command of executing the "copying" macros. This control pad exists to

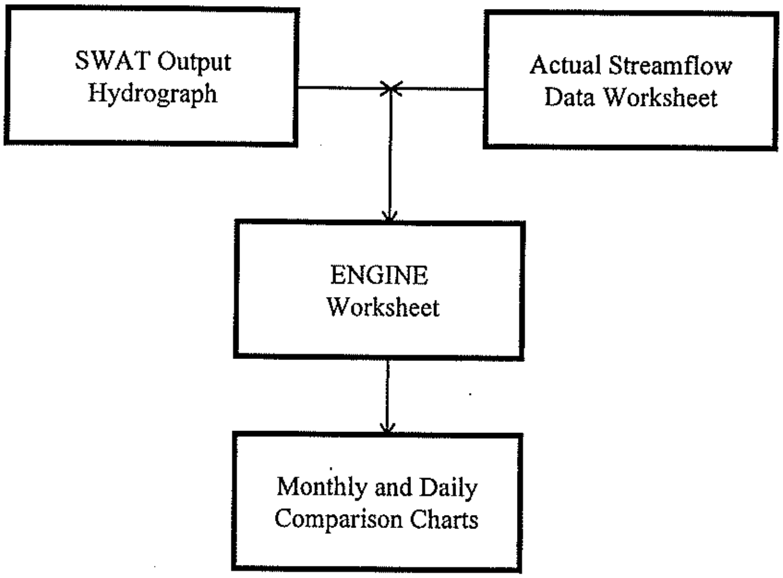


Figure 4.5: Basic Operational Concept of the Output Module.

make things easier on the user of the output module. See Appendix B for a step by step procedure for creating and operating the output module.

Depending on the size of the output file (.eve), the Microsoft Excel spreadsheet row limit of 16,384 may be encountered. This is an unlikely scenario because it would require a simulation of 44 years to approach this limit.

Like SWAT, BASINS lacks a graphical output module. The one used for comparison of the SWAT output and actual data was adopted and edited for the purpose of comparing the outputs of BASINS and SWAT.

4.8 Sensitivity Analysis

Before calibrating the SWAT model, the user must have an understanding of which inputs can be adjusted and the corresponding sensitivities of the applicable input values. Many of the input parameters for SWAT were subjected to sensitivity tests for this reason. In each case, the parameter was adjusted and its effect on the output hydrograph was recorded. Two general sensitivity analyses were conducted, one for monthly output and one for daily output. The monthly sensitivity analysis results are shown in Table 4.4, and the daily sensitivity analysis results are shown in Table 4.5. Some adjustments had no impact on the output hydrographs while others demonstrated some major effects.

Parameter Identification (File)	Change	Effect
Evapotranspiration (.cod)	Priestly-Taylor to Penman-Monteith	Increased outflow
Evapotranspiration (.cod)	Priestly-Taylor to Hargreaves	Intermittently increased outflow
Baseflow factor (.bsn)	1 to 0	No effect
Basin lag time (.bsn)	0 to 1	No effect
Initial soil-water storage (.bsn)	0 to 1	No effect
Curve number (.sub and .mgt)	77 to 25	Lowered peak outflows
Curve number (.sub and .mgt)	77 to 95	Raised peak outflows
Effective hydr. cond. (.sub and .rte)	75 to 0	Raised most outflows
Channel N value (.sub)	0.1 to 0.3	Lowered most outflows
Overland flow N value (.sub)	0.15 to 0.5	Raised and lowered a few outflows
Return flow travel time (.sub)	0 to 150	No effect
Return flow travel time (.sub) and baseflow factor (.bsn)	0 to 150 and 1 to 0.5, respectively	No effect
Average slope length (.sub)	0 to 150	Increased all outflows
Groundwater height (.gw)	0.1 to 25	No effect
Initial groundwater flow contribution to streamflow (.gw)	0.4 to 10	Raised first outflow
Alpha for groundwater (.gw)	0.6 to 1	Raised first outflow
Specific yield (.gw)	0.1 to 0.4	No effect
Groundwater delay (.gw)	7 to 400	Raised early outflows and lowered later peak outflows
Revap coeff.-fraction of recharge (.gw)	0 to 1	No effect
Fraction of root zone percolation (.gw)	0 to 1	No effect
Revap storage (.gw)	0 to 50	Lowered first several outflows
Initial deep aquifer storage (.gw)	0 to 2500	No effect
Hydraulic conductivity (.sol)	75 to 150	Lowered most outflows
Available water capacity	To lower limit	Raised most outflows
Available water capacity (.sol)	To upper limit	Lowered most outflows

Table 4.4: Monthly sensitivity analysis results.

Parameter Identification (File)	**Change**	**Effect**
Alpha factor (.gw)	0.6 to 0.95	None
Alpha factor (.gw)	0.6 to 0.05	Affects early baseflow
Specific yield (.gw)	0.1 to 0.4	No effect
Specific yield (.gw)	0.1 to 0.01	No effect
Groundwater delay (.gw)	20 to 200	Increased all outflows
Available water capacity (.sol)	To lower limit	Increased peak outflows, more sensitive
Available water capacity (.sol)	To upper limit	Lowered peak outflows, less sensitive
Basin lag time (.bsn)	0 to 10	No effect
Basin lag time (.bsn)	0 to 100	No effect
Revap storage (.gw)	50 to 0.5	Removed baseflow jump at start
Initial groundwater height (.gw)	0 to 25	No effect
Initial groundwater contribution (.gw)	5 to 1	Lowered baseflow
Hydraulic conductivity (.sol)	100 to 1000	Increased peak outflow, no lag
Hydraulic conductivity (.sol)	100 to 50	Increased lag
Overland N	0.15 to 0.6	No effect
Average slope length (.sub)	40 to 30	Increased peak outflows, more sensitive
Average slope length (.sub)	40 to 50	Increased lag

Table 4.5: Daily sensitivity analysis results.

Several important discoveries were made from the sensitivity analysis. Curve number adjustments proved to have a major effect on the magnitude of the hydrograph peaks. Low curve numbers were found to increase the amount of water which reached the shallow aquifer. The available water capacity of the soil was found to resemble the behavior of a sponge where as the available water capacity increased, so did the soil's ability to absorb rainfall. This behavior was observed in the sensitivity of the hydrograph where small precipitation events appear as small impulses for low available water capacities. As the available water capacity increases, these small precipitation events are absorbed by the soil and have less effect on the surface hydrograph.

Average slope length of the land was shown to have a major effect on the sensitivity and hydrograph lags of large precipitation events. Adjustments to the hydraulic conductivity of the soil affected the lags and peaks of the hydrographs. Revap-storage was found to have some major control over the initial groundwater contributions to streamflow. In its calculations, SWAT will not allow water to flow from the shallow aquifer until the revap-storage level is met. If the revap-storage is set fairly high, this can lead to a jump in groundwater contributions within the first several days of the simulation. This jump can be avoided by setting a low revap-storage.

4.9 Calibrate/Verify Model

Many of the inputs to the SWAT model are physically-based on the characteristics of the watershed. Although these input values were measured or determined by a definite process, they were developed based on the assumption of homogeneity throughout the subbasin. This simply is not a realistic assumption, especially as the size of the watershed is increased, so some of the input values may need to be adjusted within a reasonable range to improve the performance of the model.

In a study entitled "Estimating Hydrologic Budgets For Three Illinois Watersheds" by J.G. Arnold and P.M. Allen, a SWAT calibration was conducted (Arnold and Allen, 1996). The values of the soil input parameters were adjusted within the uncertainty ranges, and the curve number was allowed to vary between its values for good, fair, and poor hydrologic conditions. These parameters were used to manually calibrate the model for annual streamflow and annual surface runoff and groundwater contributions.

The SWAT models created in this study were calibrated based on the calibration process suggested by J.G. Arnold. He recommends the following calibration process: 1) Adjust the curve number to the poor or good limit of the hydrologic soil group, 2) adjust the available water capacity within the designated tolerances, 3) adjust the storage of the shallow aquifer or the revap storage. Adjustment of the average slope length and the hydraulic conductivity within reasonable limits was also found to have a major and justifiable effect on the streamflow.

This study has used the skill of the modeler to determine the accuracy of the output hydrographs. In the future, it is advised to incorporate some mathematical procedures to measure the accuracy of the simulations. Possible measures of model accuracy might be found in the regression line slope and R^2 methods where values close to unity correspond to high accuracy. The Nash-Sutcliffe coefficient goodness-of-fit criterion should also be considered because it is recommended by the American Society of Civil Engineers (ASCE) Task Committee on Evaluation Criteria for Watershed Models (Arnold, 1995).

When edited and run within the Windows Interface, SWAT can take 5 to 10 minutes, depending on the processing speed of the computer, to recreate all of the run files. During this process, SWAT copies over the already existing files, erasing any corrections previously made. To save time, it is recommended to make the calibration adjustments to the model in the DOS environment. It allows the user to be more efficient if the subbasins can share the same file names. An example of two subbasins sharing the same file name might be where two subbasins have the same dominant soil properties. In this case, the same soil file can be assigned to both subbasins in the "file.cio" input file. If a parameter is adjusted for calibration, then only the one soil file assigned to both subbasins would need to be edited. Also, the changes made to the routing (.fig) and soil (.sol) files do not need to be redone. SWAT can be run again in the DOS mode by the SWAT942 command.

5.0 Results

The SWAT calibration effort was conducted on a monthly and daily basis using climate and streamflow data from 1970 to 1975. For the reader's sake, the results displayed in this section are shown on a monthly basis, and the corresponding daily results are presented in Appendix C. The discussion will be focused on the trends represented in the monthly scale comparisons. In applying SWAT and BASINS to the North Fork of the Kentucky River, several different types of results were recorded.

To demonstrate SWAT's performance on a small subbasin, a run was conducted over the less than 2 square mile watershed of Clemon's Fork. The monthly results of this effort are shown in Figure 5.1. Although it is designed to model very large watersheds, SWAT appears to operate fairly well for the smaller basin.

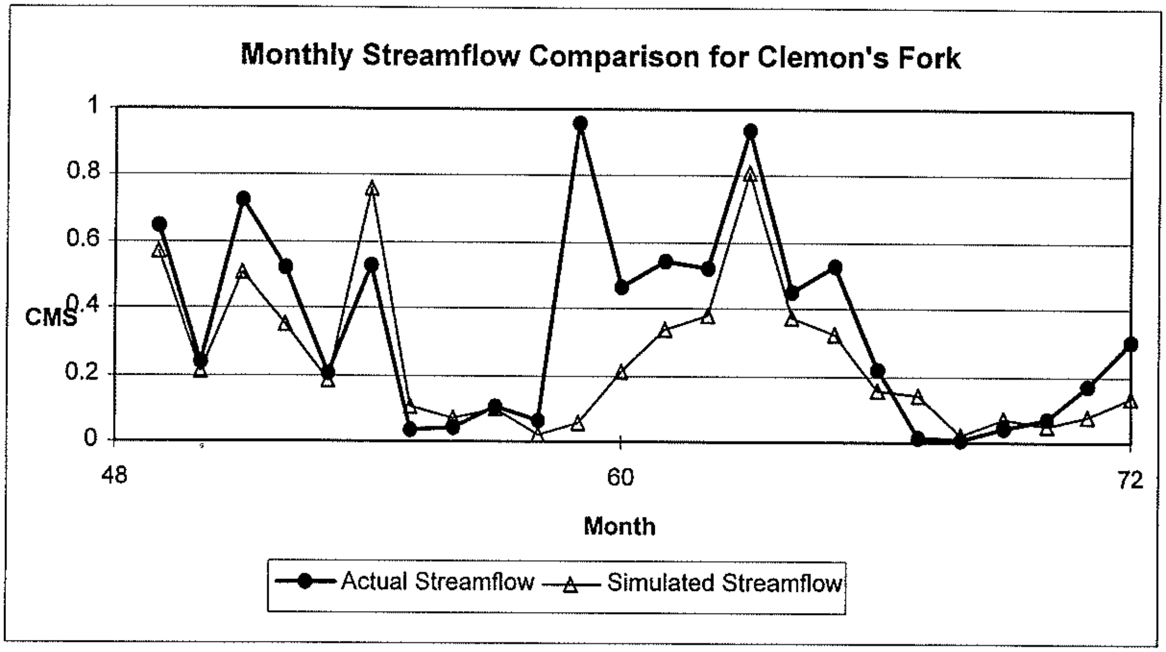


Figure 5.1: Monthly Streamflow Comparison for Clemon's Fork using SWAT.

Simulations were set up using the SWAT model for Troublesome Creek on both 14-digit and 11-digit scales. Figure 5.2 shows the monthly accuracy of the 14-digit model of Troublesome Creek when compared to the streamflow data at Noble, KY. Most all of the lower and medium flow months were extremely accurate with some error showing up during especially high flow months. This trend continues for the 11-digit model of Troublesome Creek whose output is compared to the actual streamflow collected at Noble, KY in Figure 5.3. The errors of these comparisons may be due to several factors. Rainfall variability is not fully captured in point precipitation data, and the assumption of

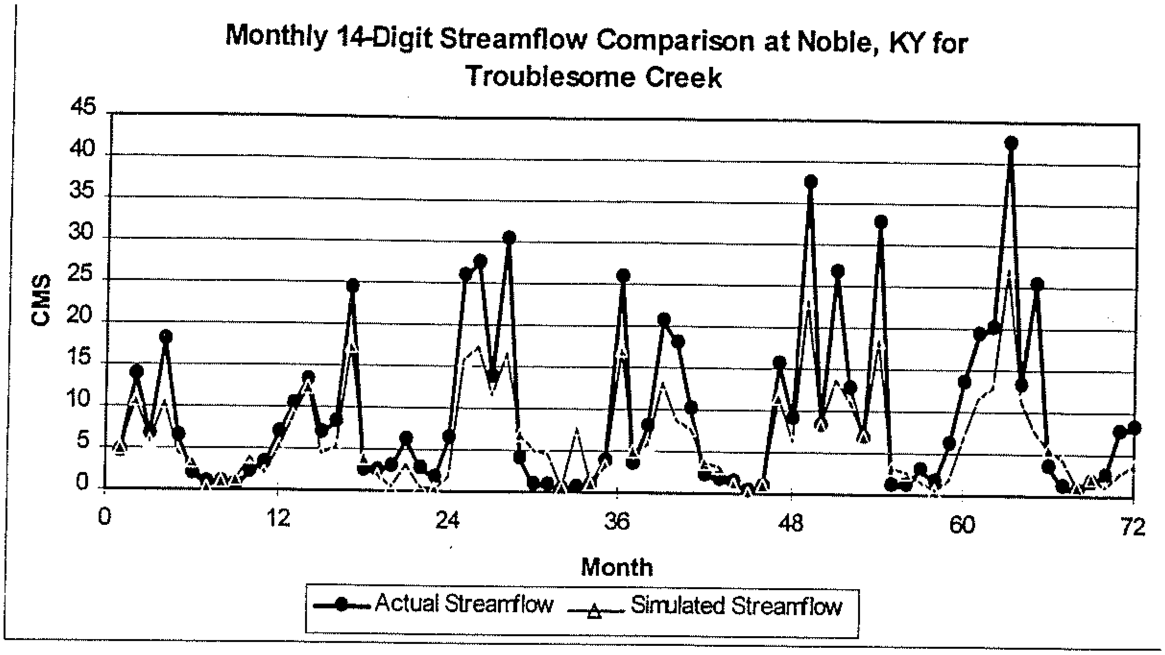


Figure 5.2: Monthly 14-digit streamflow comparison of Troublesome Creek using SWAT.

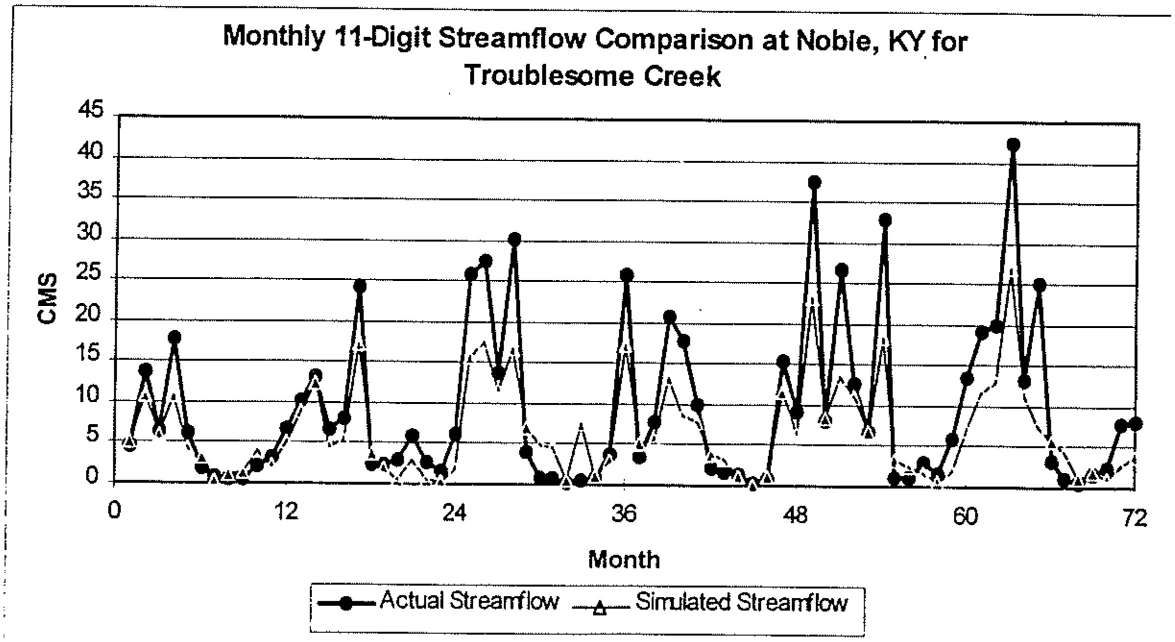


Figure 5.3: Monthly 11-digit streamflow comparison of Troublesome Creek using SWAT.

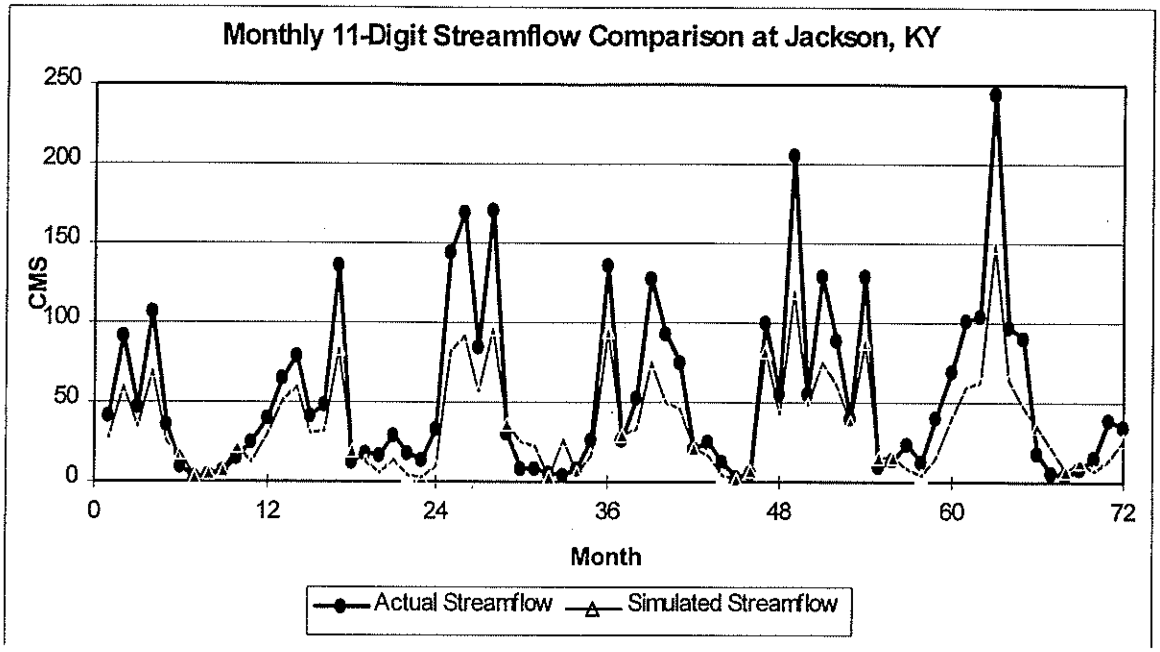


Figure 5.5: Monthly 11-digit streamflow comparison of the North Fork at Jackson, KY using SWAT.

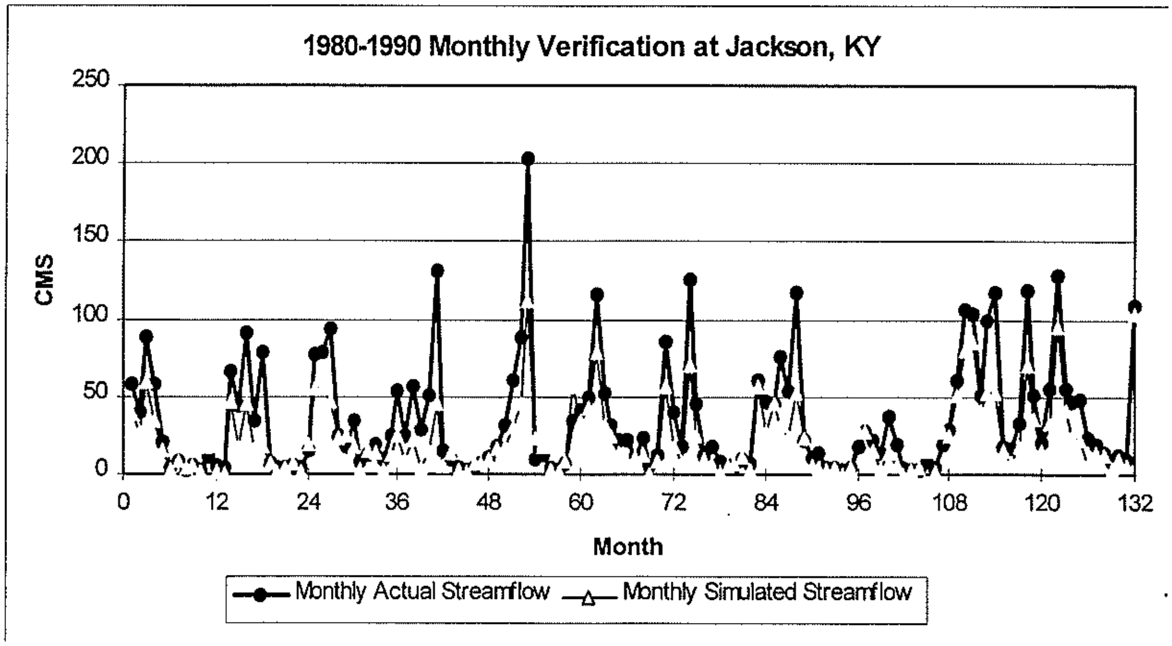


Figure 5.6: Monthly verification of SWAT at Jackson, KY between 1980 and 1990.

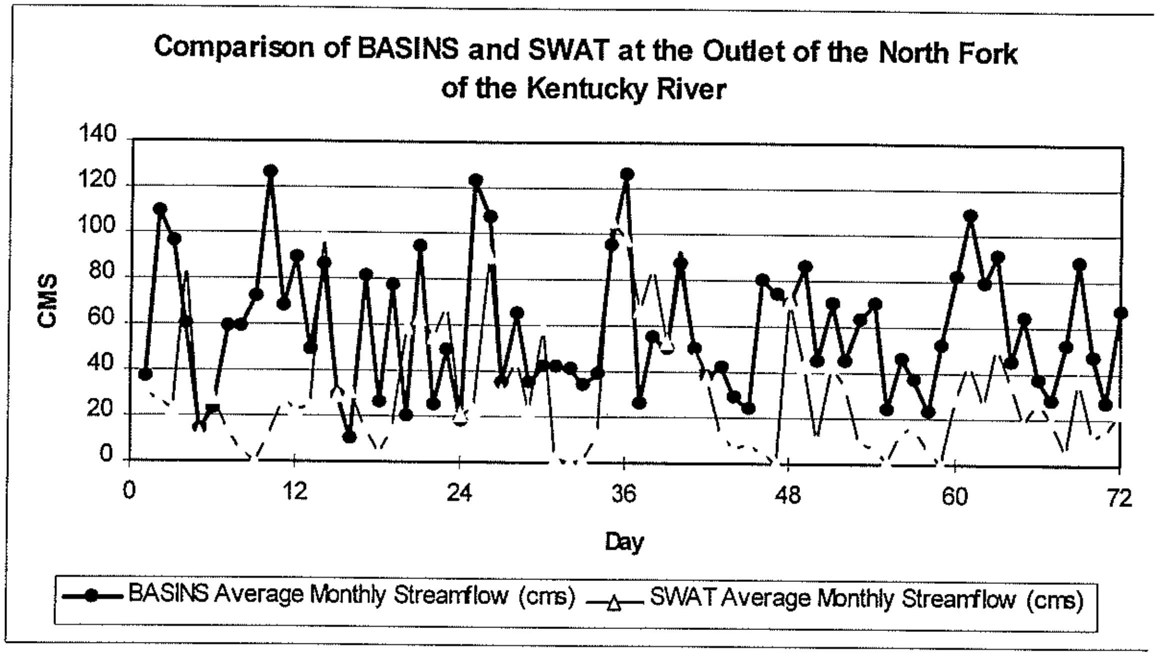


Figure 5.7: Monthly comparison of BASINS and SWAT for the North Fork.

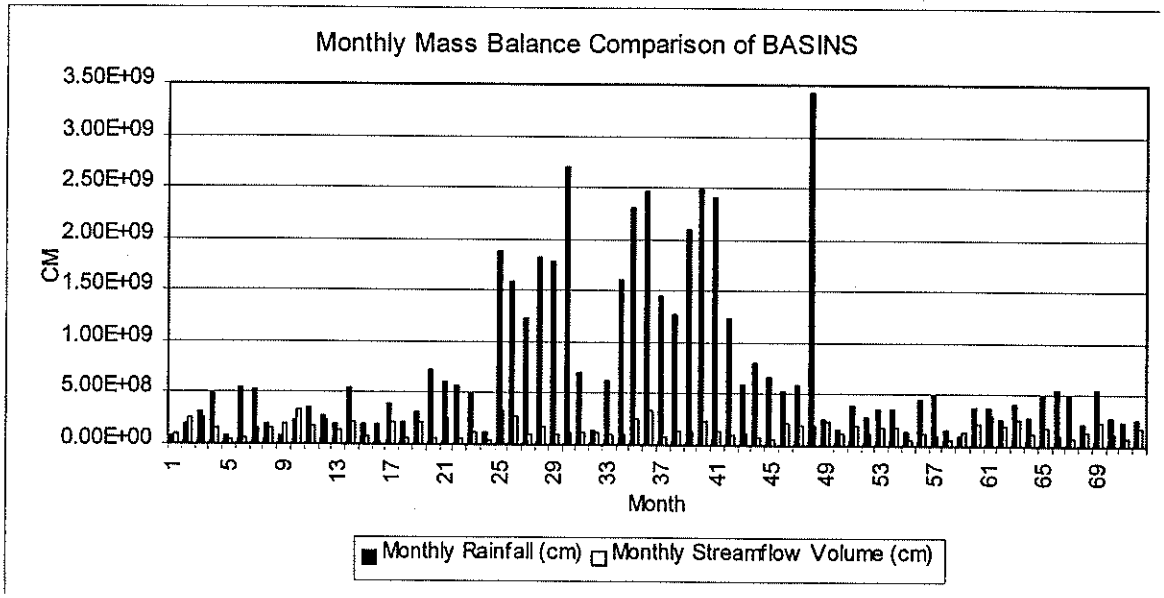


Figure 5.8: Mass Balance of BASINS.

6.0 Summary and Conclusions

As the Kentucky Division of Water pursues a comprehensive watershed management approach, computer modeling is expected to increase. Many models, such as AGNPS, HSPF, DESERT, SWAT, and BASINS were evaluated for application in this study. Based upon the project's modeling criteria, SWAT and BASINS were selected for further consideration and were tested on the North Fork of the Kentucky River.

The data needed to run the SWAT model is very extensive. Once the data needs were established, sources, such as GIS, Internet, local university studies, and Hydrosphere Data Products, Inc., were very helpful in acquiring the necessary data. Once the available data had been collected and organized, the modeling strategy was determined. The strategy focused the study on the time period of 1970 to 1975 because a large amount of data was available during this time. A GIS proved to be very useful in determining spatial coverages of climatic data, modeling scale, routing of the watershed, and watershed delineation.

After successfully running the model, an output module for SWAT was developed for a sensitivity analysis and manual calibration. The Microsoft Excel output module created in this project prepares the SWAT output hydrograph to be viewed on a daily and monthly time step in a comparison chart. The model was calibrated at three different streamflow stations: Troublesome Creek at Noble (USGS # 03278500), North Fork at Hazard (USGS # 03277500), and North Fork at Jackson (USGS # 03280000). The calibration effort was achieved by adjusting within reasonable limits the curve numbers, available water capacities, revap storages, channel slope length, and hydraulic conductivities of each subbasin. Each of these parameters were found to have a significant effect on the streamflow.

Troublesome Creek was modeled with SWAT on the 14-digit and 11-digit USGS scales and calibrated at the Noble gaging station. The entire North Fork was modeled by SWAT and BASINS. For SWAT, the North Fork was broken into two sections to account for a maximum subbasin limit of the SWAT Windows Interface. The upper section was calibrated by the Hazard station and the lower section was calibrated by the Jackson station. Since precipitation data from Charleston, WV had to be used to run BASINS, its output was compared to a SWAT also run using the Charleston, WV precipitation.

SWAT was shown to have the capability to accurately model both 14-digit and 11-digit watersheds with most of the error coming during high flow months. When compared directly, the 14-digit and 11-digit simulated streamflows were very close with the major differences occurring during high flow months. The result showed the 11-digit model had slightly better results on a monthly scale. BASINS output was shown to have little in common with the SWAT output. A successful verification of the North Fork SWAT calibration was performed at the Jackson station for 1980 to 1990. A reasonable comparison of a small watershed of 2 square miles was shown for Clemon's Fork.

Like most watershed models, SWAT is still developing. SWAT has the capability to display monthly and annual graphical outputs, but not on a daily time step. This required a graphical output module to be constructed. Some of the model's capabilities are not supported by the Windows Interface, such as saving individual hydrographs and reading in point source data. Also, some errors were found when the Interface created the soil run files. The Windows Interface is limited to 30 subbasins. If more than 30 subbasins are to be used, the watershed might be divided into sections of fewer than 30 subbasins and then linked back together by saving and inserting the output hydrographs of adjoining sections. Another option can be found by abandoning the Windows Interface to create all the run files in the DOS environment. Currently, the SWAT Windows Interface cannot be run in the Windows 95 environment, but the designers are working to achieve this capability. The Windows Interface is also limited in that it can only function in one direction. It can convert data in the Windows 3.1 format to ASCII format, but not vice versa.

BASINS is a new model with some very powerful tools for assessing the general water quality problems within 8-digit watersheds. For the modeling needs of this project, BASINS proved to be insufficient. Its rigid modeling scale, limited rainfall data selection, lack of a graphical output display module, and lack of a routing routine leave much room for improvement. Also, for the application considered, output errors were identified that are apparently attributable to long groundwater delays and the lack of a routing routine within BASINS.

7.0 Recommendations

More research needs to be done with regard to the use of watershed modeling in the plan development phase of the proposed Kentucky Framework For Watershed Management. This study focused on the streamflow aspects of the watershed, but water quality modeling should be investigated. Because the water quality modeling capabilities of SWAT are limited to the conservative constituents of sediment, nitrogen, phosphorus, and pesticides, a linkage of SWAT with a sophisticated water quality model such as QUAL2E or WASP5 might be advisable. Those in the watershed modeling field should pay close attention to the BASINS model as it develops more capabilities. Currently, BASINS is very rigid and coarse in its data inputs, but as technology grows, it has tremendous potential with its linkage of ArcView to its three models.

GIS could be used to improve upon the data collecting methods of this study. This could be done by either allowing GIS to automatically create the SWAT input files directly or simply using GIS to gather more of the input data. Work in this area has only recently been completed under the funding of the Kansas Water Office and the University of Kansas General Research Fund by Ling Bian, Hao Sun, Clayton Blodgett, Stephen Egbert, WeiPing Li, LiMei Ran, and Antonis Koussis. A report about their research can be found at http://ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/bian_ling/lbian.html on the Internet. The SWAT/ARCINFO interface created by their efforts can be downloaded as Arc Macro Files from the Internet at http://www.geog.buffalo.edu/~lbian. Other work is being done to link SWAT with ARCINFO by Yan Zhou at the University of Missouri. Her work is expected to be completed soon.

Better determinations of agreement between simulated and actual streamflow data can be distinguished by mathematical measurements. Methods such as the regression line slope, R^2 method, and Nash-Sutcliffe coefficient should be incorporated into future modeling efforts.

8.0 References

ArcView-The Geographic Information System for Everyone. Computer software. Environmental Systems Research Institute, Inc. 1995.

Arnold, J.G., J.R. Williams, and D.R. Maidment. "Continuous-Time Water and Sediment-Routing Model for Large Basins." Journal of Hydraulic Engineering 121 (1995): 171-183.

Arnold, J.G., and P.M. Allen, 1996. "Estimating Hydrologic Budgets for Three Illinois Watersheds." Journal of Hydrology 176 (1996): 57-77.

Arnold, J.G., J.R. Williams, R. Srinivasan, and K.W. King. "Soil and Water Assessment Tool-SWAT User's Manual." USDA-Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, TX. 1996.

Bicknell, B.R. , J.C. Imhoff, J. Kittle, A.S. Donigan, and R.C. Johansen. "Hydrological Simulation Program-HSPF. User's Manual for Release 10.0." EPA 600/3-84-064. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA. 1993.

Brown, L.C., and T.O. Barnwell, Jr. "The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual." EPA/600/3-87/007. U.S. Environmental Protection Agency, Washington, D.C. 1987.

El-Kadi, Aly I. "Watershed Models and Their Applicability to Conjunctive Use Management." Water Resources Bulletin 25 (1989): 125-136.

Hydrosphere Environmental Databases (Streamflow, Water Quality, Climate). Computer software. Hydrosphere Data Products, Inc. 1995.

Ivanov, P., I. Masliev, M. Kularathna, A. Kuzmin, and L. Somlyody. "DESERT: Decision Support System for Evaluating River Basin sTrategies." International Institute for Applied Systems Analysis (IIASA) Working Paper WP-95-23. 1995.

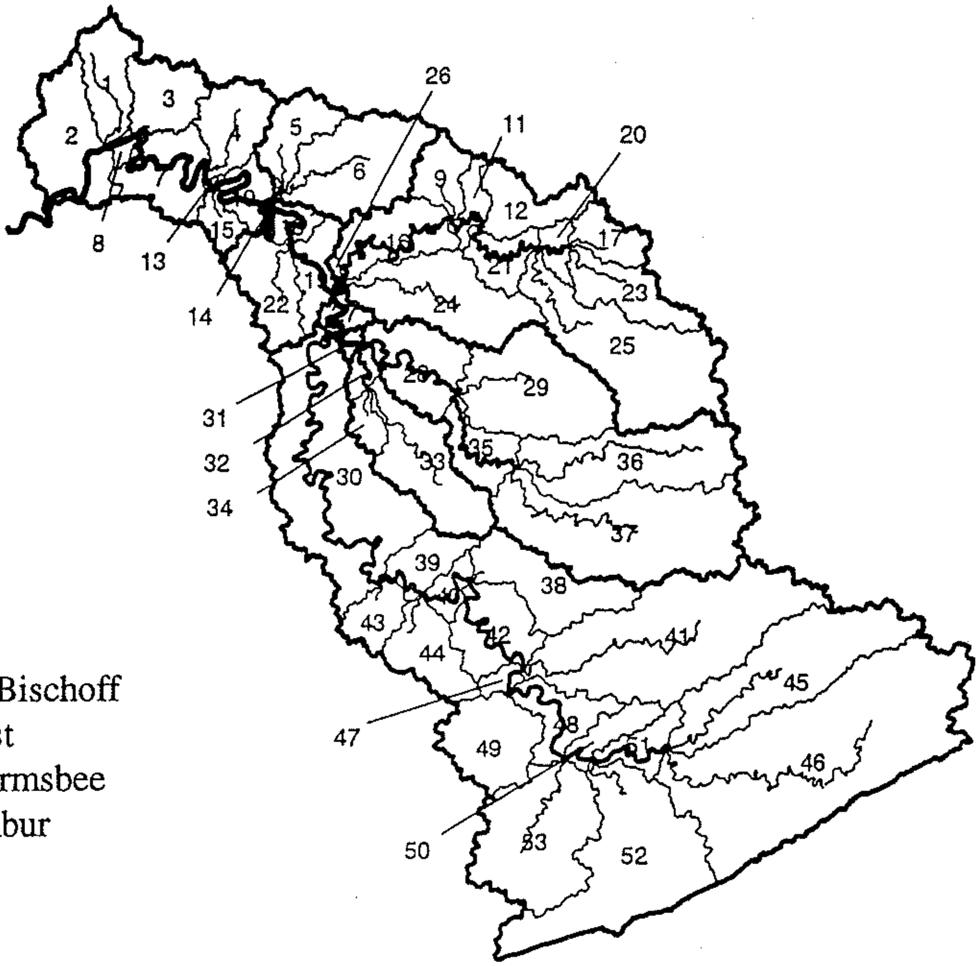
Lahlou, M., L. Shoemaker, M. Paquette, J. Bo, S. Choudhury, R. Elmer, F. Xia. "Better Assessment Science Integrating Point and Nonpoint Sources-BASINS. User's Manual for Version 1.0." EPA-823-R-96-001. U.S. Environmental Protection Agency, Exposure Assessment Branch, Washington, DC. 1996.

USEPA. "Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling." 2nd ed. EPA 600/3-85/040. U.S. Protection Agency, Environmental Research Laboratory, Athens, GA. 1985.

Viessman, Warren Jr., et al., Introduction to Hydrology. New York: 1977.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson,. "AGNPS: A non-point-source pollution model for evaluating agricultural watersheds." Journal of Soil and Water Conservation. March-April (1989): 168-173.

COMPUTER MODELING OF THE NORTH FORK OF THE KENTUCKY RIVER USING SWAT AND BASINS



Anthony Bischoff
Scott Yost
Lindell Ormsbee
Ted Stumbur

Prepared for:
The Kentucky Division of Water

Prepared By:
The University of Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky 40506

March 1997
KWRRI 9703

ABSTRACT

The purpose of this study was to investigate possible watershed models for use in the State of Kentucky's new watershed framework initiative and to apply the selected model(s) to the North Fork of the Kentucky River as part of an initial pilot project. As a result of an initial screening of over 30 models, two models were selected for a more detailed examination. These models included 1) the Soil and Water Assessment Tool (SWAT) and 2) the Better Assessment Science Integrating Point and Nonpoint Sources model (BASINS). Initial project objectives, which included both water quantity and water quality applications, were subsequently reduced to include water quantity simulations only. This modified project objective was necessitated as a result of several algorithmic problems that were identified with each model and that resulted in significant project delays as the research team was forced to interact with the initial model developers in an attempt to resolve these issues. A subsequent study will extended the hydrologic results generated in this study to include water quality impacts.

The results of this study indicate that the SWAT model can be calibrated to produce realistic results for the various watersheds modeled in this project. Subsequent validation runs revealed that the model is also able to predict the hydrologic response from the modeled watersheds with reasonable accuracy. Application of the BASINS model to the same watersheds was limited by the restriction of its application to 8-digit watersheds. Comparison of the BASINS results to the SWAT results revealed significant differences. Attempts to resolve these differences revealed the possibility of significant mass-balance problems with the BASINS model.

Although the BASINS modeling environment is superior to the SWAT environment, it would appear that the existing restriction of an 8-digit watershed application scale along with possible mass-balance inaccuracies clearly limit its general applicability in the development of detailed watershed management plans. It is our understanding that EPA is currently planning to update BASINS in order to expand its applicability to smaller basin areas as well as to improve its hydrologic modeling components. Should this be the case, it is possible that BASINS may surface as the model of choice. Until that time, however, it would appear that SWAT would be the preferable model of choice, at least for the development of detailed management plans.

Table of Contents

Water that flows through the soil layers reaches the shallow aquifer storage. From here, the water can flow to the channel as baseflow, it can escape by evaporation, or some may be lost to the deep aquifer. A simple groundwater flow model, dependent on a recession constant, determines how much of the shallow aquifer is discharged to the streamflow.

Some infiltrated water may be lost to the atmosphere through evapotranspiration. Evapotranspiration can be calculated by three different methods: Hargreaves, Priestly-Taylor, and Penman-Monteith. The Hargreaves method requires only air temperature data. Priestly-Taylor method needs solar radiation and air temperature information. The Penman-Monteith method uses solar radiation, air temperature, wind speed, and relative humidity data. When data is limited, the Hargreaves and Priestly-Taylor methods tend to give accurate results in most cases.

Moisture is lost to the atmosphere by simple evaporation from the soil and plant surfaces. Potential soil water evaporation depends on the potential evapotranspiration and leaf area index. The actual soil evaporation is calculated as an exponential function of the soil depth and water content. Plant water evaporation is dependent linearly on the potential evapotranspiration and leaf area index.

When snow is present, it is allowed to melt when the temperature is above 0°C. As snow melts, it is treated just like rainfall in determining the runoff and the percolation, except the energy of the rainfall is set to zero. When the rainfall energy is zero, the erosion caused by the impact of rainfall on the soil is not considered. For snow melt, a uniformly distributed 24 hour rainfall is assumed in order to calculate the peak runoff rate.

As water flows through the channels of the watershed, some is lost through the channel bed. Lane's method is used to calculate these transmission losses. They are dependent on the channel dimensions and flow duration.

Some of the surface flow is retained in surface impoundments such as small farm ponds. Outflow from these ponds are simulated assuming the properties of an emergency spillway. Storage is a function of pond capacity, daily inflows and outflows, seepage, and evaporation. When the pond is below capacity, its surface area is estimated non-linearly from the storage.

3.2 Weather

The five major factors controlling climate in SWAT are precipitation, air temperature, solar radiation, wind speed, and relative humidity. Daily precipitation and air temperature data can input directly into the model if data is available. SWAT also allows different weather data to be used for individual subbasins. If no data is available, SWAT can generate precipitation and air temperature values, along with values for solar radiation, wind speed, and relative humidity.

When no actual rainfall data is available, SWAT generates precipitation based on a first-order Markov chain model. The input of the monthly probability of rainfall occurring on a certain day depends on whether or not the previous day was wet or dry. As the model runs it uses the wet/dry state to determine stochastically the days when rainfall occurs. The amount of rainfall that occurs is then determined by a skewed normal daily precipitation distribution. Air temperature determines the precipitation to be rain or snow.

A normal distribution is used to calculate the air temperature and solar radiation with a correction for days when the weather is changing or is raining. Daily wind speed and daily humidity are found from their average monthly values based on a modified exponential equation and triangular distribution, respectively. Humidity is also corrected for rainy days.

3.3 Sedimentation

As flow occurs, so does erosion, which leads to sediment transport. Sediment loss is a function of runoff volume, peak runoff rates, above-ground biomass, crop residue on the surface, and the minimum crop management factor for the crop.

The hydrology and residue decay are affected by the temperature of the soil layers. Soil temperature of each layer is found independently and is a function of the damping depth of each layer and air temperature.

3.4 Crop Growth Model

SWAT simulates the growth of different crops on an annual rotation. The amount of energy absorbed by the crop depends on the solar radiation and the leaf area index of that particular crop. Growth of the crop depends on each crop's ability to convert the energy to biomass. As the crop grows, the leaf area index increases according to the heat units attained. Harvesting the crop is simulated by the harvest index which increases nonlinearly from zero at planting to a mature heat unit level at maturity.

3.5 Nutrients

Nitrogen can be found in the soil layers and it can be applied to the soil for agricultural purposes. It is present in the surface runoff, interflow, and percolation. The nitrogen loading is calculated as the product of the volume of water and the average concentration in the water. The organic nitrogen lost is based on the organic nitrogen concentration in the upper soil layer, the sediment yield, and the enrichment ratio.

Phosphorus is also found in the soil and can be added to the soil as fertilizer. Soluble phosphorus runoff is dependent on the amount of labile phosphorus in the top soil layer, runoff volume, and a partitioning factor. The sediment movement of phosphorus is estimated as a loading function just like organic nitrogen transport.

3.6 Pesticides

Many farming applications involve pesticides, so pesticide concentrations in the streamflow can become a serious problem and worthy of consideration in modeling. Pesticides can be applied at any depth in the soil or on the surface. Surface application efficiency depends on the leaf area index. The application efficiency determines the amount of pesticide that reaches the foliage, topsoil, and atmosphere. Not all of the pesticide that falls on the foliage and ground surface reaches the streamflow; some is lost to degradation and percolation. Pesticide degradation on plant foliage and in the soil is an exponential function of its half-life. Some pesticide is allowed to leach through the soil parallel to percolation.

3.7 Agricultural Management

A maximum of three crops per year can be simulated, with an unlimited number of crop rotations possible. The tillage component of SWAT controls the amount of biomass removed, tilled into the soil, and left as surface residue during times of harvest.

Dates and amounts of irrigation, nutrient applications, and pesticide applications can be specified. These can be applied by a trigger mechanism which activates when the soil reaches different threshold levels.

3.8 Channel Routing

The water that flows as surface runoff will flow into the channels. These channels must be routed to and from each other to create a stream network for the watershed. The channel flow is affected by reach length, channel slope, bankfull width and depth, channel side slope, flood plain slope, and Manning's n for both the channel and floodplain. Manning's equation is used to calculate the flowrate and average velocity. Travel time in the channel is important to the timeliness of the routing process and is found by dividing the channel length by the velocity. Adjustments to the channel flow are made as necessary for transmission losses, evaporation, diversions, and return flow.

Sediment routing in the channels has two components: deposition and degradation. Deposition deals with the rate at which the particle falls to the bottom of the channel as governed by Stokes Law. In Stokes Law, settling speed is a function of particle diameter. The major control of bed degradation, or erosion, is Bagnold's stream power concept. Stream power is the product of water density, flow rate, and water surface slope.

Nutrients and pesticides are treated as conservative constituents during channel simulation. Degradation of soluble chemicals is not modeled and chemicals attached to sediment settle to the bottom with the particle.

3.9 Reservoir Routing

Water that flows through a reservoir behaves quite differently from the streamflow and overland flow and requires unique treatment within the model. Water balance of reservoirs considers inputs from inflow, rainfall on the surface, and return flow. It also considers outputs from outflow, evaporation, seepage from the reservoir bottom, and diversions. Three methods are possible for modeling the outflow from the reservoir. First, the actual outflow data is read in as streamflow while all the other modeling components operate normally. The second method simulates small reservoirs to release flow at a specific rate when the storage level exceeds the principle storage. A third method handles large reservoirs where a monthly target release volume approach is utilized.

Sedimentation in a reservoir is also an important consideration. Sediment outflow is estimated as the product of the sediment concentration and the outflow volume. In between storms, the concentration is allowed to decrease over time where the median particle size decreases in the influent.

In simulating nutrients in the reservoir, the following assumptions are made: 1) completely mixed lake, 2) phosphorus limited, 3) total phosphorus can be a measure of trophic status. A completely mixed lake does not consider a stratification and the high level of phytoplankton in the epilimnon. A limited phosphorus condition would exist when nonpoint sources dominate. When total phosphorus is a measure of a lake's trophic status, then a relationship must exist between the total phosphorus and biomass. The phosphorus mass balance depends on the concentration in the lake, inflow, outflow, and an overall loss rate.

For pesticides, a well-mixed situation is assumed and a balance model is applied. This process involves a well-mixed surface water layer underlain by a well-mixed sediment layer. The pesticide is then separated into a soluble phase and particulate in the water and sediment layers. Major processes in the pesticide reservoir model include loading, outflow, reactions, volatilization, settling, diffusion, resuspension, and burial.

4.0 Methodology

4.1 Model Selection

Of the models identified earlier in this report, two were chosen for streamflow application in this study. Both Soil and Water Assessment Tool (SWAT) and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) meet many of the necessary modeling criteria. Although the models have different strengths and weaknesses, they are both applied to the North Fork of the Kentucky River for this study. SWAT is used to model both the entire North Fork watershed of 3416 km^2 and its Troublesome Creek tributary of 458 km^2. Each watershed is shown in Figure 4.1. Due to its limited 8-digit scale resolution, BASINS is used only to predict the streamflow out of the entire North Fork watershed; the Troublesome Creek tributary is too small of an area for BASINS to simulate. Because the input data for the BASINS model is generated automatically upon selection of a watershed and an associated rainfall station, the following discussion focuses on SWAT.

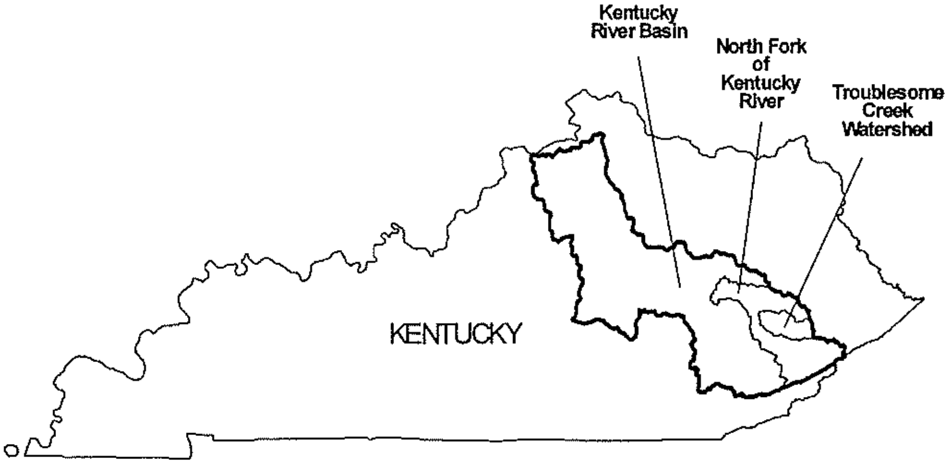


Figure 4.1: Location map of the North Fork of the Kentucky River and Troublesome Creek.

4.2 SWAT Input Data Requirements

SWAT is very data intensive and many parameters must be defined in order to use the model. There are nine types of input files per subbasin allowing the user to input well over 100 types of data per subbasin. Taking into account the number of subbasins in the model, this can result in an enormous amount of data that must be entered into SWAT. However, many of the parameters are given in tables provided by the User's Manual

(Arnold et al. 1996) and the help feature of the model. The physical data of the watershed can be determined from dependable survey data. Other data such as climate and streamflow data must be collected.

Because of the large amount of data to be acquired, special methods were used. GIS was used to collect and manage much of the physical data in the watershed, and Hydrosphere Data Products, Inc. data sets were used for the climate and streamflow data. The following physical data was collected using GIS: total watershed area, subbasin area, channel routing structure, distance to the furthest point in subbasin, mean subbasin elevation, mean subbasin slope, channel length, mean channel slope, landuse, climate gage and streamflow gage locations, and watershed delineation. Use of GIS significantly reduced the time in the data collection process and allowed the production of maps showing the layout of the study area in relation to the locations of the gaging stations.

All data was manually input into SWAT. The data input procedures assume that each subbasin contains homogeneous conditions. For example, one set of dominant soil properties are assumed constant over an entire subbasin area of several km^2. In reality, a wide range of soil properties exists throughout the subbasin and affects the runoff quite differently from the homogeneous situation. For the sake of simplicity and remaining within the limits of accuracy of the model, the assumption of a subbasin with homogeneous characteristics suffices. With proper calibration, the homogeneous characteristics input into the model can lead to an accurate simulation. Global settings of the model, such as the time period and time step, must also be defined.

4.3 Data Collection

Topography, soils, climate, streamflow, and water quality data are necessary for the SWAT model. Many sources of data were investigated, such as the Internet, United States Geological Survey (USGS), EPA STORET database, United States Department of Agriculture (USDA), Soil Conservation Service (SCS) Soil Surveys, University of Kentucky studies of Robinson Forest, National Climatic Data Center (NCDC), and the Midwestern Climate Center. For climate data, the NCDC and the Midwestern Climate Center were located at the Internet addresses in Table 4.1. Streamflow information was located at the USGS Internet address listed in Table 4.1, and locally within the University of Kentucky. The local information was found from a study conducted on Robinson Forest, an area which lies in the Troublesome Creek region of the North Fork. Water quality data was discovered at some USGS gaging stations, in the STORET EPA database, and locally within the University of Kentucky from the Robinson Forest study. After determining the data to be gathered and the means to acquire it, Hydrosphere Data Products, Inc. was selected as the source for climatic, streamflow, and water quality data. Hydrosphere provides a search engine to allow easy management of the data. The Hydrosphere software also allows the user to download the data in several formats, making it easier to convert to a usable form. A comparison of the data sources and their costs can be found in Table 4.2. The University of Kentucky library was used to collect soil surveys and topographical maps.

Description	**Internet Address**
NCDC	www.ncdc.noaa.gov
Midwestern Climate Center	http://mcc.sws.uiuc.edu
USGS	http://h2o.usgs.gov

Table 4.1: Internet addresses for data.

Source	**Description**	**Media**	**Cost**
NCDC	KY daily prec. and temp. data	CD	$120 per CD
Midwestern Climate Center	Daily prec. and temp. data	FTP	$2 per site
Hydrosphere	Subscription to daily prec. And temp. data	CD	$495 per CD
Hydrosphere	Subscription to daily streamflow	CD	$495 per CD
Hydrosphere	Subscription to STORET EPA Geoselect database	CD	$995 per CD
USGS	Daily streamflow for many stations	Diskettes	$250
Univ. of KY Forestry Dept.	Water quality and streamflow	Diskettes	free
STORET EPA	Water quality	FTP	free

Table 4.2: Data sources and applicable costs.

4.4 Determine General Guidelines of Simulation

Prior to running each model, some global modeling factors must be determined to focus the modeling effort. Organizing the geographical location and general descriptions of the available data is imperative to the project. GIS is very useful for learning about the spatial aspects of the available data.

By knowing locations of gaging stations and dates of the available climate and streamflow data, the user can determine the most appropriate time period and basin subdivision for modeling and subsequent calibration. This early step in the modeling process allows for strategic watershed delineations to align with the streamflow gaging station locations and for a realistic rain gage coverage to be assembled.

For this study, climatic data was found at a large number of stations, but the accuracy of the data was found to be suspect, especially in cases where many records of data were missing. The missing data was replaced by the record for that day from the nearest gaging station. Stations with a significant amount of missing data were omitted from the model. Climatic gaging stations used for the SWAT runs in this project are listed in

Table 4. In BASINS, all the climate data exists in the program, and the user must select from a list of five provided weather stations. These stations are DE Wilmington Airport, PA Philadelphia Airport, VA Richmond Airport, DC National Airport, and WV Charleston Airport. For this study, weather data from the WV Charleston Airport station was chosen. Although it is located 200 miles away, it remains the closest of the possible climate station choices for use in comparing the results of both SWAT and BASINS. When performing a direct comparison between SWAT and BASINS, the WV Charleston Airport climate data was converted to daily data for use in the SWAT model.

Title/Location of Climate Station	**Station ID Number**
Heidelberg	3741
Jackson	4196
Salyersville 2 SE	7134
Buckhorn Lake	1080
Hindman 11 NNE	3896
Hazard Water Works	3714
Jeremiah 1 S	4255
Pine Mountain 3 NW	6379
Cumberland	1964
Cumberland 2	1965

Table 4.3: Climatic gaging stations available for the SWAT model.

Streamflow stations used for model comparison were located at Noble (USGS # 03278500), Hazard (USGS # 03277500), Jackson (USGS # 03280000), and Clemon's Fork. The station at Noble is used to calibrate the outflow of Troublesome Creek. A streamflow comparison of Clemon's Fork, within Troublesome Creek, was also conducted. Unfortunately, streamflow data at the outlet of the North Fork could not be located, so streamflow data at Hazard and Jackson were used to calibrate the upper and lower runs of the entire North Fork. For a spatial representation of the climate and streamflow gages used during this study see Figure 4.2.

After examining the available streamflow data, the period from 1970 to 1975 was selected as a focus for the study because of the reliability and amount of data. This range of time allowed data from many of the streamflow and climate stations to overlap which led to dependable comparisons during the calibration phase of the project.

The process of assembling the rainfall and temperature input files for use in the SWAT model requires significant effort. Not only downloading data from the source, but converting it into proper units and format requires considerable preprocessing efforts. For example, precipitation data downloaded from the Hydrosphere database needs to be

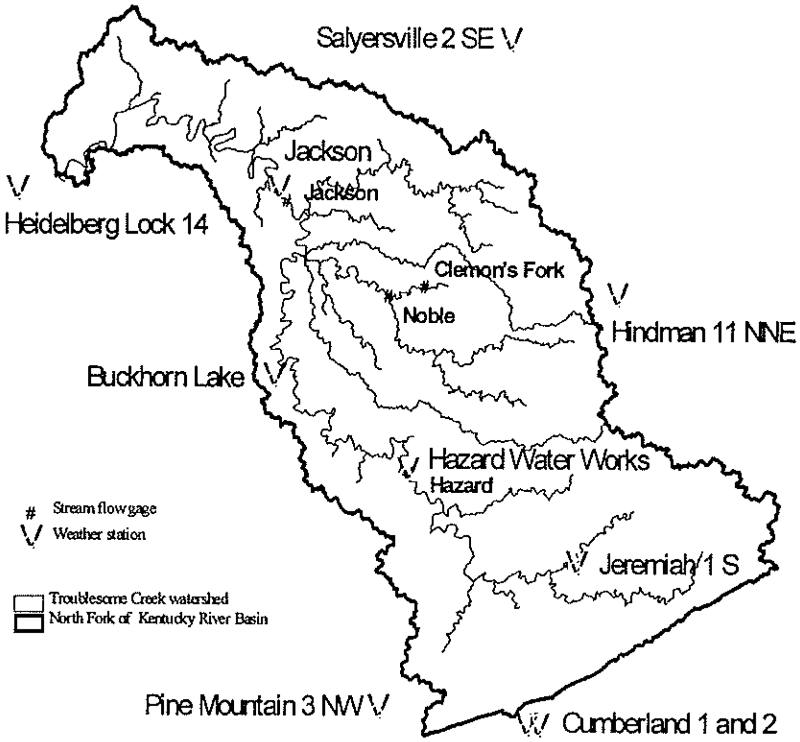


Figure 4.2: Map of climate and streamflow stations.

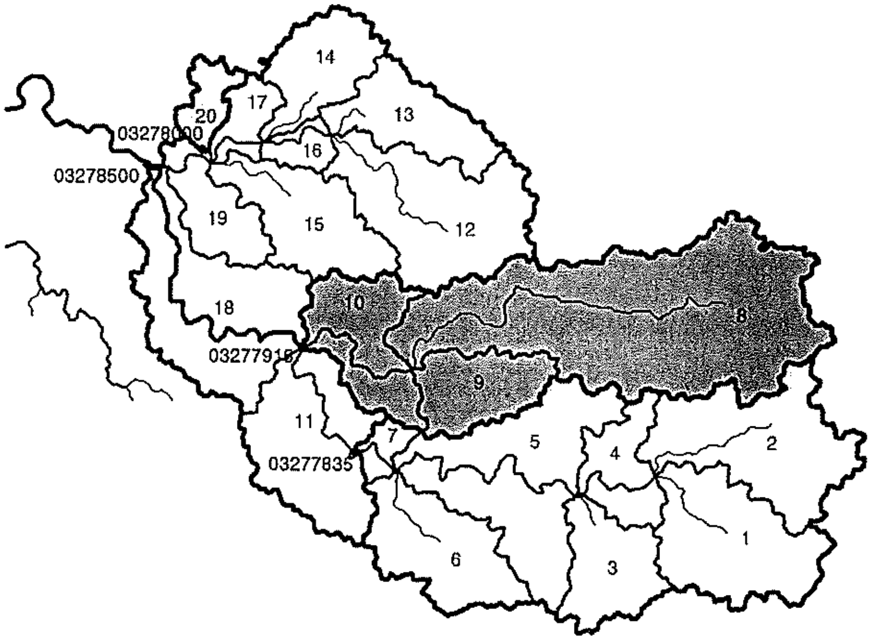


Figure 4.3: Troublesome Creek (14-digit watershed delineation).

Figure 4.4: Entire North Fork of the Kentucky River (11-digit watershed delineation).

converted from inches to millimeters. Then, the precipitation data must be converted to an ASCII file in a proper format for SWAT input. These two tasks are performed using a spreadsheet application and a FORTRAN data conversion program.

It is very important to delineate the number of subbasins in the watershed prior to applying a model. The entire North Fork of the Kentucky River watershed exists without any delineation at the USGS 8-digit scale. Troublesome Creek is subdivided into 19 subbasins at a 14-digit scale and 4 subbasins at the 11-digit scale. These delineations are shown in Figures 4.3 and 4.4. The entire North Fork was modeled at the 11-digit scale resulting in 53 subbasins. This creates a problem for the modeler because the SWAT Windows Interface maximum subbasin limit is 30. To address this problem, the watershed was split into two sections: an upper section and a lower section. The two sections were run sequentially separately and linked by the output hydrograph from the upper section. An 8-digit scale was used for the BASINS run of the entire North Fork because this scale is the only delineation BASINS can simulate.

4.5 Developing the Soil Input Parameters

The soil input parameters are dependent on the many different qualities of the dominant soil association within a particular subbasin. For each basin, the dominant soil association is determined, and the percentages of the major types of soils within the association are found. Next, each of the major types of soils is located in the SWAT soils database, and the values for each soil are recorded. Then, a weighted average using the soil values and the percentages of the soil association is calculated. This weighted average represents the average soil qualities for the entire subbasin, and its values are input manually into the soil file (.sol) of SWAT.

The development of the soil input files for SWAT could be an automated process through incorporation of GIS. By utilizing the STATSGO database as a coverage layer, GIS has the capabilities to determine the dominant soil coverages over individual subbasins and export the associated soil qualities to a table. This table can then be arranged into a format acceptable for a SWAT run. Future work in this area and others like it would prove very useful in assisting the SWAT modeler in completing a SWAT run.

4.6 Running the Model

SWAT can be controlled from a DOS environment or from the Windows Interface. By running SWAT from the DOS environment, much time can be conserved. The data input into the Windows environment is converted into ASCII file format by SWAT when it creates the run files in a preprocessing routine. Once the run files have been completed, some editing of them may be necessary. This project required some editing to link two watershed sections, known as the upper and lower, and some adjustments had to be made to the soil files (.sol).

To accomplish the watershed linkage, a SWAT run for each section is made. Logically, the upper, or higher elevation, section is run first because it feeds the lower section. The output hydrograph from the upper run is saved using the SAVE command in the routing structure file (.fig). The file is saved under the title listed in the second row of the first column of the input data file listing of the "file.cio" file. The hydrograph from the upper run is then read into the lower run at the location in the watershed where the upper section connects to the lower section. The read file command, RECDAY, is inserted into the proper location in the routing structure file (.fig), and it references the file name listed on the next line. Using the SAVE command again in the routing structure file (.fig) of the lower section, any designated hydrograph may be saved for analysis. For an example of these ".fig" and "file.cio" files see Appendix A. This entire process is accomplished from the DOS environment because these features cannot be controlled using the Windows Interface.

Another editing issue to be addressed involves editing the soil files (.sol). The Windows Interface does not create the soil files accurately. When the Windows Interface creates the run files, some of the data in the soil files are missing, and some are located in the wrong columns. This should be corrected in the DOS environment according to the soil files (.sol) shown in Appendix A.

After completing these changes, the model is run in the DOS mode using the command SWAT942. When the model stops running, either an error message or "Stop - Program terminated." will appear on the screen. If the message says "Stop - Program terminated.", then the run was successful. If a different message occurs, a problem was encountered, and it must be fixed before the run is successful.

4.7 Output Module

A successful run of SWAT will indicate that all the data is input correctly, and calibration becomes the next step. To obtain a decent calibration, the output of the model must be analyzed on a daily time step. Calibration efforts based on a monthly time step proved to be unsuccessful because the filtering process of taking the average monthly flows could lead to improved monthly results at the expense of daily accuracy. The monthly or annual time scale does not give the user accurate information about the peak flows, baseflows, and hydrograph lags being modeled. Also, the monthly and annual time scales do not show the user exactly how the hydrograph was affected by an adjustment of the input data. A daily time step will show these essential details making it very valuable to the calibration effort. **The SWAT model, however, does not come with a daily output comparison module.** A daily output comparison module was created for this project using the Microsoft Excel spreadsheet.

The output module imports the SWAT output hydrograph and presents daily and monthly streamflow comparison charts to the modeler. All necessary conversion calculations and data organization is accomplished by the output module "with the push of a button." The basic operational concept of the output module is shown in Figure 4.5.

The major components of the output module are the engine, actual streamflow data storage, charts, macros, and control pad. The engine is given its own worksheet and acts as the driving mechanism of the spreadsheet. It performs the necessary conversions to the SWAT output data. For the explicit purpose of comparing the two data sets in a graphical display, the engine acts as a temporary housing station for the actual and simulated streamflow data. For each station of actual streamflow data, a separate worksheet exists to keep the data organized. This is the permanent storage area for the actual streamflow data. When the data is needed for charting purposes, it is copied into the engine worksheet. The charts are also located within a separate worksheet for the sake of organization. Charts are created on both a daily and monthly basis to compare the simulated streamflow to the actual streamflow. The processes of copying the simulation output hydrograph and the actual hydrograph into the engine worksheet are recorded as separate macros. A separate macro is created to each station of actual streamflow data into the engine. Finally, a control pad is designed to contain multiple hotkeys which are assigned the command of executing the "copying" macros. This control pad exists to

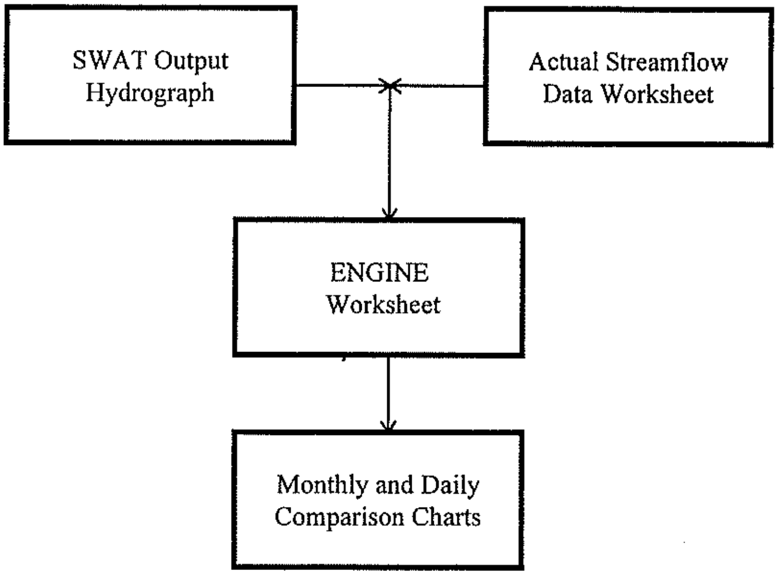


Figure 4.5: Basic Operational Concept of the Output Module.

make things easier on the user of the output module. See Appendix B for a step by step procedure for creating and operating the output module.

Depending on the size of the output file (.eve), the Microsoft Excel spreadsheet row limit of 16,384 may be encountered. This is an unlikely scenario because it would require a simulation of 44 years to approach this limit.

Like SWAT, BASINS lacks a graphical output module. The one used for comparison of the SWAT output and actual data was adopted and edited for the purpose of comparing the outputs of BASINS and SWAT.

4.8 Sensitivity Analysis

Before calibrating the SWAT model, the user must have an understanding of which inputs can be adjusted and the corresponding sensitivities of the applicable input values. Many of the input parameters for SWAT were subjected to sensitivity tests for this reason. In each case, the parameter was adjusted and its effect on the output hydrograph was recorded. Two general sensitivity analyses were conducted, one for monthly output and one for daily output. The monthly sensitivity analysis results are shown in Table 4.4, and the daily sensitivity analysis results are shown in Table 4.5. Some adjustments had no impact on the output hydrographs while others demonstrated some major effects.

Parameter Identification (File)	**Change**	**Effect**
Evapotranspiration (.cod)	Priestly-Taylor to Penman-Monteith	Increased outflow
Evapotranspiration (.cod)	Priestly-Taylor to Hargreaves	Intermittently increased outflow
Baseflow factor (.bsn)	1 to 0	No effect
Basin lag time (.bsn)	0 to 1	No effect
Initial soil-water storage (.bsn)	0 to 1	No effect
Curve number (.sub and .mgt)	77 to 25	Lowered peak outflows
Curve number (.sub and .mgt)	77 to 95	Raised peak outflows
Effective hydr. cond. (.sub and .rte)	75 to 0	Raised most outflows
Channel N value (.sub)	0.1 to 0.3	Lowered most outflows
Overland flow N value (.sub)	0.15 to 0.5	Raised and lowered a few outflows
Return flow travel time (.sub)	0 to 150	No effect
Return flow travel time (.sub) and baseflow factor (.bsn)	0 to 150 and 1 to 0.5, respectively	No effect
Average slope length (.sub)	0 to 150	Increased all outflows
Groundwater height (.gw)	0.1 to 25	No effect
Initial groundwater flow contribution to streamflow (.gw)	0.4 to 10	Raised first outflow
Alpha for groundwater (.gw)	0.6 to 1	Raised first outflow
Specific yield (.gw)	0.1 to 0.4	No effect
Groundwater delay (.gw)	7 to 400	Raised early outflows and lowered later peak outflows
Revap coeff.-fraction of recharge (.gw)	0 to 1	No effect
Fraction of root zone percolation (.gw)	0 to 1	No effect
Revap storage (.gw)	0 to 50	Lowered first several outflows
Initial deep aquifer storage (.gw)	0 to 2500	No effect
Hydraulic conductivity (.sol)	75 to 150	Lowered most outflows
Available water capacity	To lower limit	Raised most outflows
Available water capacity (.sol)	To upper limit	Lowered most outflows

Table 4.4: Monthly sensitivity analysis results.

Parameter Identification (File)	Change	Effect
Alpha factor (.gw)	0.6 to 0.95	None
Alpha factor (.gw)	0.6 to 0.05	Affects early baseflow
Specific yield (.gw)	0.1 to 0.4	No effect
Specific yield (.gw)	0.1 to 0.01	No effect
Groundwater delay (.gw)	20 to 200	Increased all outflows
Available water capacity (.sol)	To lower limit	Increased peak outflows, more sensitive
Available water capacity (.sol)	To upper limit	Lowered peak outflows, less sensitive
Basin lag time (.bsn)	0 to 10	No effect
Basin lag time (.bsn)	0 to 100	No effect
Revap storage (.gw)	50 to 0.5	Removed baseflow jump at start
Initial groundwater height (.gw)	0 to 25	No effect
Initial groundwater contribution (.gw)	5 to 1	Lowered baseflow
Hydraulic conductivity (.sol)	100 to 1000	Increased peak outflow, no lag
Hydraulic conductivity (.sol)	100 to 50	Increased lag
Overland N	0.15 to 0.6	No effect
Average slope length (.sub)	40 to 30	Increased peak outflows, more sensitive
Average slope length (.sub)	40 to 50	Increased lag

Table 4.5: Daily sensitivity analysis results.

Several important discoveries were made from the sensitivity analysis. Curve number adjustments proved to have a major effect on the magnitude of the hydrograph peaks. Low curve numbers were found to increase the amount of water which reached the shallow aquifer. The available water capacity of the soil was found to resemble the behavior of a sponge where as the available water capacity increased, so did the soil's ability to absorb rainfall. This behavior was observed in the sensitivity of the hydrograph where small precipitation events appear as small impulses for low available water capacities. As the available water capacity increases, these small precipitation events are absorbed by the soil and have less effect on the surface hydrograph.

Average slope length of the land was shown to have a major effect on the sensitivity and hydrograph lags of large precipitation events. Adjustments to the hydraulic conductivity of the soil affected the lags and peaks of the hydrographs. Revap-storage was found to have some major control over the initial groundwater contributions to streamflow. In its calculations, SWAT will not allow water to flow from the shallow aquifer until the revap-storage level is met. If the revap-storage is set fairly high, this can lead to a jump in groundwater contributions within the first several days of the simulation. This jump can be avoided by setting a low revap-storage.

4.9 Calibrate/Verify Model

Many of the inputs to the SWAT model are physically-based on the characteristics of the watershed. Although these input values were measured or determined by a definite process, they were developed based on the assumption of homogeneity throughout the subbasin. This simply is not a realistic assumption, especially as the size of the watershed is increased, so some of the input values may need to be adjusted within a reasonable range to improve the performance of the model.

In a study entitled "Estimating Hydrologic Budgets For Three Illinois Watersheds" by J.G. Arnold and P.M. Allen, a SWAT calibration was conducted (Arnold and Allen, 1996). The values of the soil input parameters were adjusted within the uncertainty ranges, and the curve number was allowed to vary between its values for good, fair, and poor hydrologic conditions. These parameters were used to manually calibrate the model for annual streamflow and annual surface runoff and groundwater contributions.

The SWAT models created in this study were calibrated based on the calibration process suggested by J.G. Arnold. He recommends the following calibration process: 1) Adjust the curve number to the poor or good limit of the hydrologic soil group, 2) adjust the available water capacity within the designated tolerances, 3) adjust the storage of the shallow aquifer or the revap storage. Adjustment of the average slope length and the hydraulic conductivity within reasonable limits was also found to have a major and justifiable effect on the streamflow.

This study has used the skill of the modeler to determine the accuracy of the output hydrographs. In the future, it is advised to incorporate some mathematical procedures to measure the accuracy of the simulations. Possible measures of model accuracy might be found in the regression line slope and R^2 methods where values close to unity correspond to high accuracy. The Nash-Sutcliffe coefficient goodness-of-fit criterion should also be considered because it is recommended by the American Society of Civil Engineers (ASCE) Task Committee on Evaluation Criteria for Watershed Models (Arnold, 1995).

When edited and run within the Windows Interface, SWAT can take 5 to 10 minutes, depending on the processing speed of the computer, to recreate all of the run files. During this process, SWAT copies over the already existing files, erasing any corrections previously made. To save time, it is recommended to make the calibration adjustments to the model in the DOS environment. It allows the user to be more efficient if the subbasins can share the same file names. An example of two subbasins sharing the same file name might be where two subbasins have the same dominant soil properties. In this case, the same soil file can be assigned to both subbasins in the "file.cio" input file. If a parameter is adjusted for calibration, then only the one soil file assigned to both subbasins would need to be edited. Also, the changes made to the routing (.fig) and soil (.sol) files do not need to be redone. SWAT can be run again in the DOS mode by the SWAT942 command.

9.0 Appendices

Appendix A: Editing SWAT Files

Appendix B: Steps to Create and Operate the Output Module

Appendix C: Daily Output Charts

Appendix D: Information Sources

Appendix A: Editing SWAT Files

“Upper.fig” is the routing file for the upper section of the North Fork. The save command was added near the end of the file. The number 9 corresponds with the save command and the 79 defines the hydrograph to be saved. In this case, 79 is the output hydrograph of the simulation.

The “file.cio” file is presented to show where the title of the output hydrograph is located. Notice the file name “upper.out” in the second row of the first column of data files. The output hydrograph saved in the “upper.fig” file will be assigned this title.

“Lower.fig” is the routing file for the lower section of the North Fork. It serves as the link between the upper and lower sections. The recday command inserts the hydrograph saved under the title “upper.out” to be inserted at this point in the routing file. The number 10 corresponds to the recday command, and the 77 is the number to be assigned to the imported hydrograph.

The last two files are shown to demonstrate the edits necessary to the soil input files. Note the differences between the pre-edited file and the post-edited file.

UPPER.FIG

```
subbasin  1     1     1     1
subbasin  1     2     2     2
subbasin  1     3     3     3
subbasin  1     4     4     4
subbasin  1     5     5     5
subbasin  1     6     6     6
subbasin  1     7     7     7
subbasin  1     8     8     8
subbasin  1     9     9     9
subbasin  1     10    10    10
subbasin  1     11    11    11
subbasin  1     12    12    12
subbasin  1     13    13    13
subbasin  1     14    14    14
subbasin  1     15    15    15
subbasin  1     16    16    16
subbasin  1     17    17    17
subbasin  1     18    18    18
subbasin  1     19    19    19
subbasin  1     20    20    20
subbasin  1     21    21    21
subbasin  1     22    22    22
subbasin  1     23    23    23
subbasin  1     24    24    24
subbasin  1     25    25    25
subbasin  1     26    26    26
subbasin  1     27    27    27
route     2     28    3     1
add       5     29    3     28
route     2     30    3     2
add       5     31    29    30
route     2     32    5     31
add       5     33    5     32
route     2     34    5     4
add       5     35    33    34
route     2     36    7     35
add       5     37    7     36
route     2     38    7     6
add       5     39    37    38
route     2     40    9     39
add       5     41    9     40
route     2     42    9     8
add       5     43    41    42
route     2     44    11    43
add       5     45    11    44
route     2     46    11    10
add       5     47    45    46
route     2     48    13    47
add       5     49    13    48
route     2     50    13    12
add       5     51    49    50
route     2     52    15    51
add       5     53    15    52
route     2     54    15    14
add       5     55    53    54
route     2     56    17    55
add       5     57    17    56
route     2     58    17    16
```

```
add       5     59    57    58
route     2     60    27    59
add       5     61    27    60
route     2     62    20    18
add       5     63    20    62
route     2     64    20    19
add       5     65    63    64
route     2     66    22    65
add       5     67    22    66
route     2     68    22    21
add       5     69    67    68
route     2     70    26    69
add       5     71    26    70
route     2     72    25    23
add       5     73    25    72
route     2     74    25    24
add       5     75    73    74
route     2     76    26    75
add       5     77    71    76
route     2     78    27    77
add       5     79    61    78
save      9     79
finish    0
```

```
file.cio file for project: UPPERNFKY

upper.std    upper.sbs    upper.rch    upper.rsv    upper.lqo    upper.pso
upper.out     crop.dat     till.dat     pest.dat    upper.cod    upper.bsn
upper.lwq    upper.fig    0            upper.bsb
   1   1
nf8090.pcp


nf8090.tmp



1    0 0    0 0  upper1.sub   upper1.rte   upper1.pnd   upper1.chm   upper1.sol
  upper1.mgt   upper1.mco   upper1.gw    upper1.wgn   7   1
2    0 0    0 0  upper2.sub   upper2.rte   upper2.pnd   upper2.chm   upper1.sol
  upper2.mgt   upper2.mco   upper2.gw    upper2.wgn   7   1
3    0 0    0 0  upper3.sub   upper3.rte   upper3.pnd   upper3.chm   upper1.sol
  upper3.mgt   upper3.mco   upper3.gw    upper3.wgn   7   1
4    0 0    0 0  upper4.sub   upper4.rte   upper4.pnd   upper4.chm   upper1.sol
  upper4.mgt   upper4.mco   upper4.gw    upper4.wgn   2   1
5    0 0    0 0  upper5.sub   upper5.rte   upper5.pnd   upper5.chm   upper1.sol
  upper5.mgt   upper5.mco   upper5.gw    upper5.wgn   7   1
6    0 0    0 0  upper6.sub   upper6.rte   upper6.pnd   upper6.chm   upper1.sol
  upper6.mgt   upper6.mco   upper6.gw    upper6.wgn   2   1
7    0 0    0 0  upper7.sub   upper7.rte   upper7.pnd   upper7.chm   upper1.sol
  upper7.mgt   upper7.mco   upper7.gw    upper7.wgn   6   1
8    0 0    0 0  upper8.sub   upper8.rte   upper8.pnd   upper8.chm   upper1.sol
  upper8.mgt   upper8.mco   upper8.gw    upper8.wgn   6   1
9    0 0    0 0  upper9.sub   upper9.rte   upper9.pnd   upper9.chm   upper1.sol
  upper9.mgt   upper9.mco   upper9.gw    upper9.wgn   6   1
10   0 0    0 0  upper10.sub  upper10.rte  upper10.pnd  upper10.chm  upper1.sol
  upper10.mgt  upper10.mco  upper10.gw   upper10.wgn  6   1
11   0 0    0 0  upper11.sub  upper11.rte  upper11.pnd  upper11.chm  upper1.sol
  upper11.mgt  upper11.mco  upper11.gw   upper11.wgn  6   1
12   0 0    0 0  upper12.sub  upper12.rte  upper12.pnd  upper12.chm  upper1.sol
  upper12.mgt  upper12.mco  upper12.gw   upper12.wgn  6   1
13   0 0    0 0  upper13.sub  upper13.rte  upper13.pnd  upper13.chm  upper1.sol
  upper13.mgt  upper13.mco  upper13.gw   upper13.wgn  6   1
14   0 0    0 0  upper14.sub  upper14.rte  upper14.pnd  upper14.chm  upper1.sol
  upper14.mgt  upper14.mco  upper14.gw   upper14.wgn  6   1
15   0 0    0 0  upper15.sub  upper15.rte  upper15.pnd  upper15.chm  upper1.sol
  upper15.mgt  upper15.mco  upper15.gw   upper15.wgn  6   1
16   0 0    0 0  upper16.sub  upper16.rte  upper16.pnd  upper16.chm  upper1.sol
  upper16.mgt  upper16.mco  upper16.gw   upper16.wgn  6   1
17   0 0    0 0  upper17.sub  upper17.rte  upper17.pnd  upper17.chm  upper1.sol
  upper17.mgt  upper17.mco  upper17.gw   upper17.wgn  5   1
18   0 0    0 0  upper18.sub  upper18.rte  upper18.pnd  upper18.chm  upper1.sol
  upper18.mgt  upper18.mco  upper18.gw   upper18.wgn  6   1
19   0 0    0 0  upper19.sub  upper19.rte  upper19.pnd  upper19.chm  upper1.sol
  upper19.mgt  upper19.mco  upper19.gw   upper19.wgn  6   1
20   0 0    0 0  upper20.sub  upper20.rte  upper20.pnd  upper20.chm  upper1.sol
  upper20.mgt  upper20.mco  upper20.gw   upper20.wgn  5   1
21   0 0    0 0  upper21.sub  upper21.rte  upper21.pnd  upper21.chm  upper1.sol
  upper21.mgt  upper21.mco  upper21.gw   upper21.wgn  5   1
22   0 0    0 0  upper22.sub  upper22.rte  upper22.pnd  upper22.chm  upper1.sol
  upper22.mgt  upper22.mco  upper22.gw   upper22.wgn  5   1
23   0 0    0 0  upper23.sub  upper23.rte  upper23.pnd  upper23.chm  upper1.sol
  upper23.mgt  upper23.mco  upper23.gw   upper23.wgn  5   1
```

```
24   0 0    0 0  upper24.sub  upper24.rte  upper24.pnd  upper24.chm  upper1.sol
  upper24.mgt  upper24.mco  upper24.gw   upper24.wgn  5   1
25   0 0    0 0  upper25.sub  upper25.rte  upper25.pnd  upper25.chm  upper1.sol
  upper25.mgt  upper25.mco  upper25.gw   upper25.wgn  5   1
26   0 0    0 0  upper26.sub  upper26.rte  upper26.pnd  upper26.chm  upper1.sol
  upper26.mgt  upper26.mco  upper26.gw   upper26.wgn  4   1
27   0 0    0 0  upper27.sub  upper27.rte  upper27.pnd  upper27.chm  upper1.sol
  upper27.mgt  upper27.mco  upper27.gw   upper27.wgn  4   1
```

LOWER.FIG

```
subbasin  1     1     1     1
subbasin  1     2     2     2
subbasin  1     3     3     3
subbasin  1     4     4     4
subbasin  1     5     5     5
subbasin  1     6     6     6
subbasin  1     7     7     7
subbasin  1     8     8     8
subbasin  1     9     9     9
subbasin  1     10    10    10
subbasin  1     11    11    11
subbasin  1     12    12    12
subbasin  1     13    13    13
subbasin  1     14    14    14
subbasin  1     15    15    15
subbasin  1     16    16    16
subbasin  1     17    17    17
subbasin  1     18    18    18
subbasin  1     19    19    19
subbasin  1     20    20    20
subbasin  1     21    21    21
subbasin  1     22    22    22
subbasin  1     23    23    23
subbasin  1     24    24    24
subbasin  1     25    25    25
subbasin  1     26    26    26
route     2     27    3     1
add       5     28    3     27
route     2     29    3     2
add       5     30    28    29
route     2     31    6     30
add       5     32    6     31
route     2     33    6     4
add       5     34    32    33
route     2     35    8     5
add       5     36    8     35
route     2     37    8     34
add       5     38    36    37
route     2     39    10    7
add       5     40    10    39
route     2     41    10    38
add       5     42    40    41
route     2     43    11    9
add       5     44    11    43
route     2     45    11    42
add       5     46    44    45
route     2     47    12    46
add       5     48    12    47
recday    10    77
          upper.out
add       5     78    77    48
route     2     49    14    78
add       5     50    14    49
route     2     51    14    13
add       5     52    50    51
route     2     53    18    52
add       5     54    18    53
route     2     55    15    16
```

```
add       5     56    15    55
route     2     57    15    17
add       5     58    56    57
route     2     59    20    19
add       5     60    20    59
route     2     61    22    21
add       5     62    22    61
route     2     63    24    23
add       5     64    24    63
route     2     65    26    25
add       5     66    26    65
route     2     67    18    58
add       5     68    54    67
route     2     69    20    68
add       5     70    60    69
route     2     71    22    70
add       5     72    62    71
route     2     73    24    72
add       5     74    64    73
route     2     75    26    74
add       5     76    66    75
save      9     49
finish    0
```

```
UPPER1.SOL (PRE EDIT)

.sol file for project: UPPERKY    subbasin number: 1
 4db
 Maximum rooting depth               .00
 Texture                             .00
 Depth (mm)                       222.50      745.74      866.65         .00
 Bulk Density (t/m^3)               1.34        1.35        1.35         .00
 Available Water Cap (m/m)           .11         .09         .07         .00
 Sat. Cond. (mm/h)                 30.24       20.08       15.71         .00
 Organic Carbon Content(%)          1.57
 Clay Content(%)                   15.32       14.48       12.16         .00
 Silt Content(%)**                   .00
 Sand Content(%)**                   .00
 Rock Fragments(%)**                 .00
 Moist Soil Albedo**                 .00
 Dry Soil Albedo**                   .00
 USLE Erosion K-factor               .21
 Salinity**                          .00
 Initial NO3 Conc (g/t)            10.00        5.00        5.00
```

UPPER1.SOL (POST EDIT)

```
.sol file for project: UPPERNFKY    subbasin number: 1
 4db
 Maximum rooting depth              .00
 Texture                            .00
 Depth (mm)                       10.00       222.50       745.74       866.65
 Bulk Density (t/m^3)              1.34         1.34         1.35         1.35
 Available Water Cap (m/m)          .11          .11          .09          .07
 Sat. Cond. (mm/h)                30.24        30.24        20.08        15.71
 Organic Carbon Content(%)         1.57         1.57
 Clay Content(%)                  15.32        15.32        14.48        12.16
 Silt Content(%)**                  .00
 Sand Content(%)**                  .00
 Rock Fragments(%)**                .00
 Moist Soil Albedo**                .00
 Dry Soil Albedo**                  .00
 USLE Erosion K-factor              .21
 Salinity**                         .00
 Initial NO3 Conc (g/t)           10.00        10.00         5.00         5.00
```

Appendix B: Steps to Create and Operate the Output Module

The output module is site specific and must be rewritten for each specific application. A modification or new macro creation would be necessary if a change in watershed selection or length of simulation time period was conducted. A modification would also be necessary if the name of the SWAT output file was changed. Below are instructions on creating and operating the SWAT output module.

1. Export actual streamflow data, for the applicable years, from the Hydrosphere database in the Lotus spreadsheet format to an individual file for each station.

2. Open the Microsoft Excel spreadsheet.

3. Assign titles to individual worksheets for the ENGINE, CONTROL PAD, and CHARTS. Also, assign a title for each station of actual streamflow data to individual worksheets. This sets up the structure of the output module.

4. Copy the actual data for each station into its appropriate worksheet in the output module. Assemble the data into a continuous column removing the extra space left in for leap years. Perform a check by counting the number of records copied and formatted by turning an adjacent column into a timeline. Convert the actual streamflow data from CFS to CMS. CMS are the units that will be used for comparison.

5. In the ENGINE worksheet, assign titles to the columns for days, daily actual data (CMS), daily simulated data (CMS), daily simulated data input (CMD), months, monthly actual data (CMS), and monthly simulated data (CMS). These columns will be used to temporarily house the associated comparison data and convert the simulated output from CMD to CMS.

6. Create a timeline in the days and months columns in the ENGINE worksheet.

7. Import the simulated streamflow data from the SWAT output file (.eve) into the daily simulated input (CMD) column of the ENGINE worksheet. Create a macro that will open the SWAT output file and do this automatically.

8. Convert the simulated data from CMD to CMS, placing the result in the daily simulated data (CMS) column.

9. Copy the actual streamflow data from the associated actual streamflow data worksheet into the daily actual data (CMS) column. Create a macro that will do this automatically.

10. Using the actual and simulated daily data just established, sum up and average it on a monthly basis. Place the results under the monthly actual data and monthly simulated data, accordingly.

11. In the CHARTS worksheet, create a set of charts that will show a comparison of the daily actual and simulated data over time. Do the same for the monthly results.

12. On the CONTROL PAD worksheet, create multiple hotkeys to run the individual macros recorded in steps 7 and 9. Entitle each hotkey according to the function of the specific macro it will run.

13. After a SWAT run is complete, the CONTROL PAD will allow the user to run the output module automatically. The necessary actual streamflow data can be loaded into the ENGINE "with the push of a button." Just as easily, the SWAT output data can also be imported into the ENGINE.

14. A shift to the CHARTS worksheet will show a graphical comparison of the SWAT run to the actual data on both a daily and monthly basis.

Appendix C: Daily Output Charts

C.1: Daily streamflow comparison for Clemon's Fork using SWAT.

C.2: Daily 14-digit streamflow comparison of Troublesome Creek using SWAT.

C.3: Daily 11-digit streamflow comparison of Troublesome Creek using SWAT.

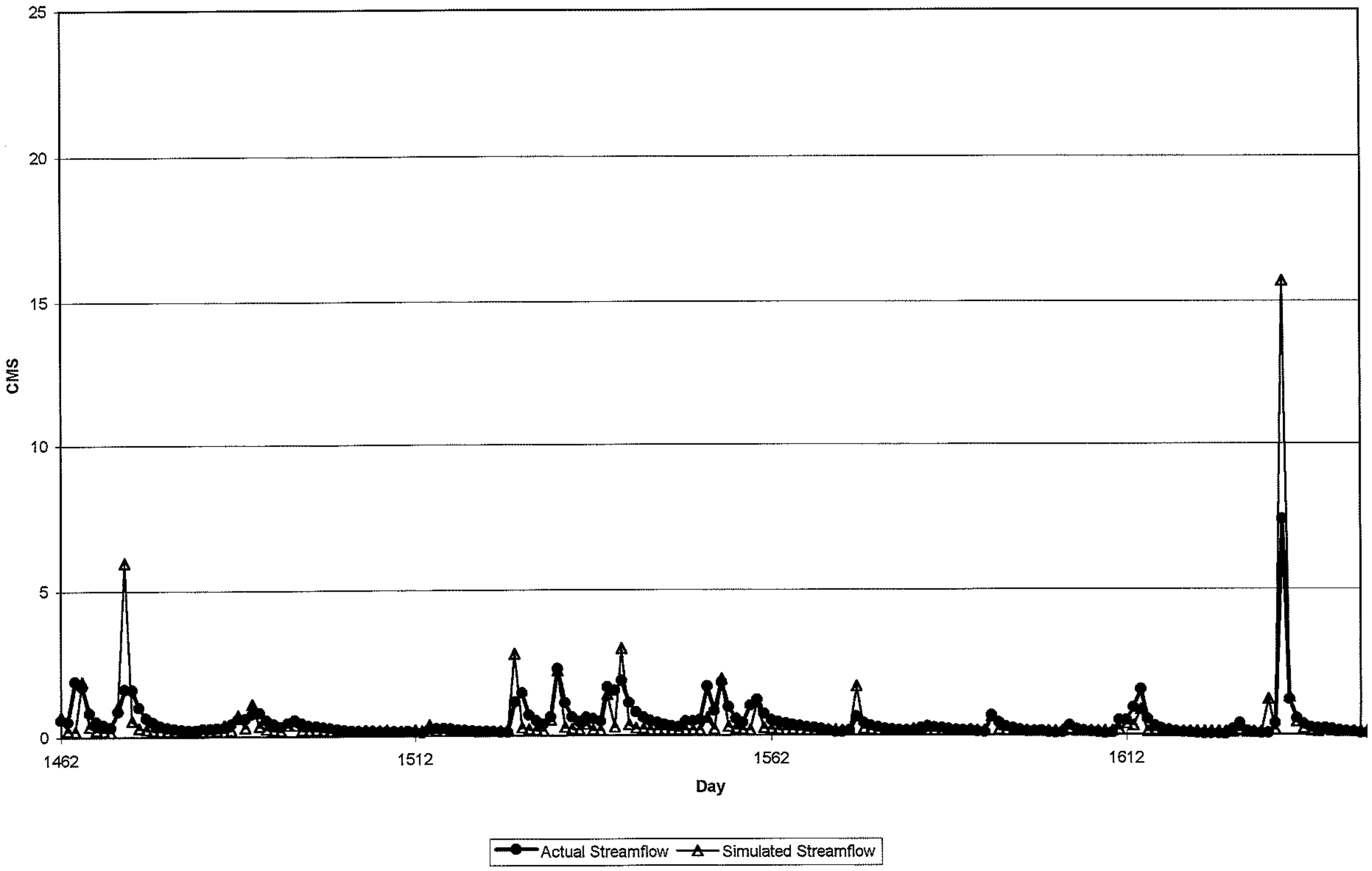
C4: Daily 11-digit streamflow comparison of the North Fork at Jackson, KY using SWAT.

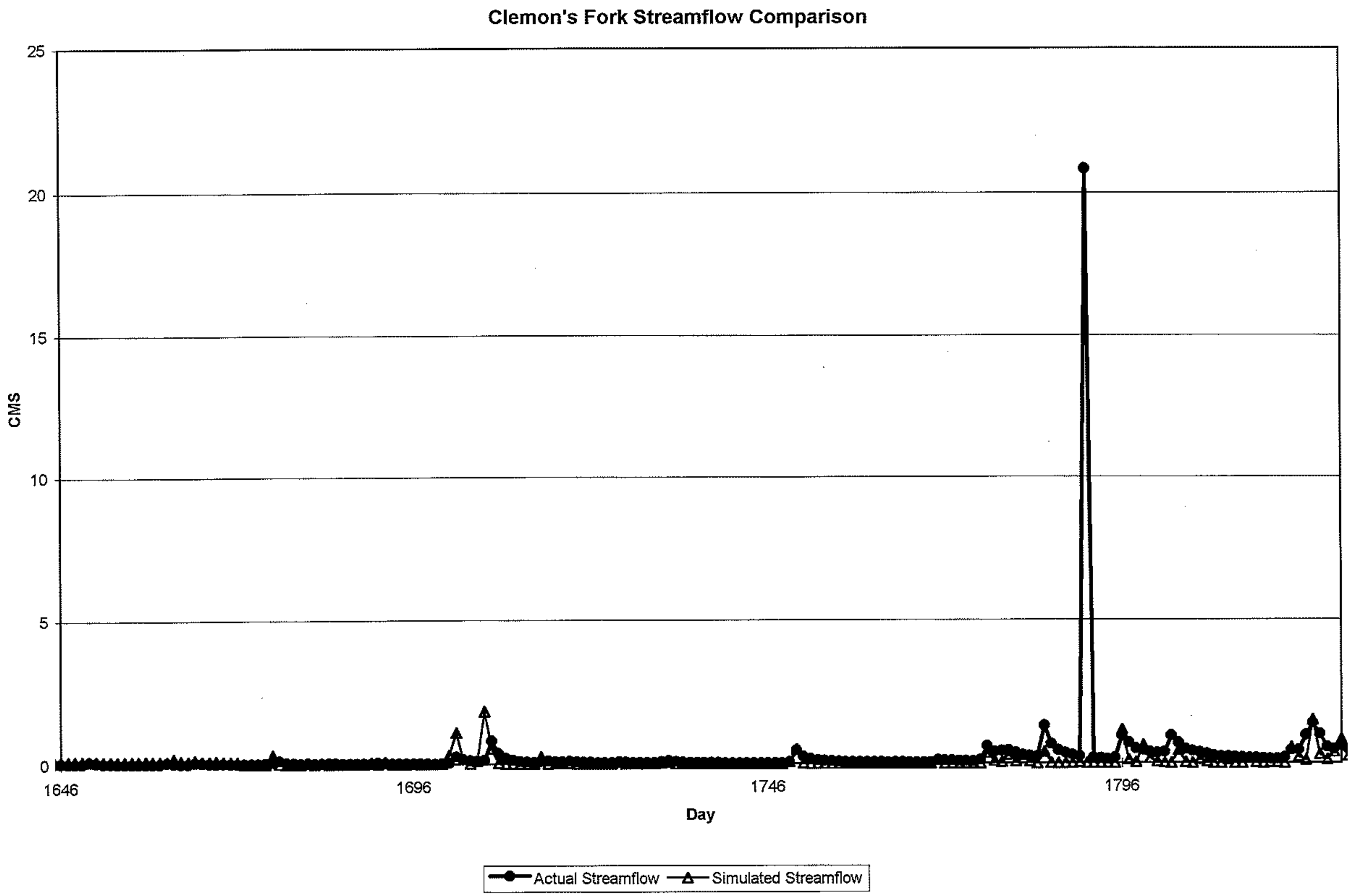
C5: Daily verification run of SWAT for 1982-1984 and 1988-1990.

C6: Daily volumetric comparison of SWAT and BASINS to daily rainfall volume.

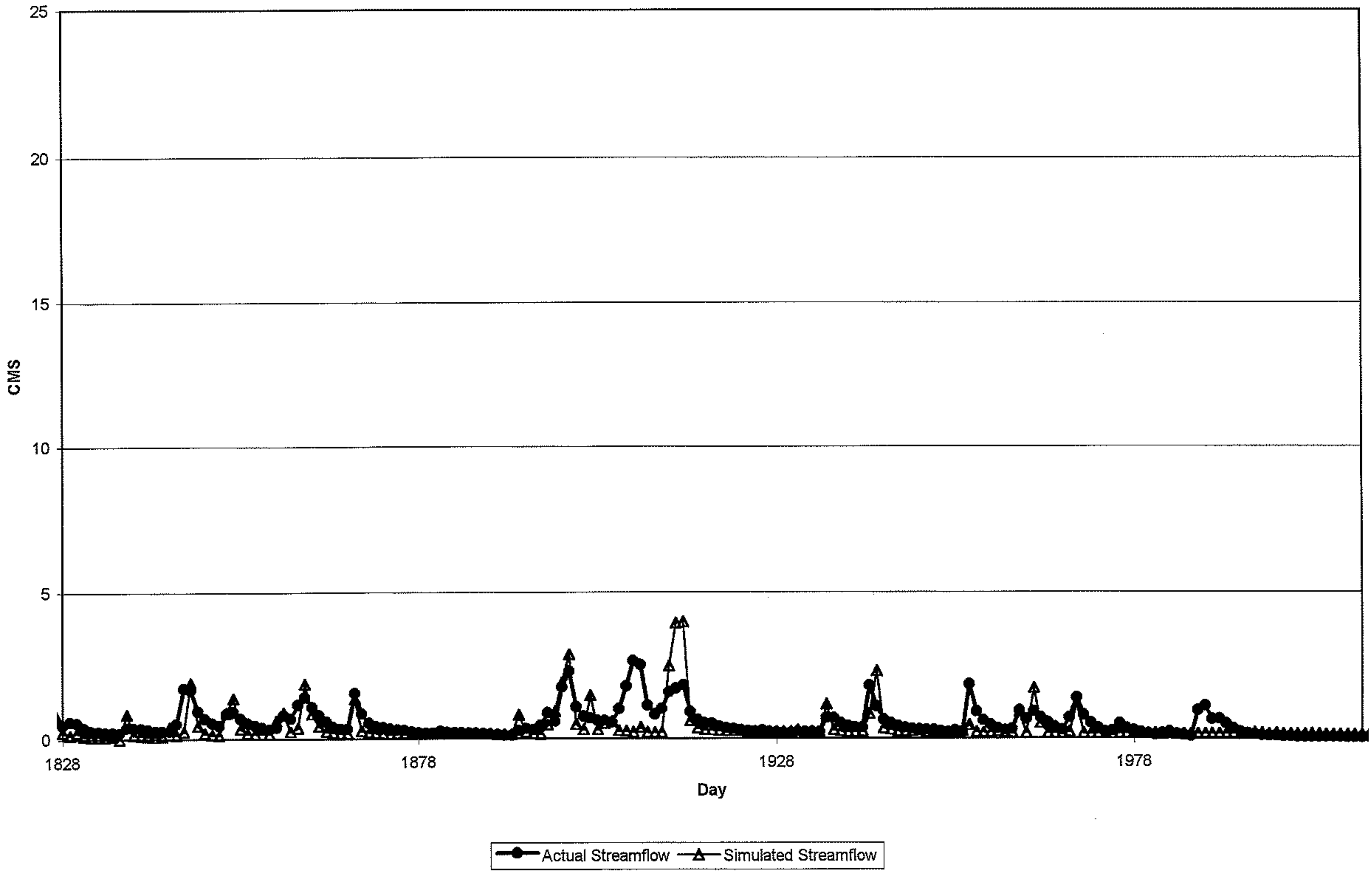
Appendix C.1: Daily streamflow comparison for Clemon's Fork using SWAT.

Clemon's Fork Streamflow Comparison

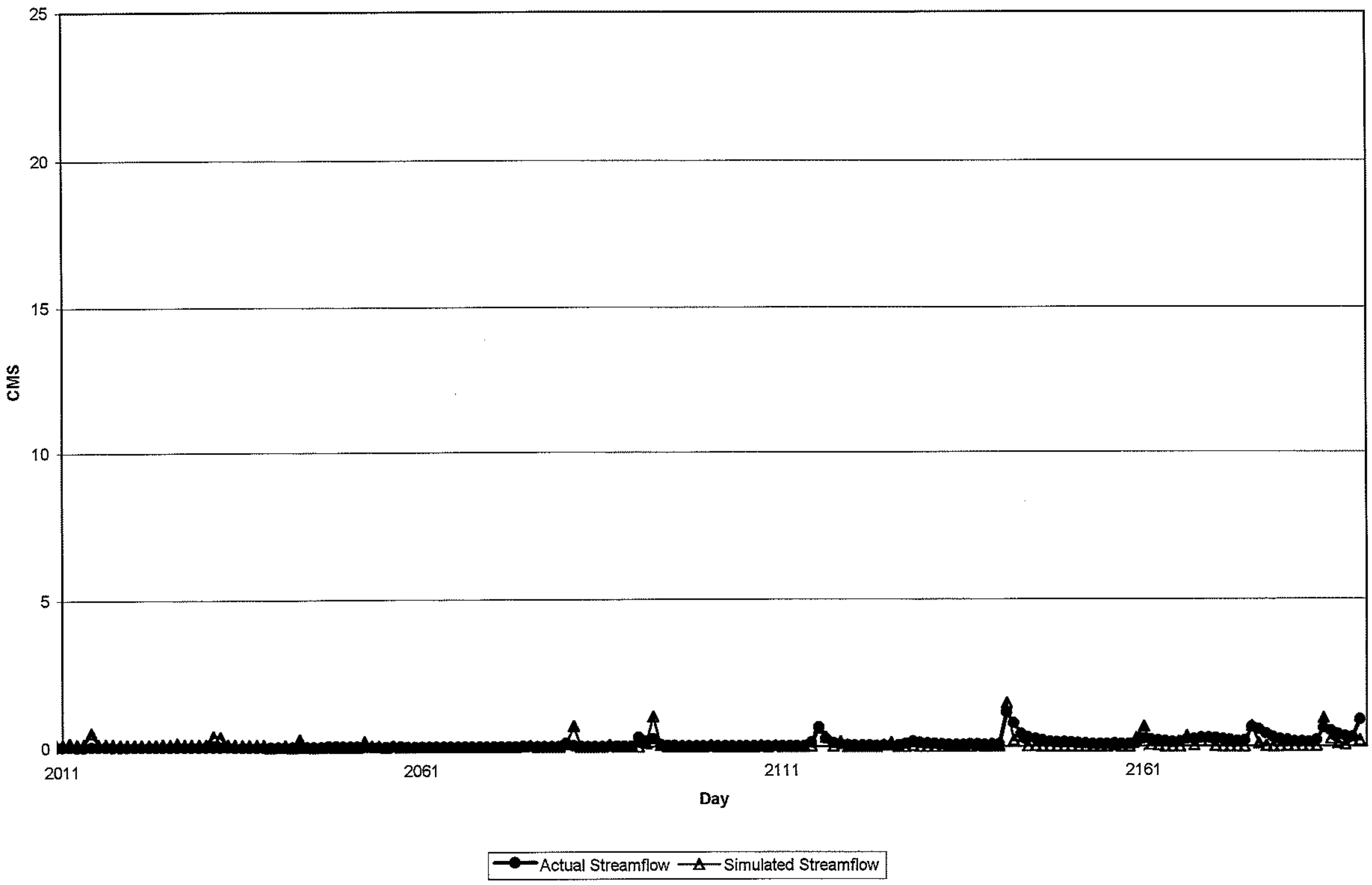



Clemon's Fork Streamflow Comparison
CMS
25
20
15
10
5
0
1646
1696
1746
1796
Day
Actual Streamflow
Simulated Streamflow

Clemon's Fork Streamflow Comparison

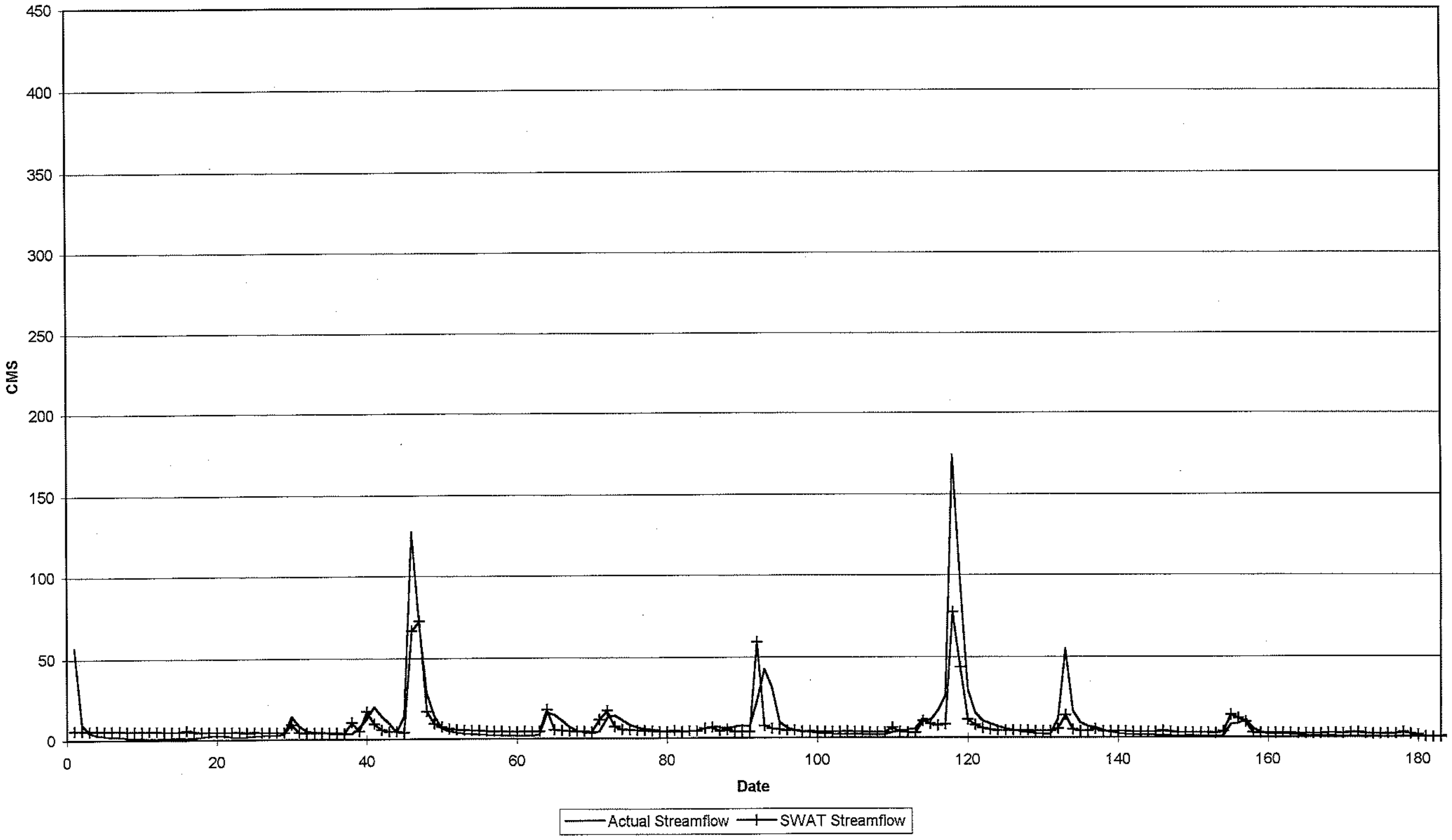


Clemon's Fork Streamflow Comparison

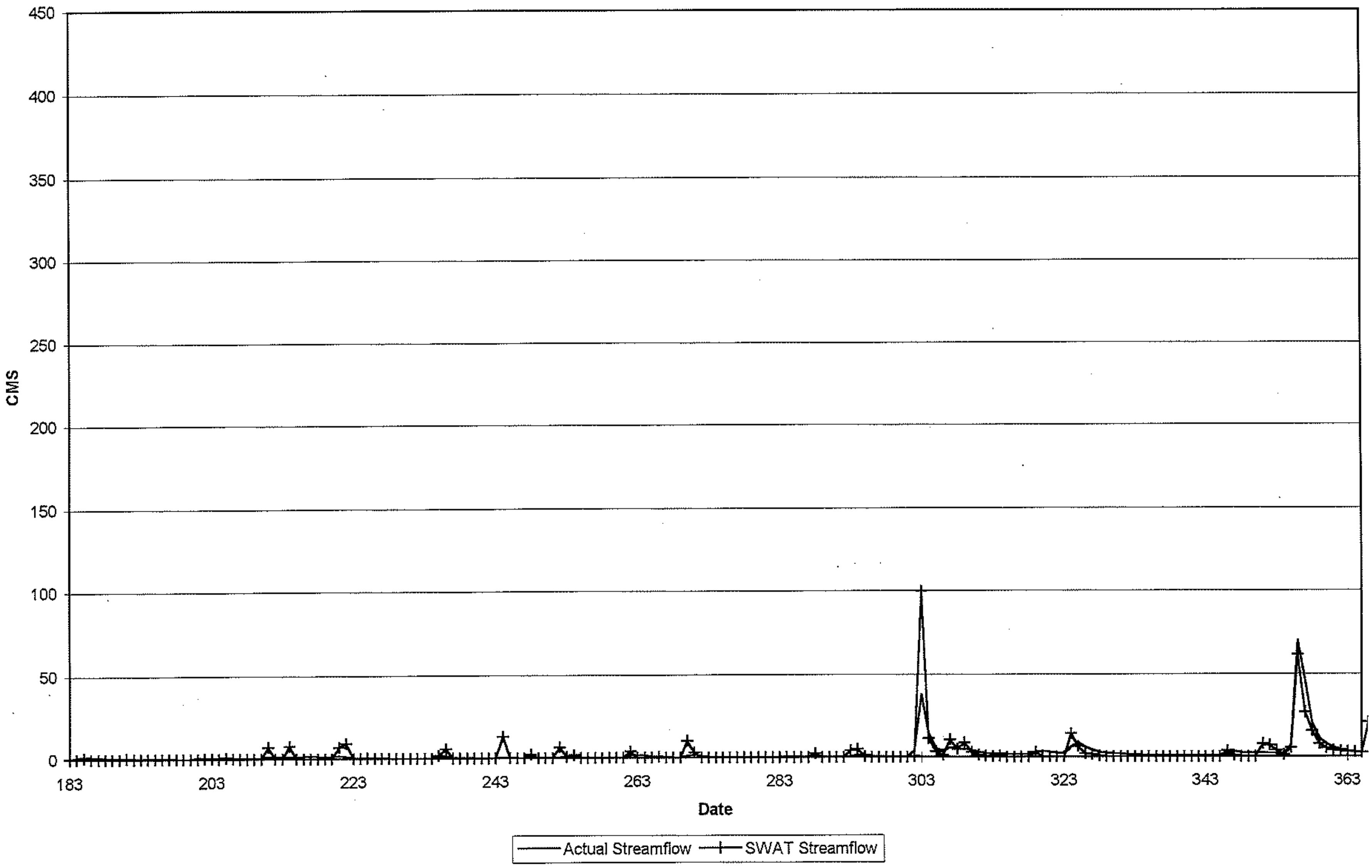


Appendix C.2: Daily 14-digit streamflow comparison of Troublesome Creek using SWAT.

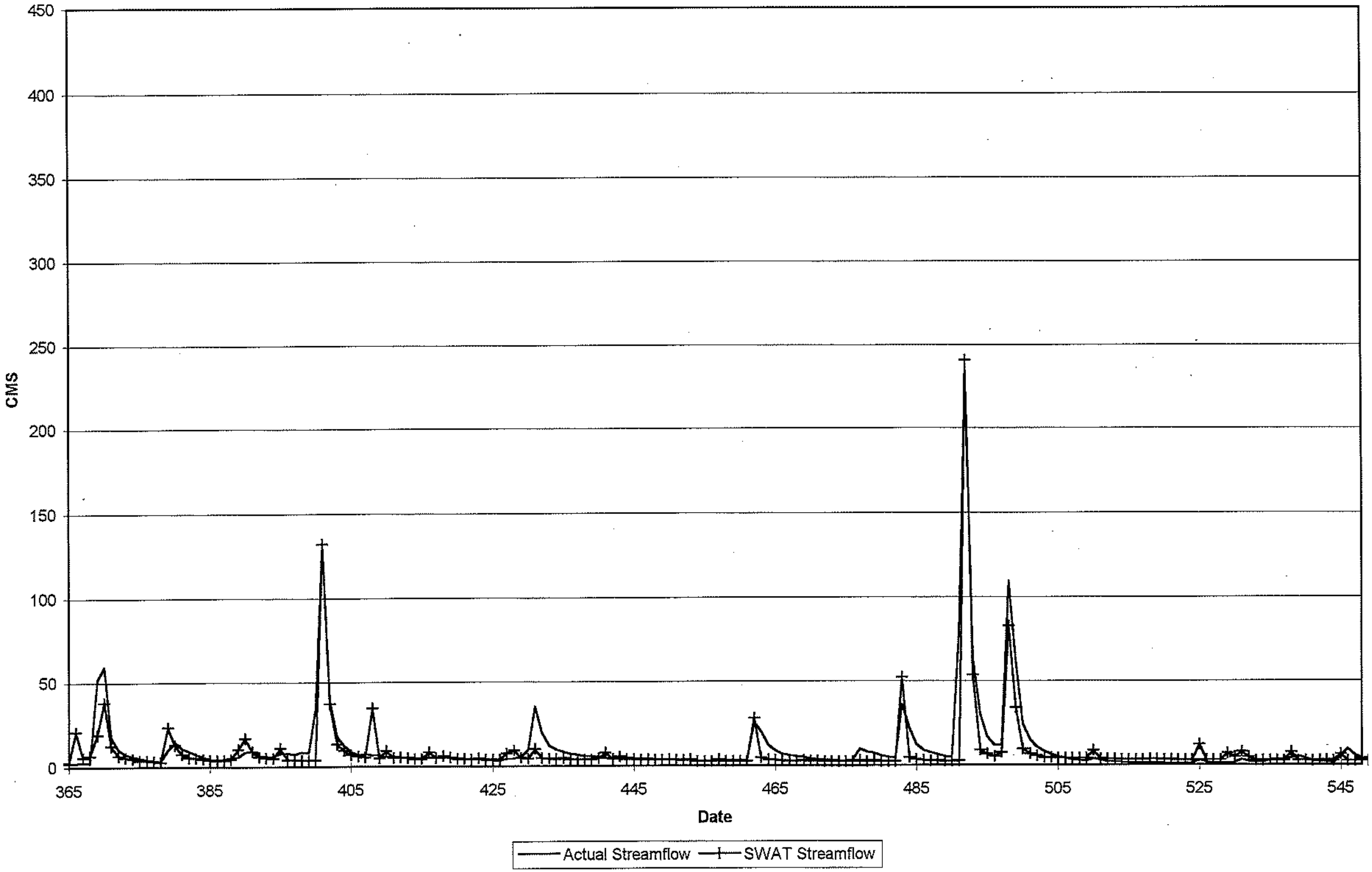
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



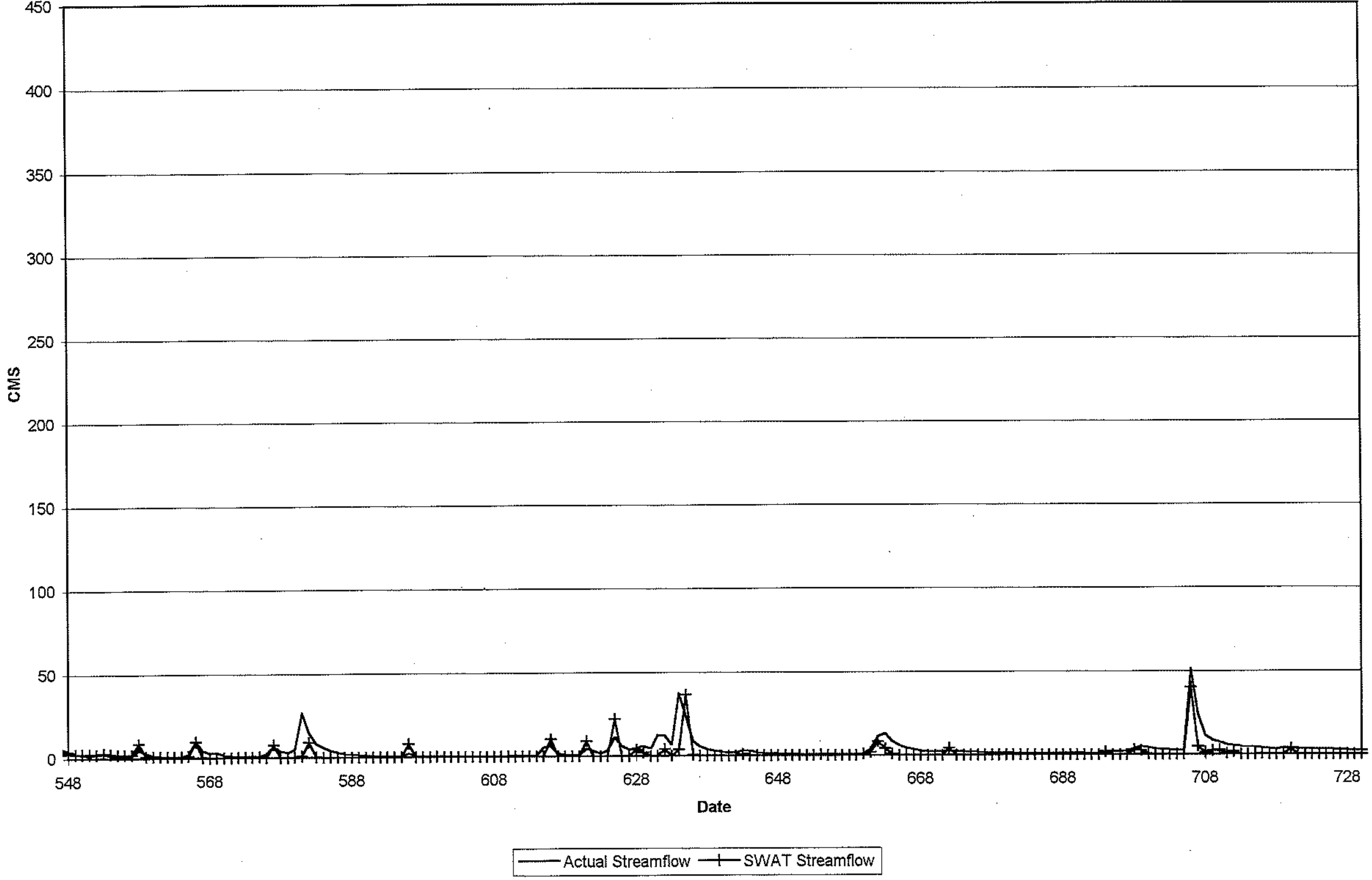
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek

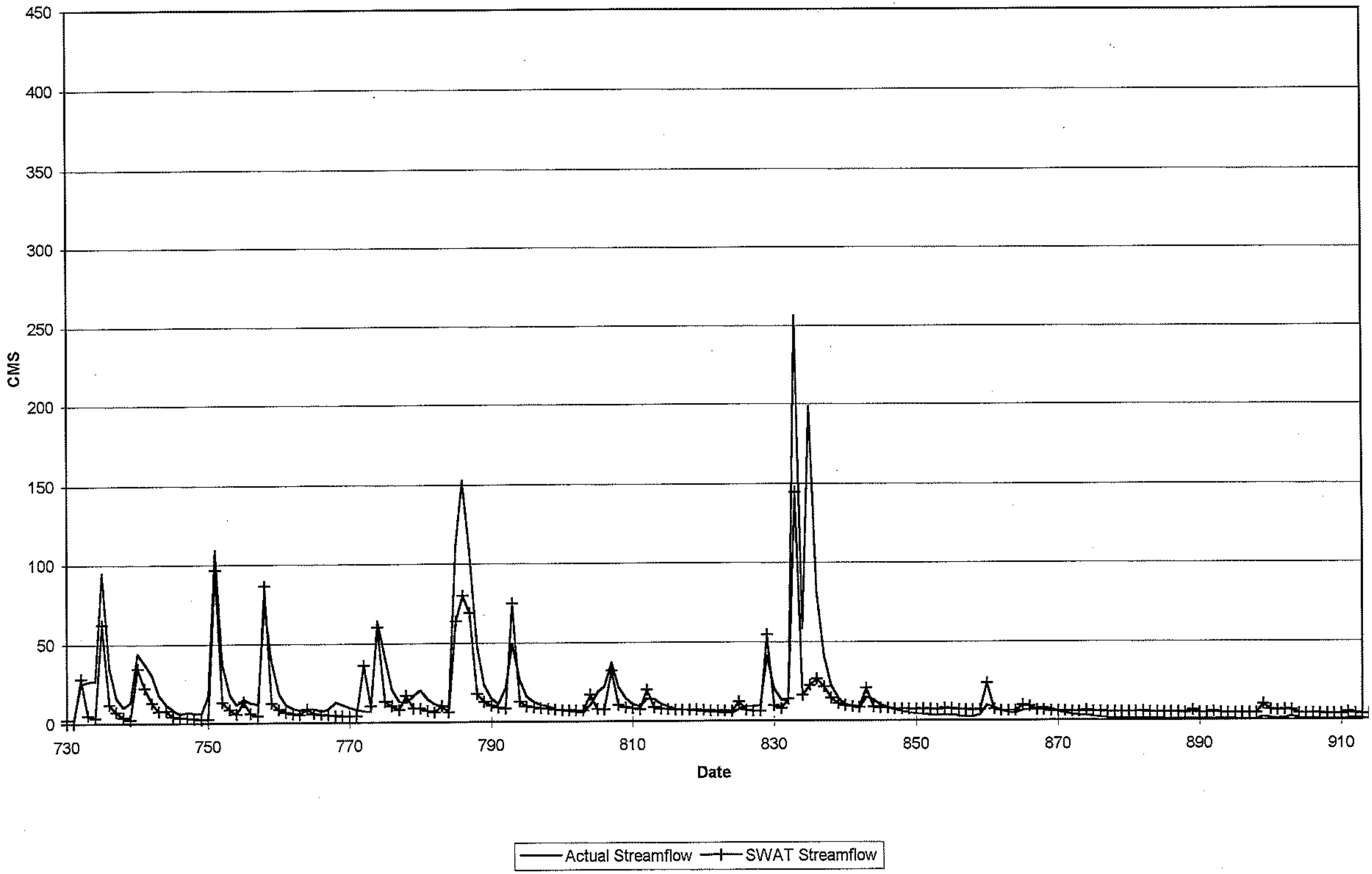


14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



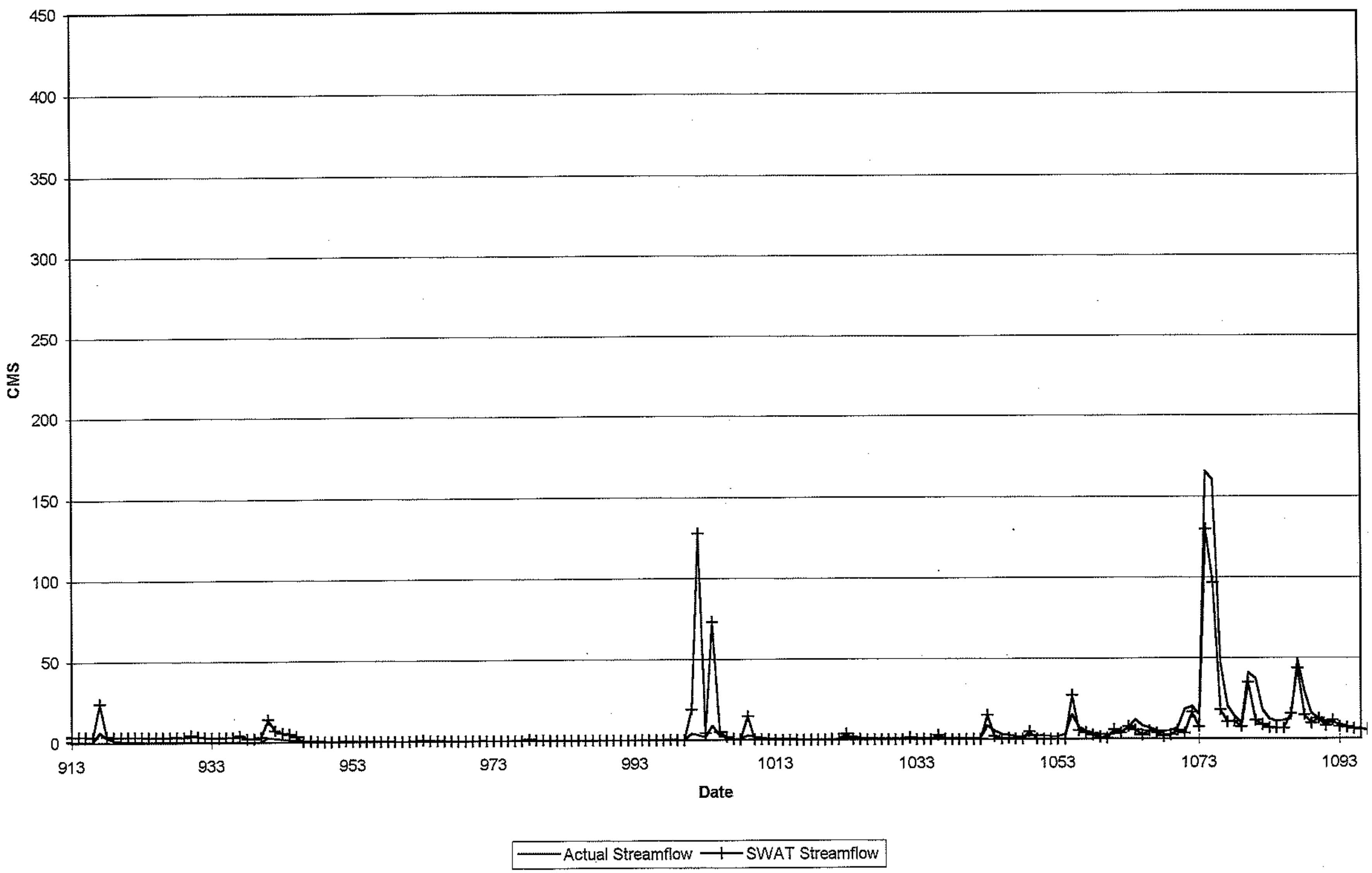
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



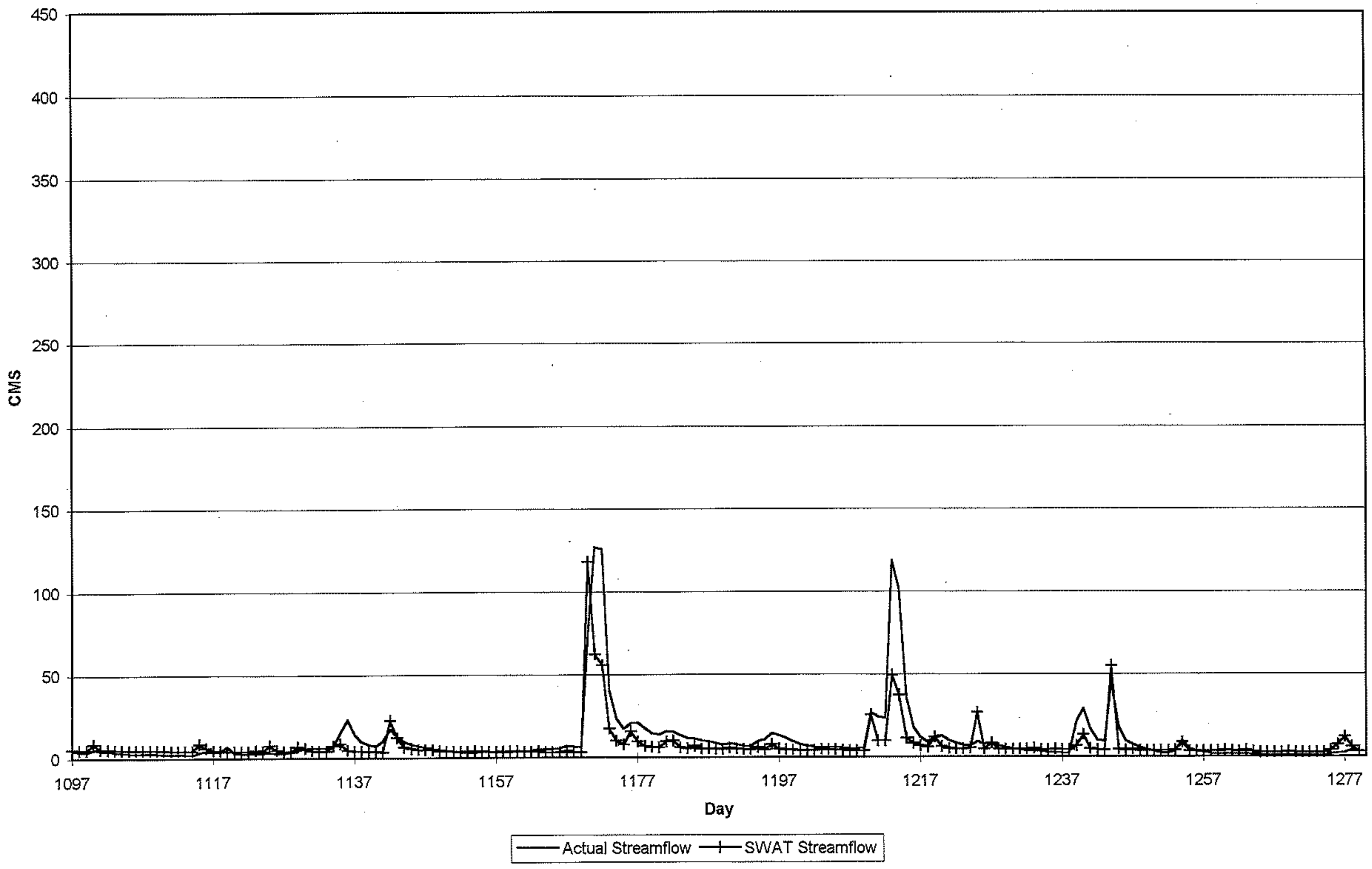


14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek

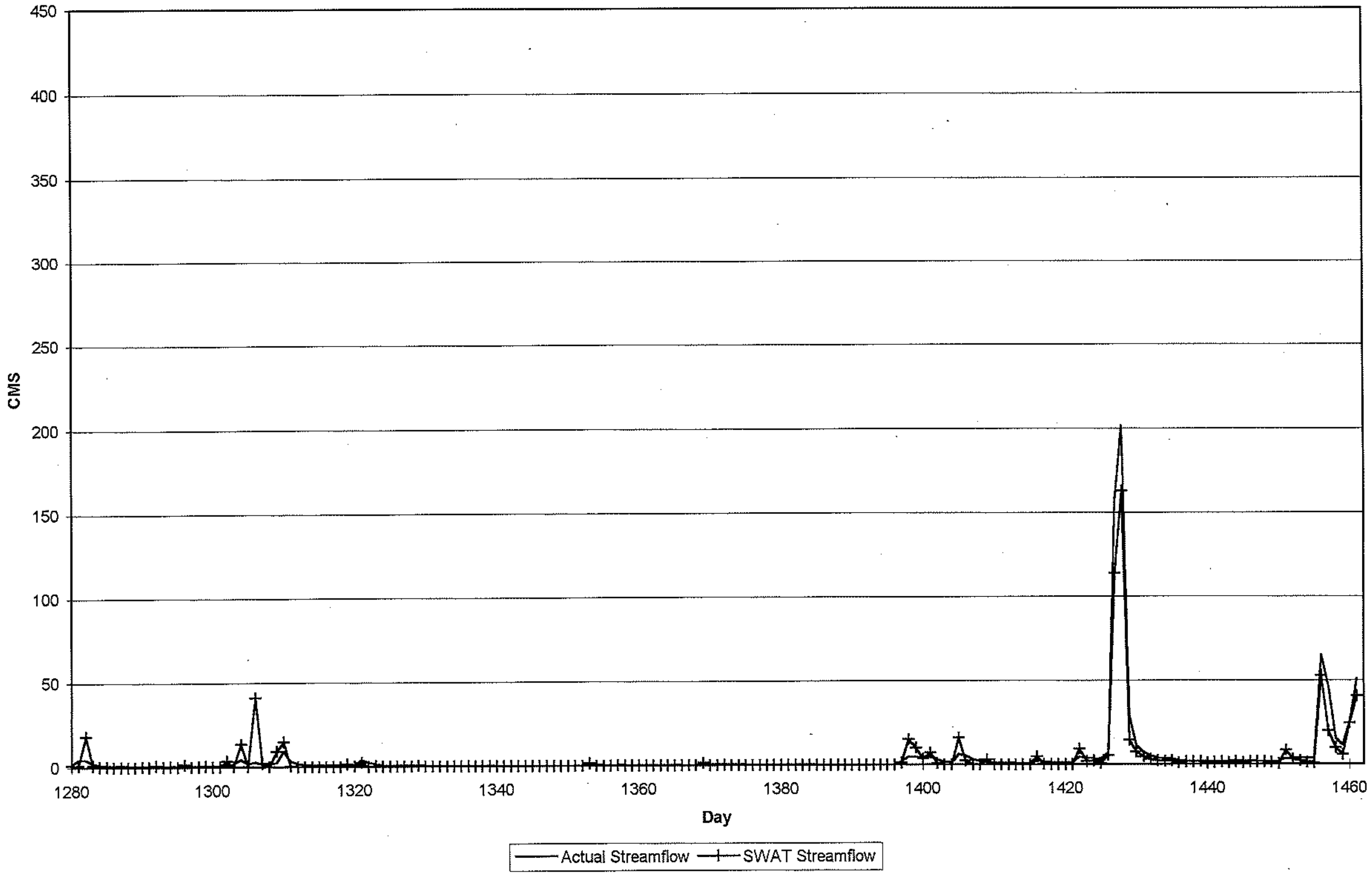
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



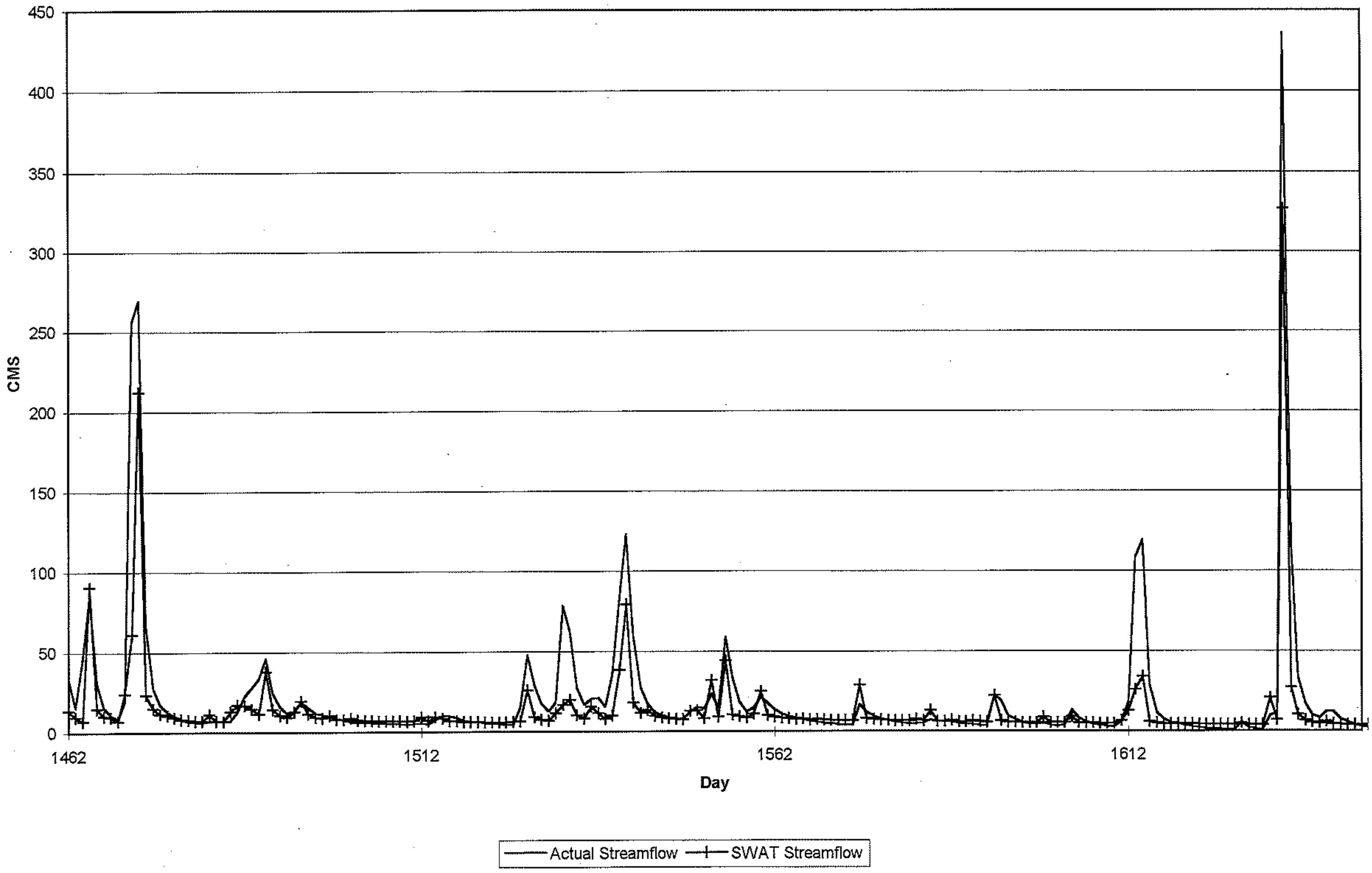
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



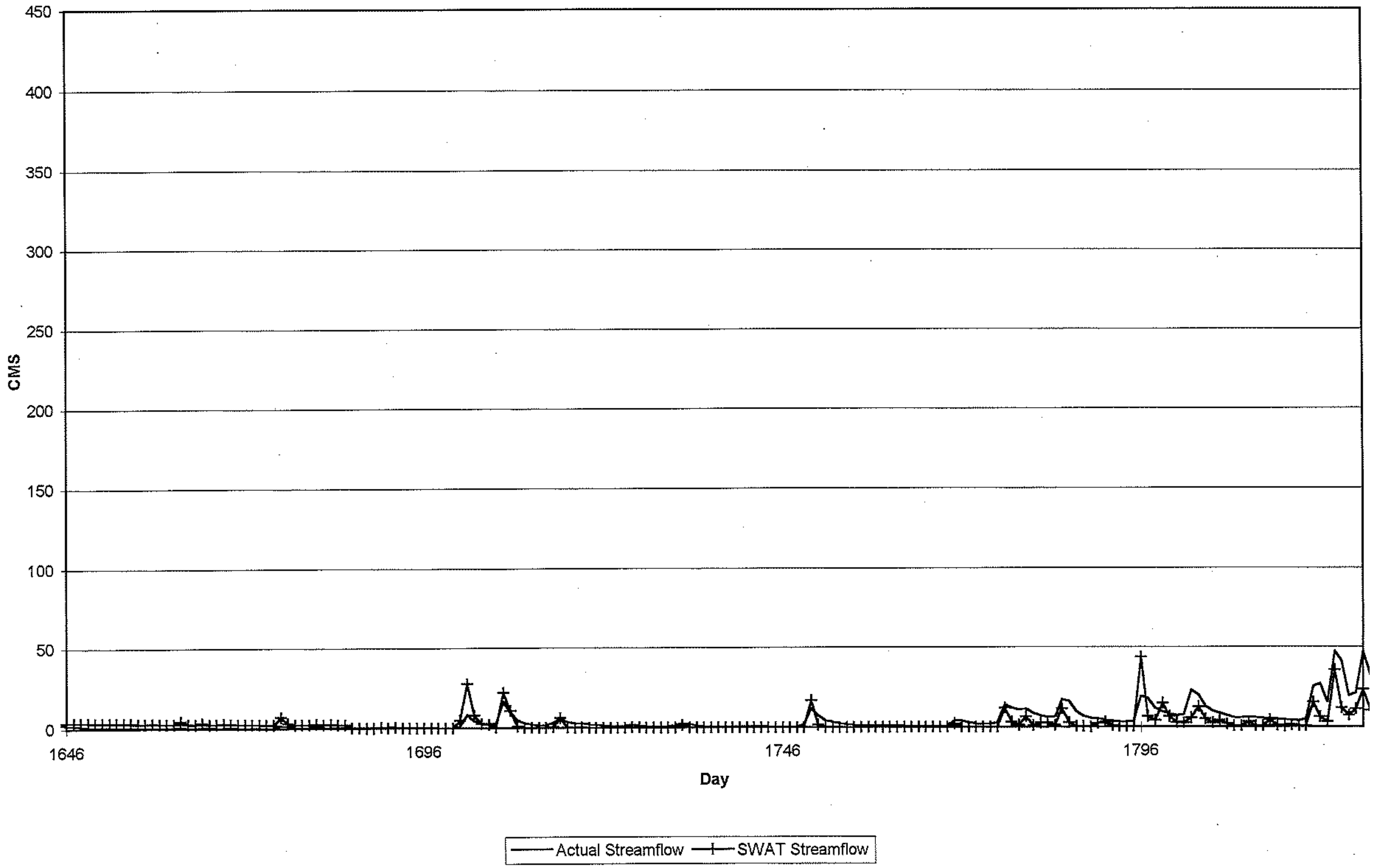
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



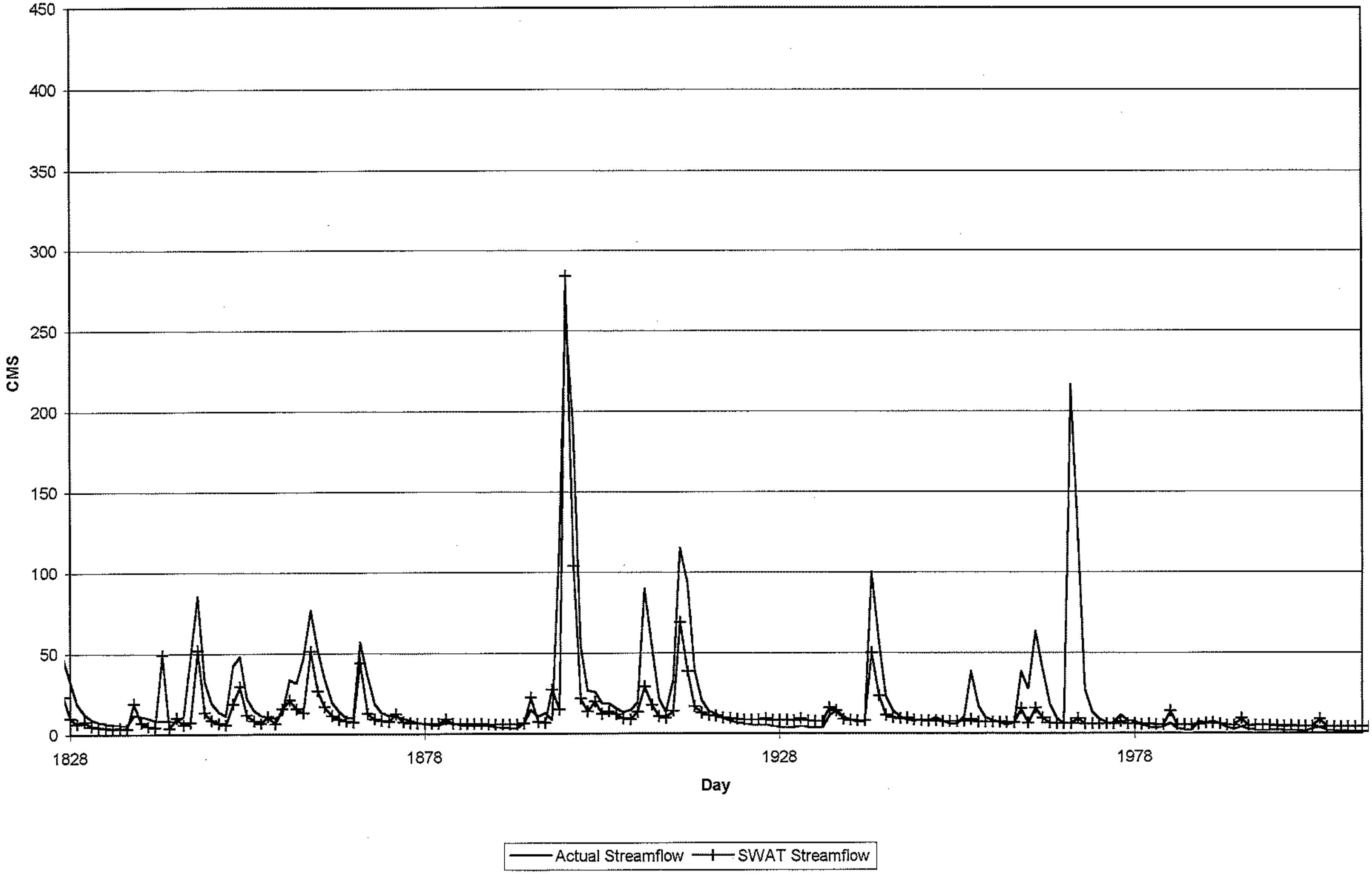
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



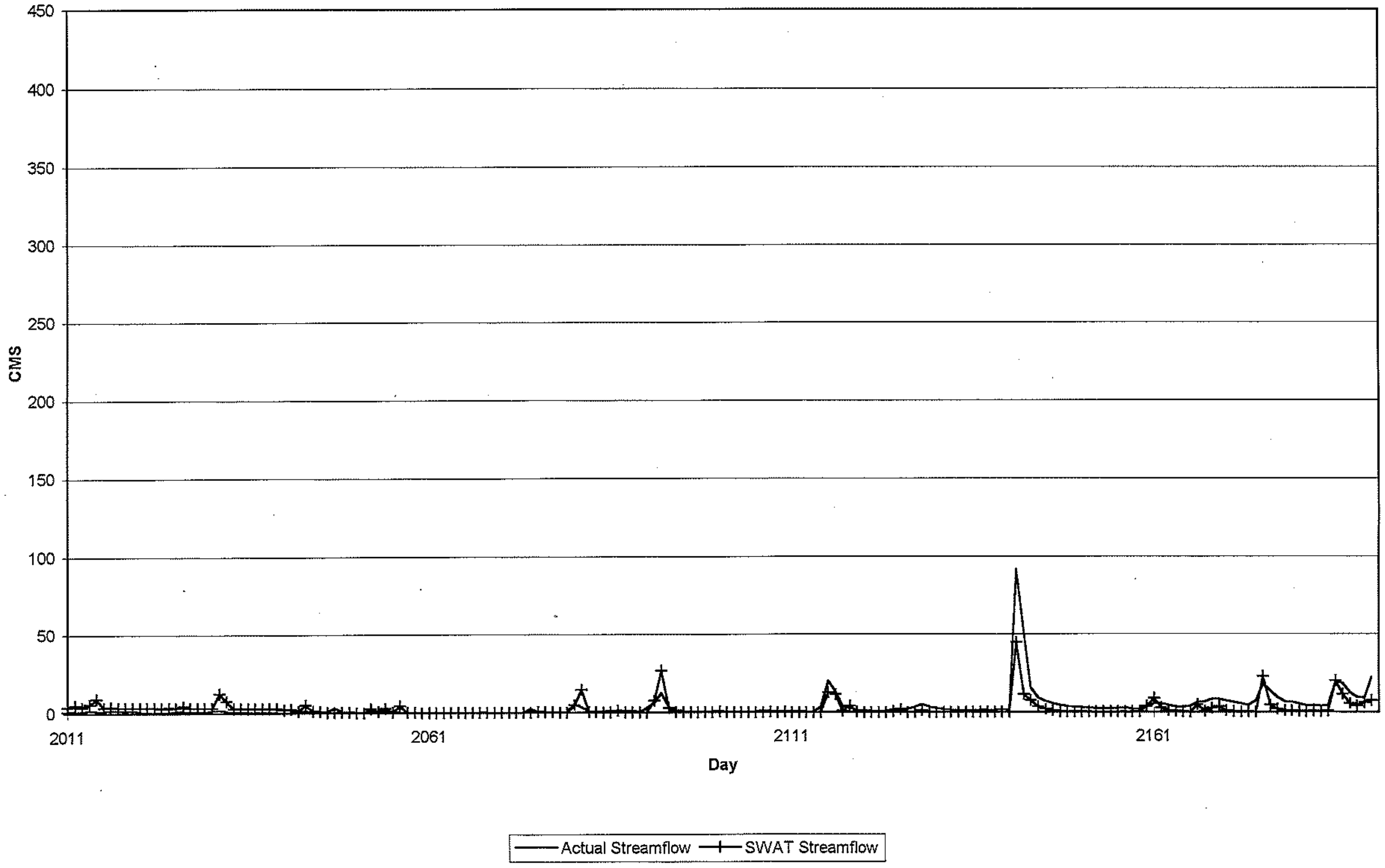
14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek

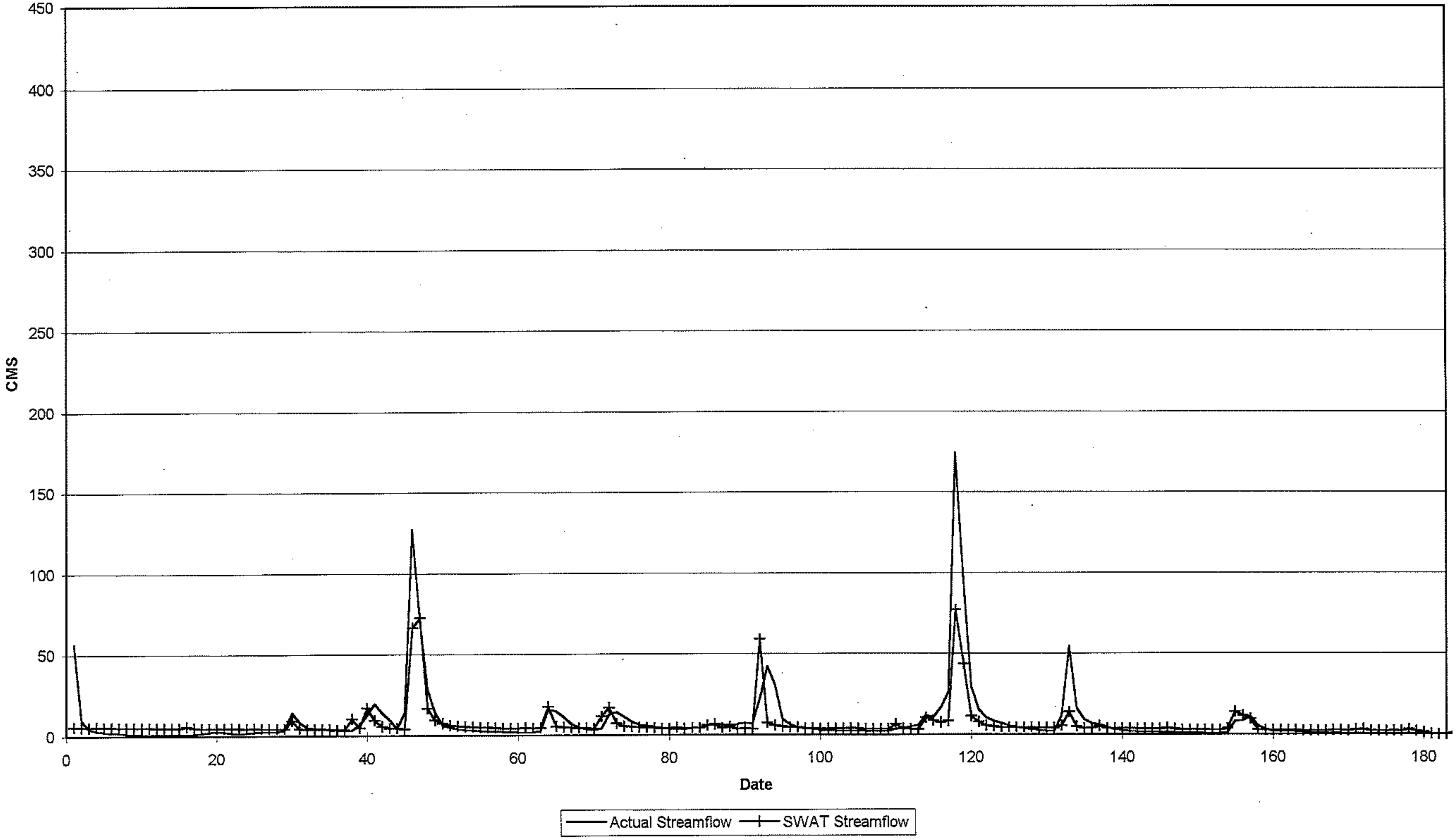


14-Digit Streamflow Comparison at Noble, KY for Troublesome Creek

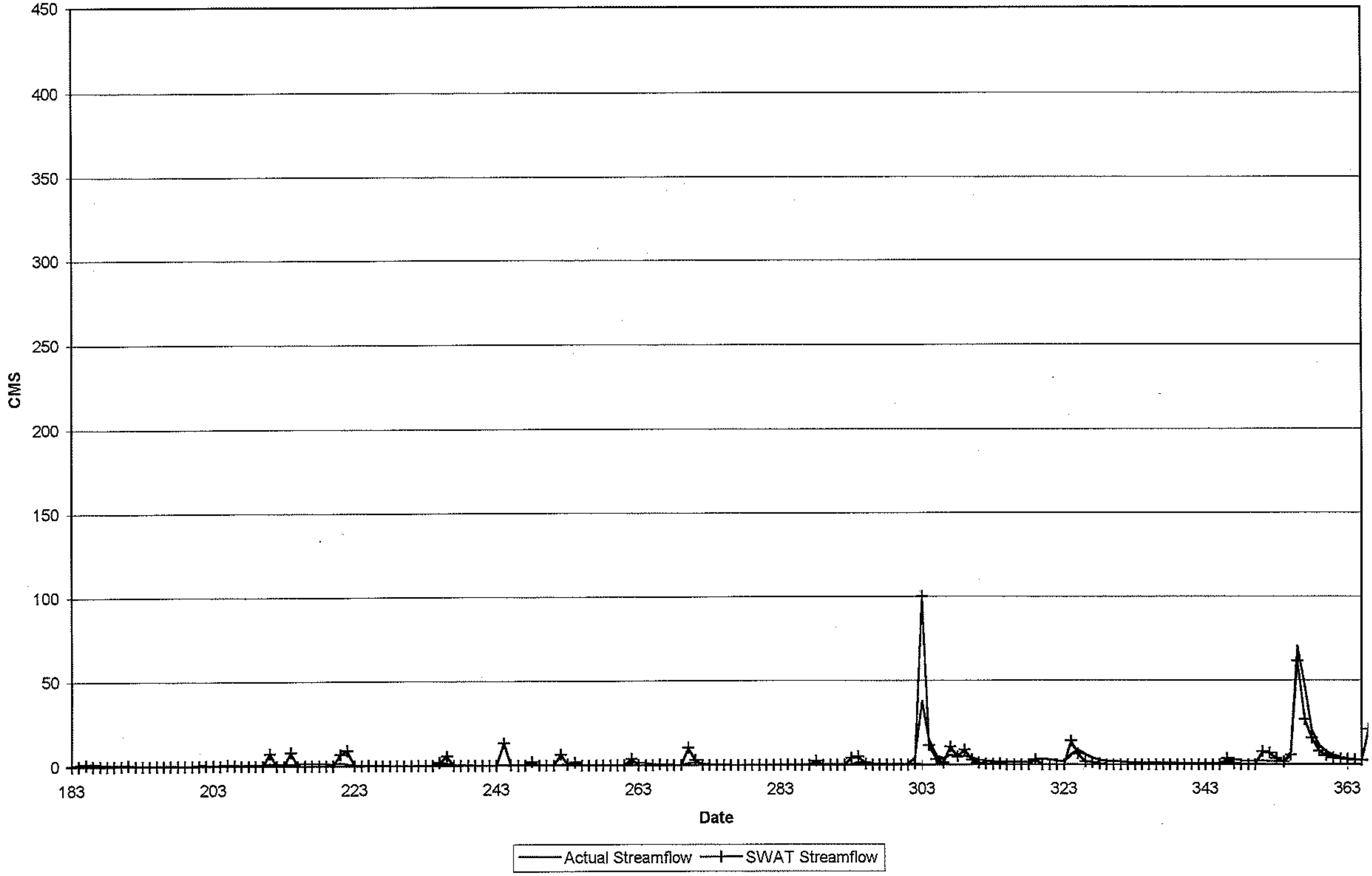


Appendix C.3: Daily 11-digit streamflow comparison of Troublesome Creek using SWAT.

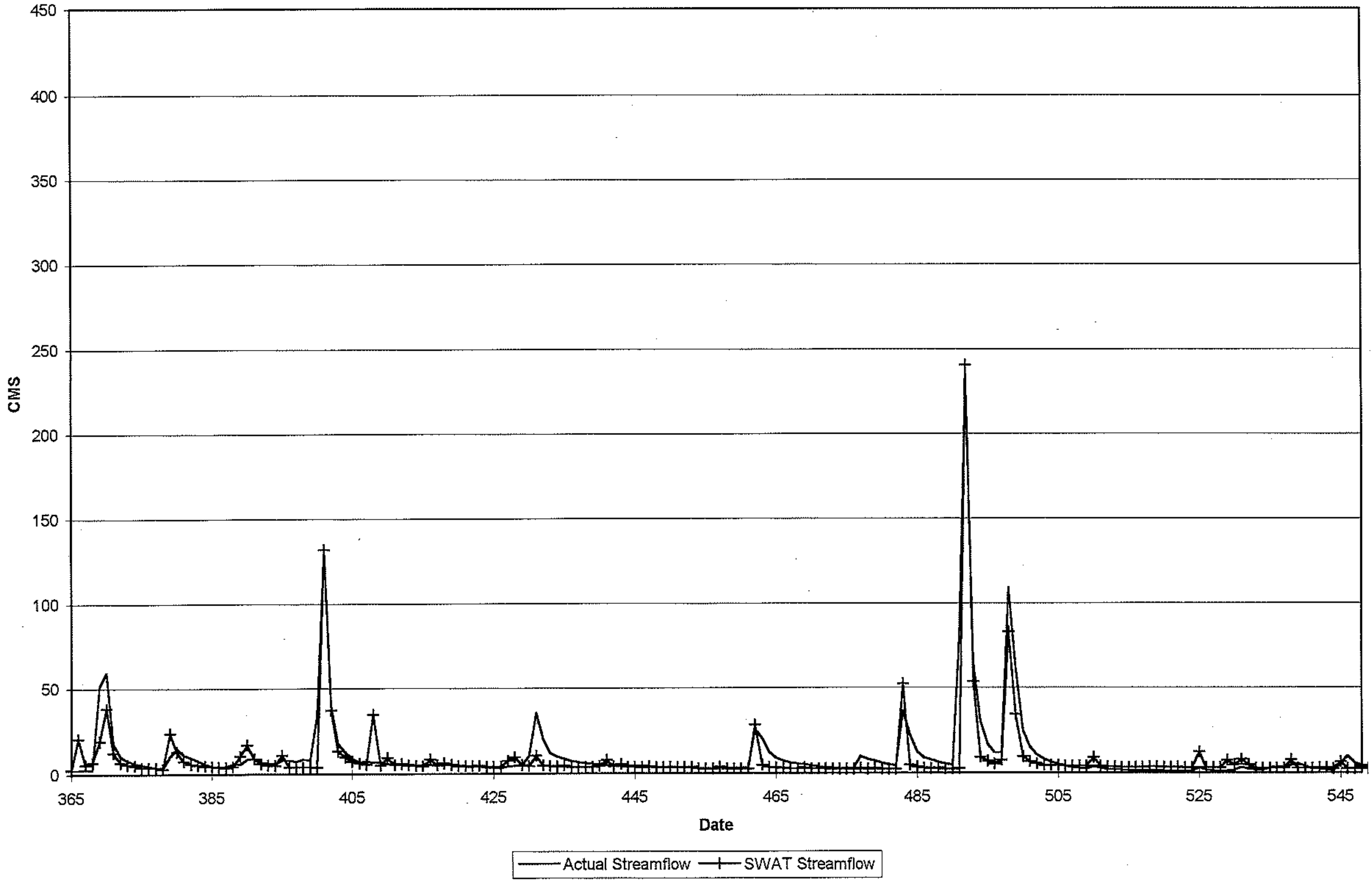
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



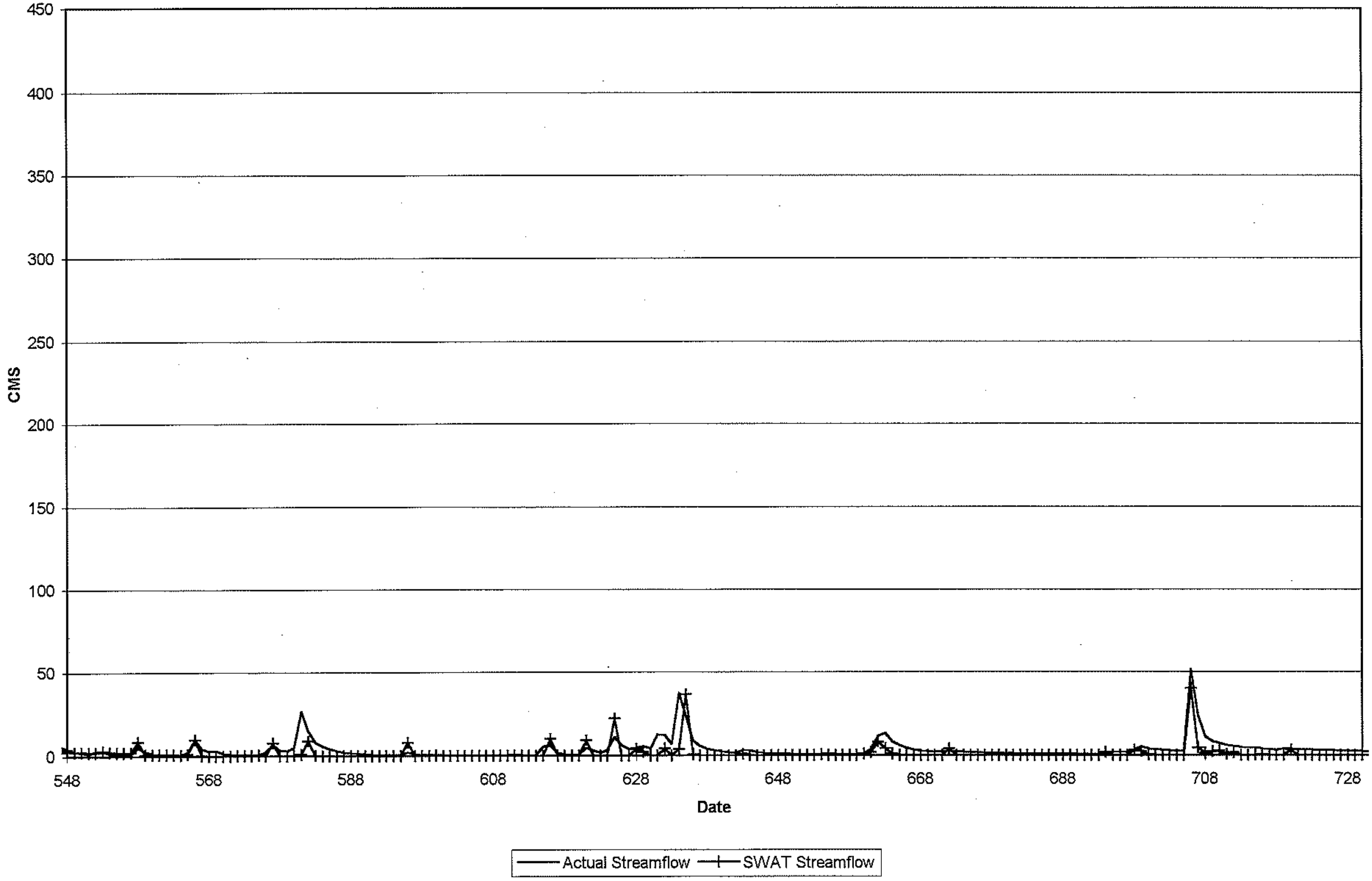
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



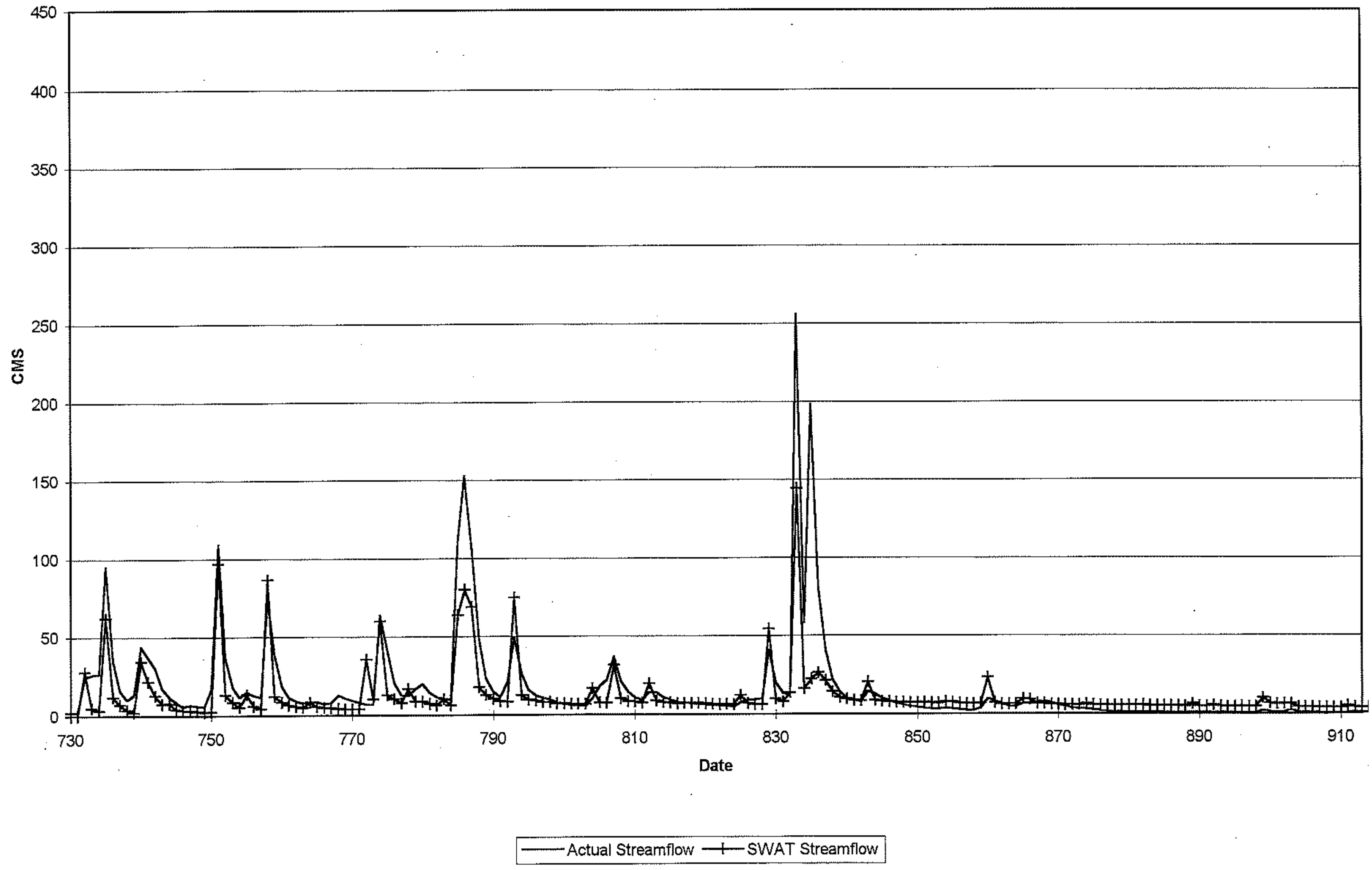
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



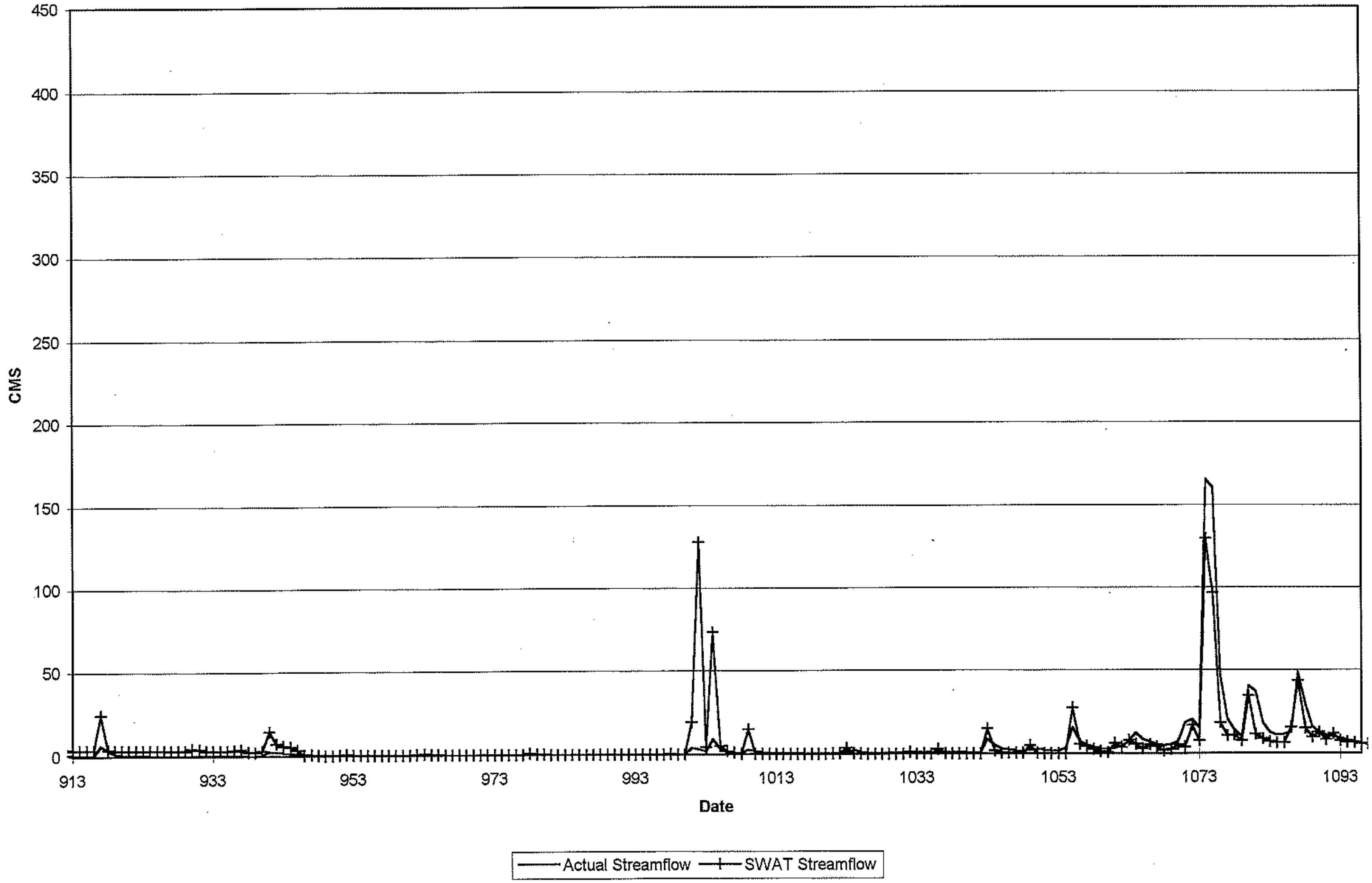
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



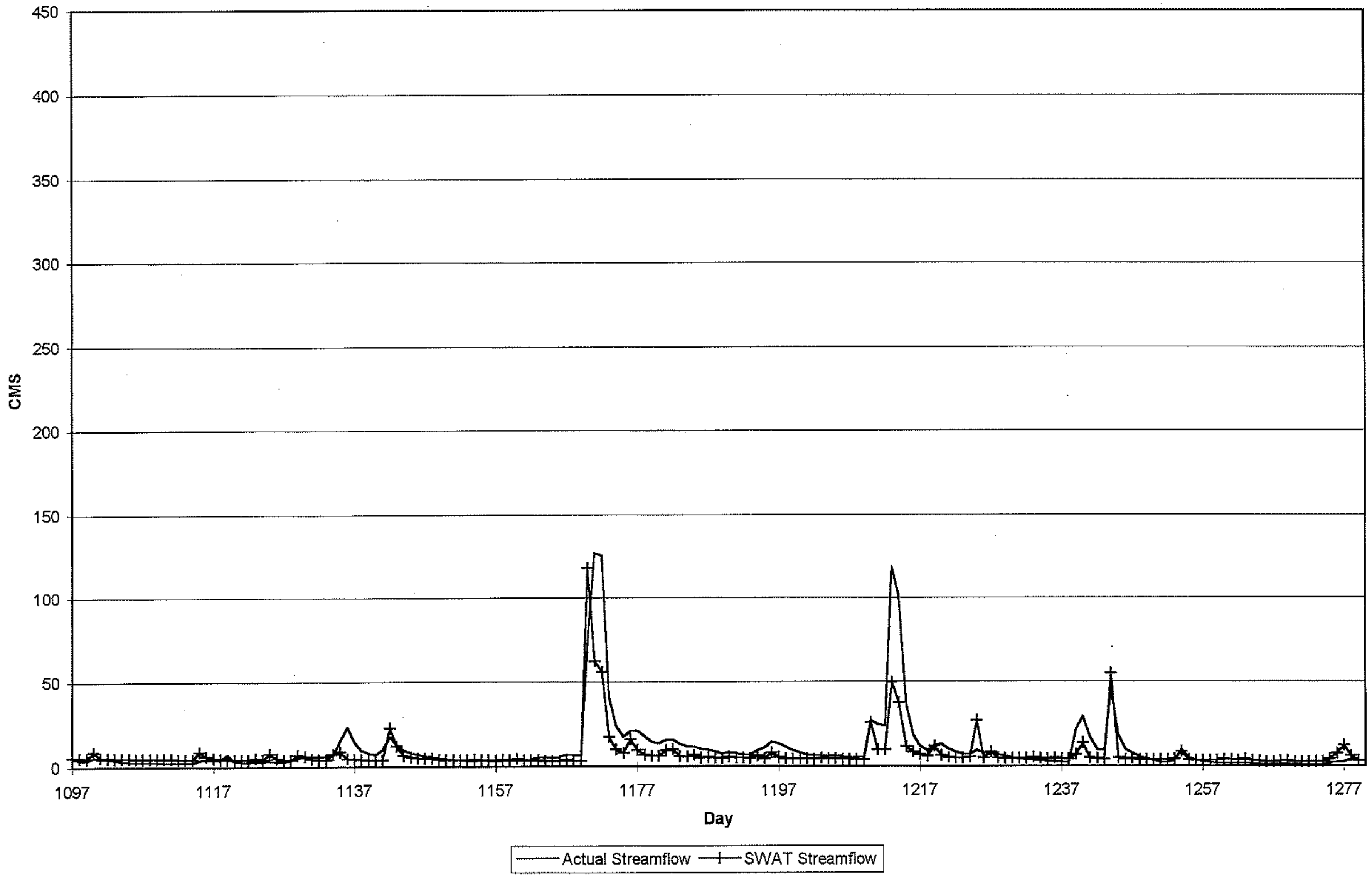
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



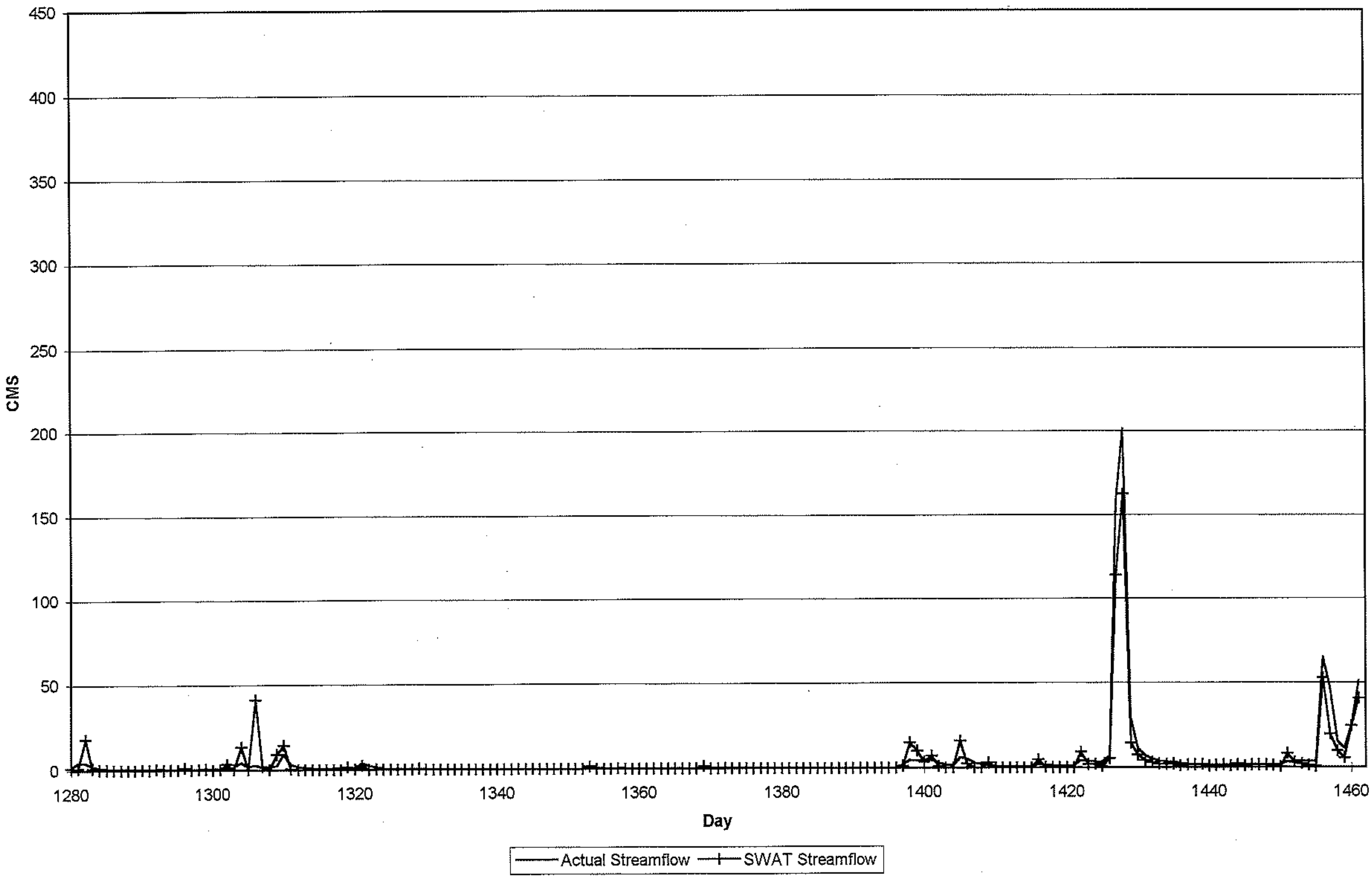
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



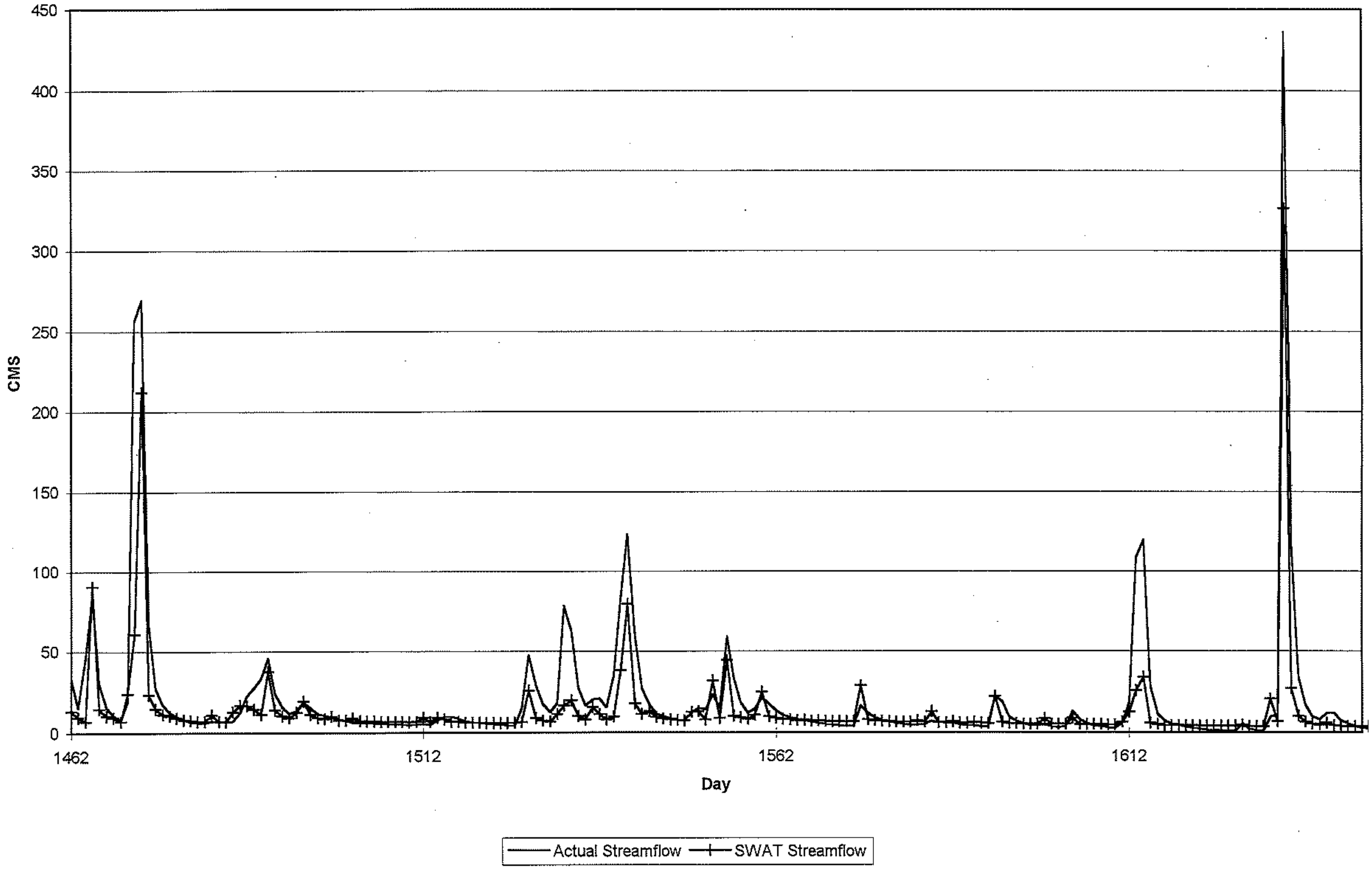
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



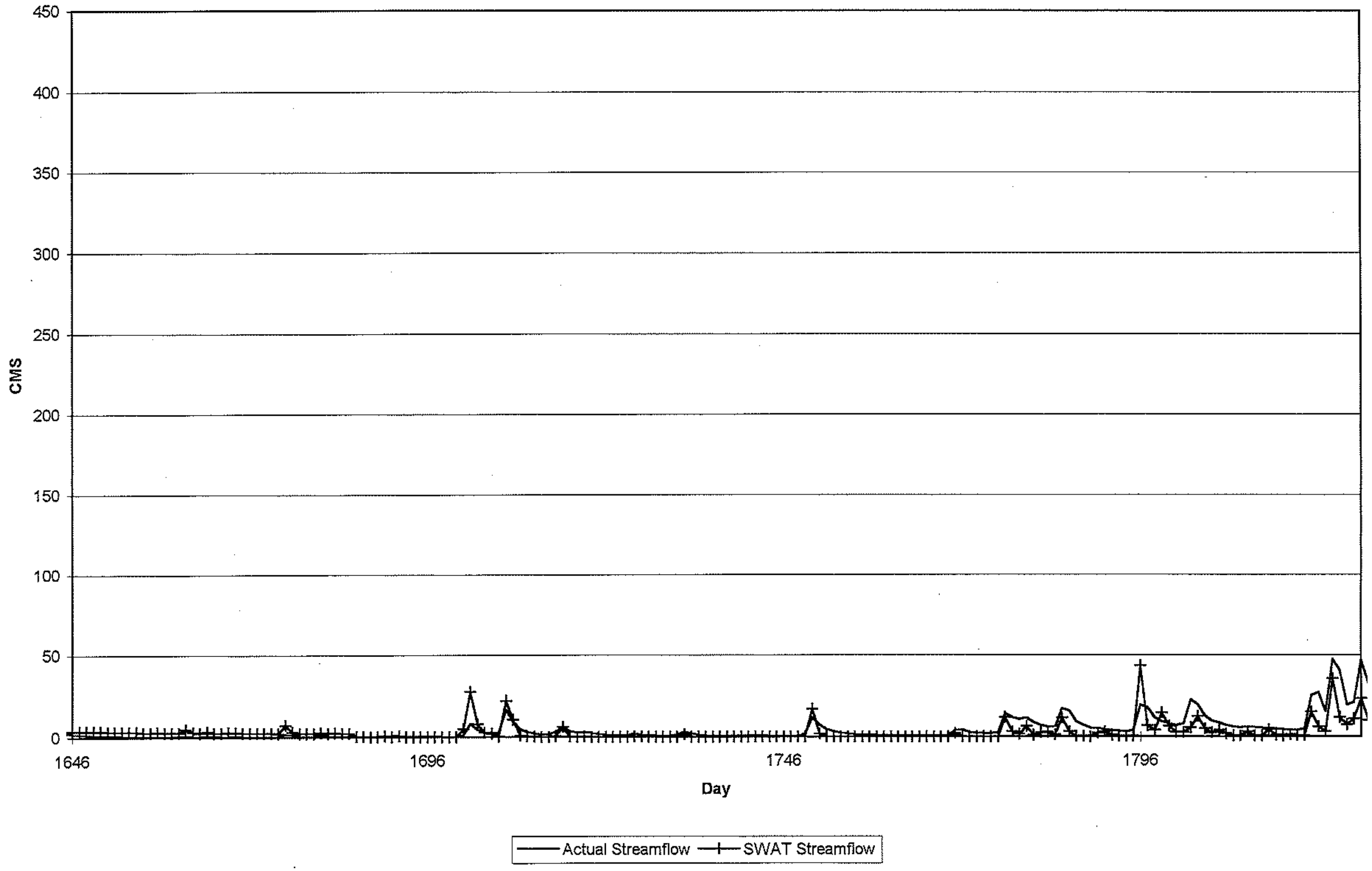
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



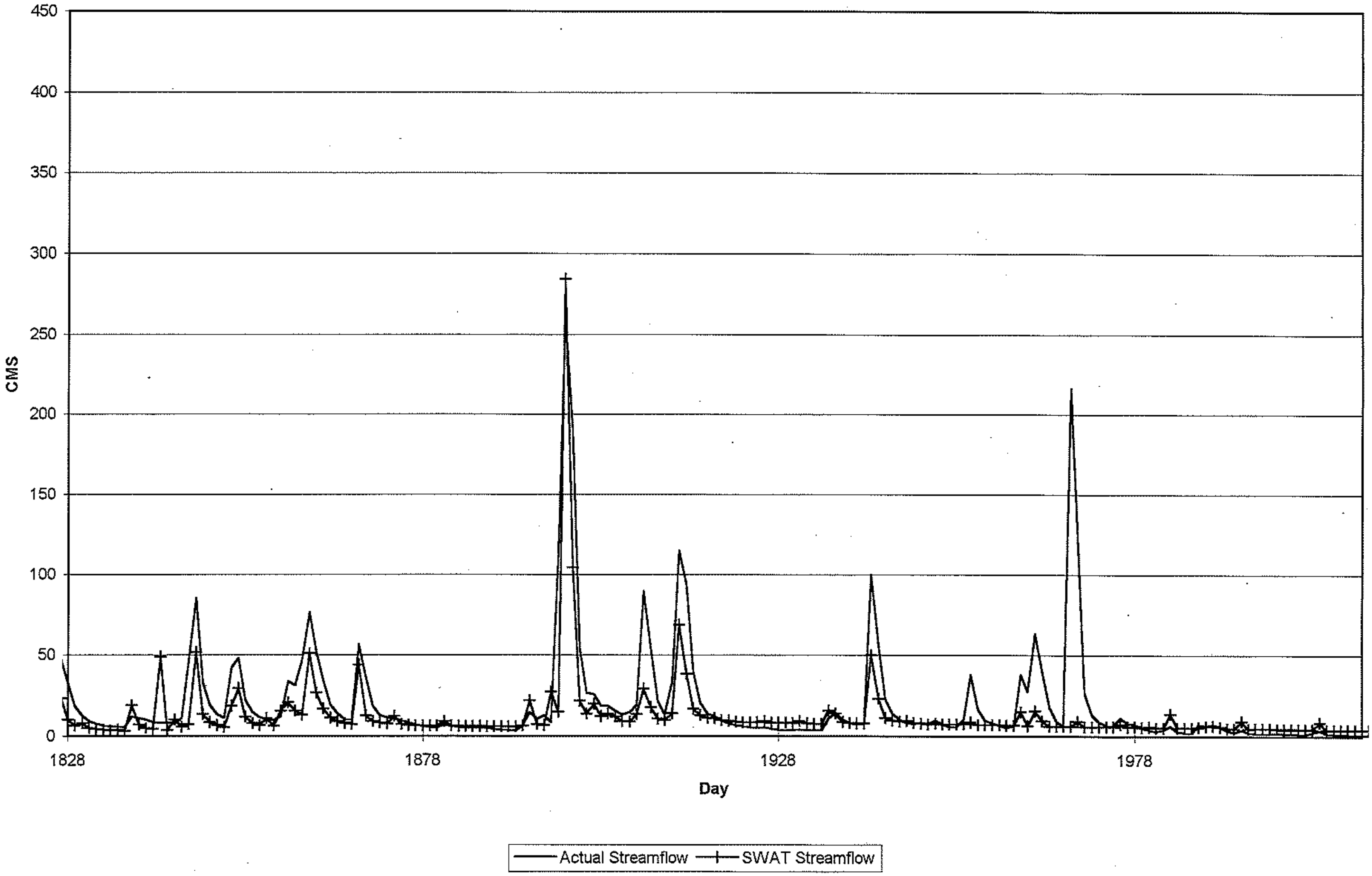
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



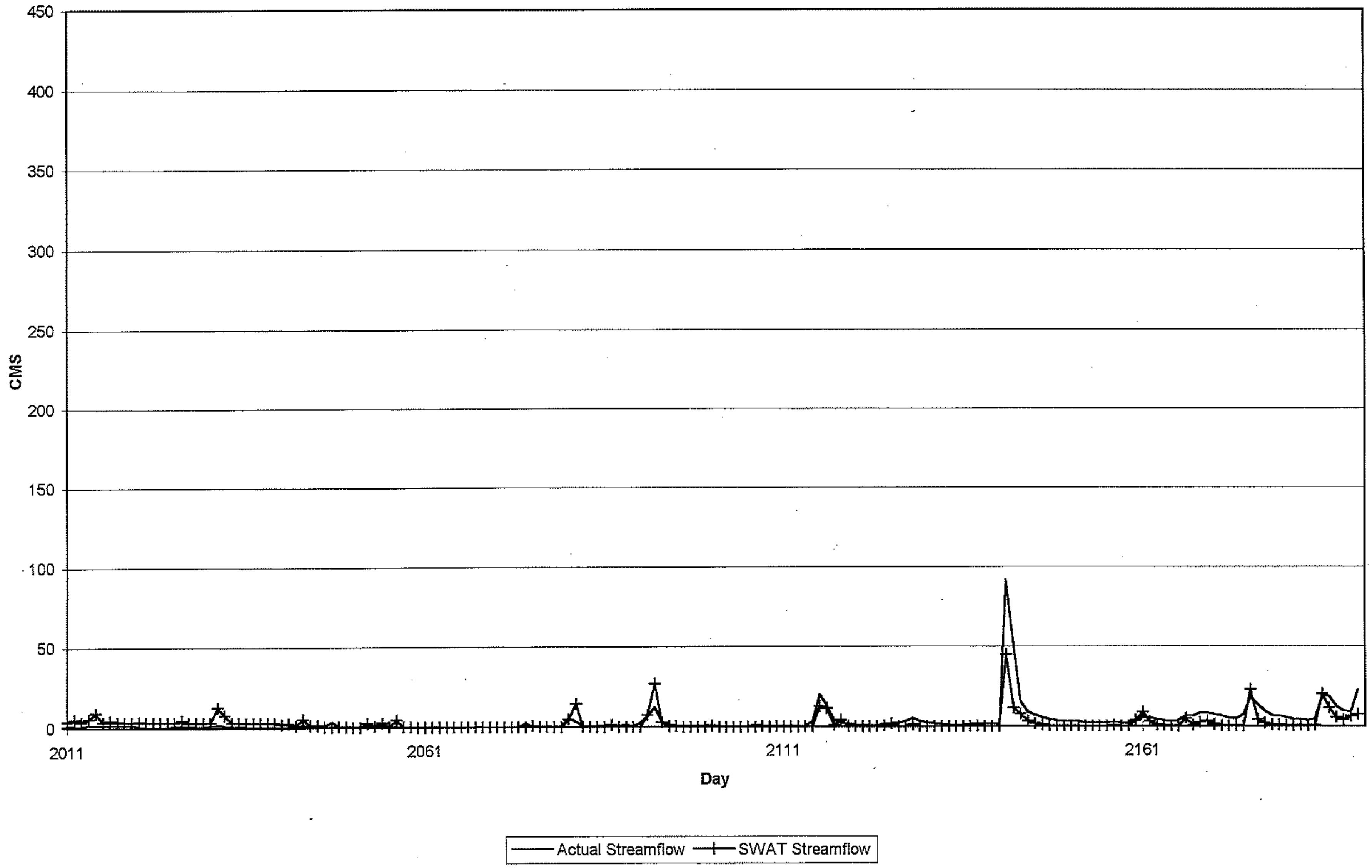
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



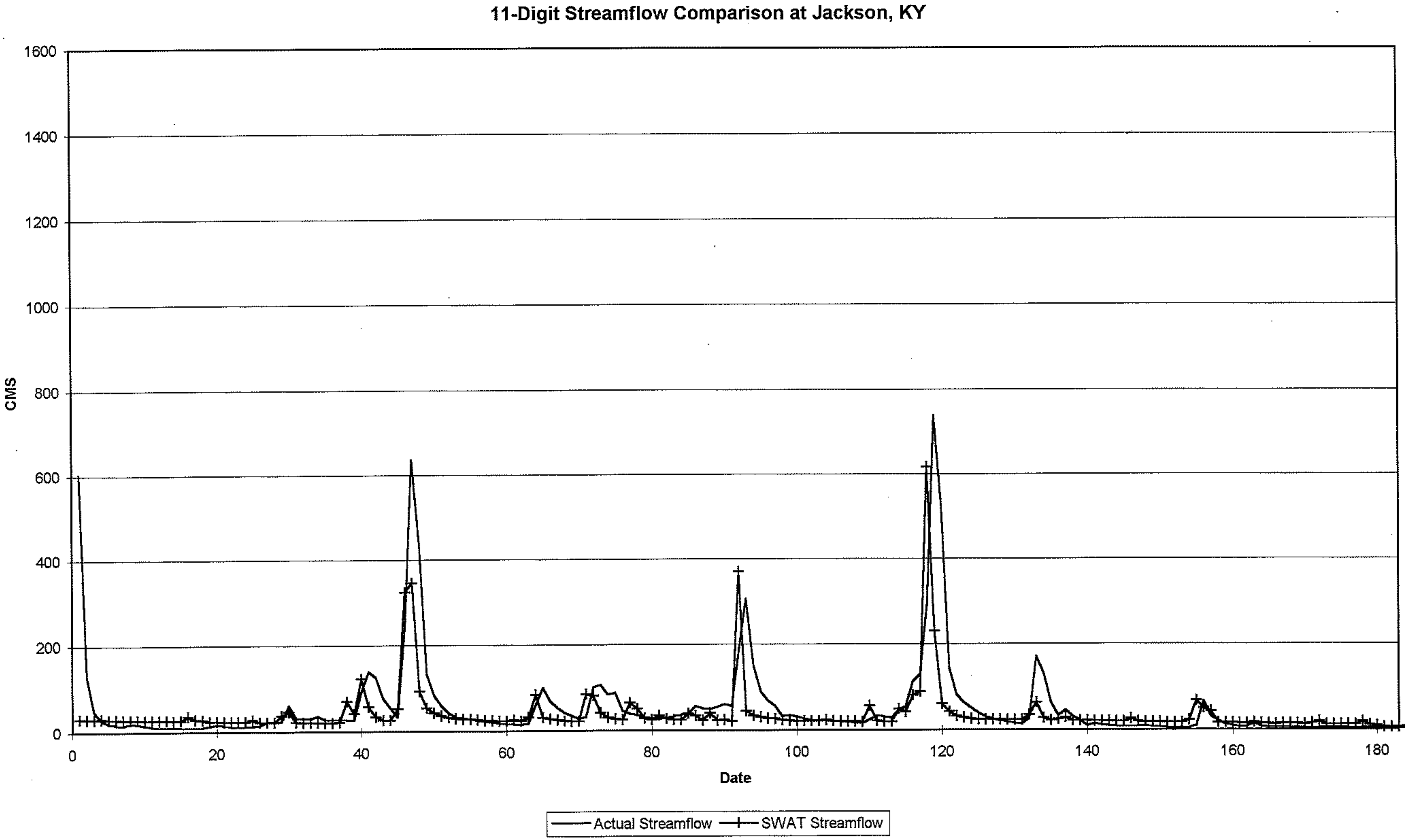
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



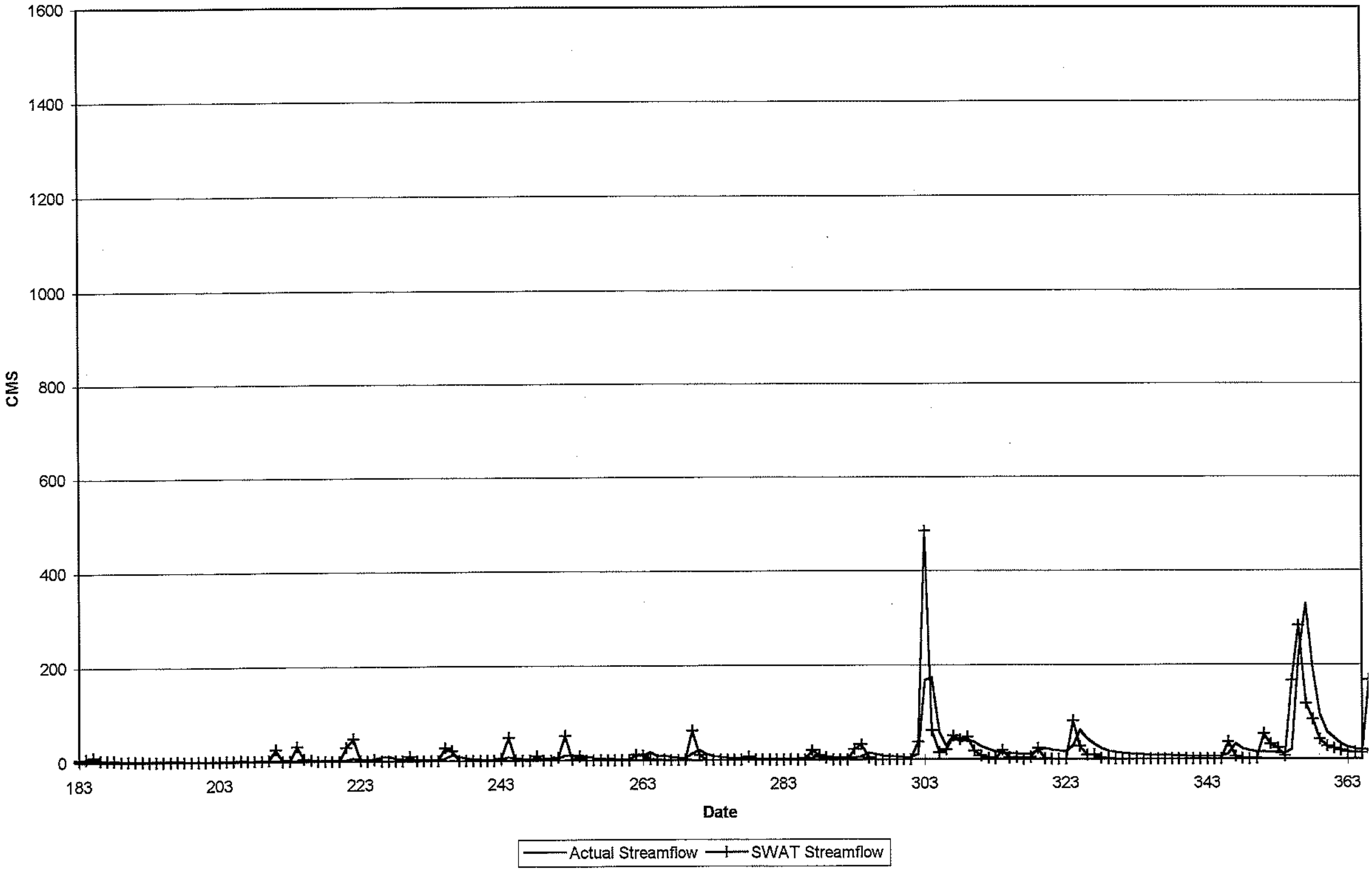
11-Digit Streamflow Comparison at Noble, KY for Troublesome Creek



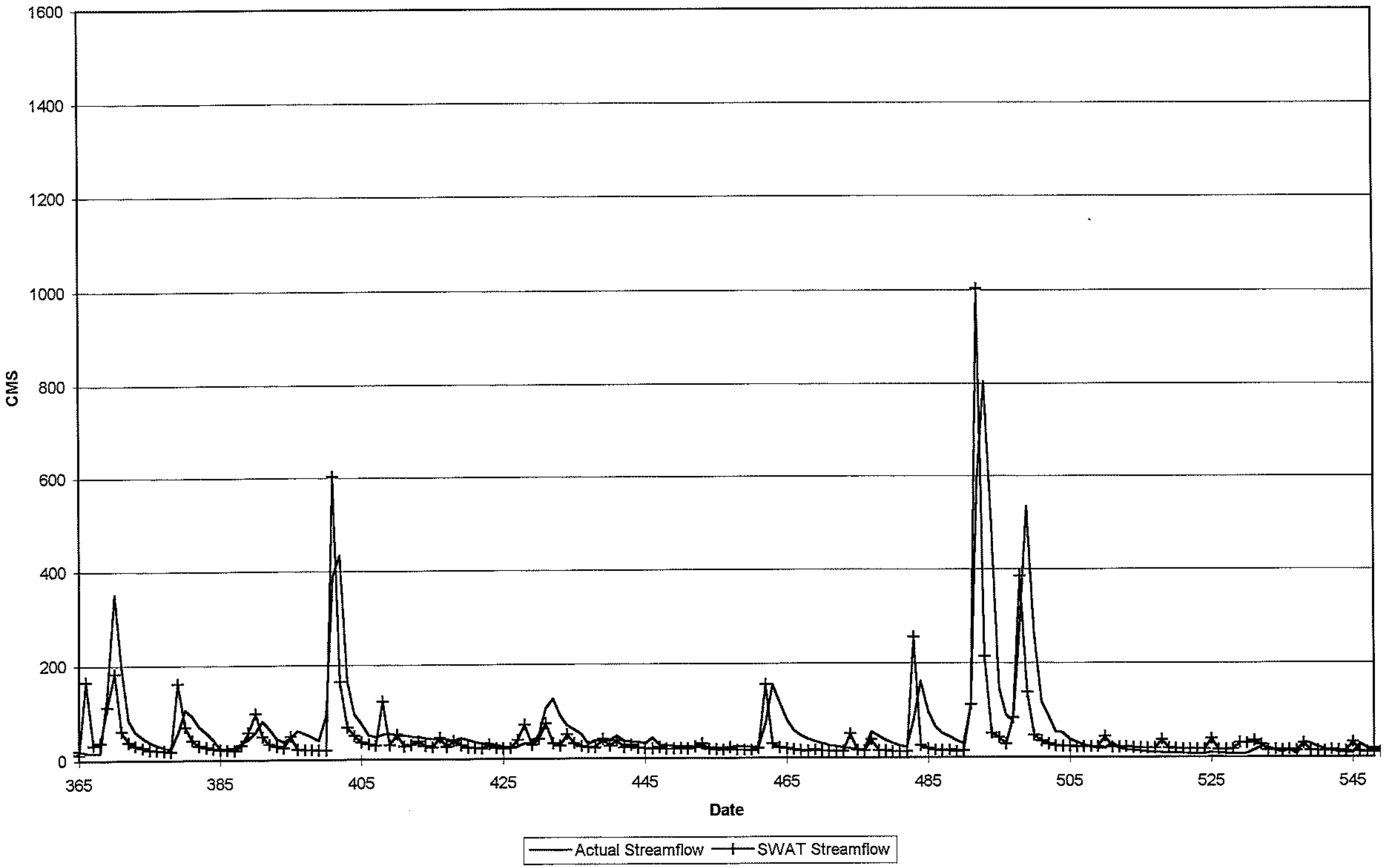
Appendix C4: Daily 11-digit streamflow comparison of the North Fork at Jackson, KY using SWAT.


11-Digit Streamflow Comparison at Jackson, KY
CMS
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Date
Actual Streamflow
SWAT Streamflow

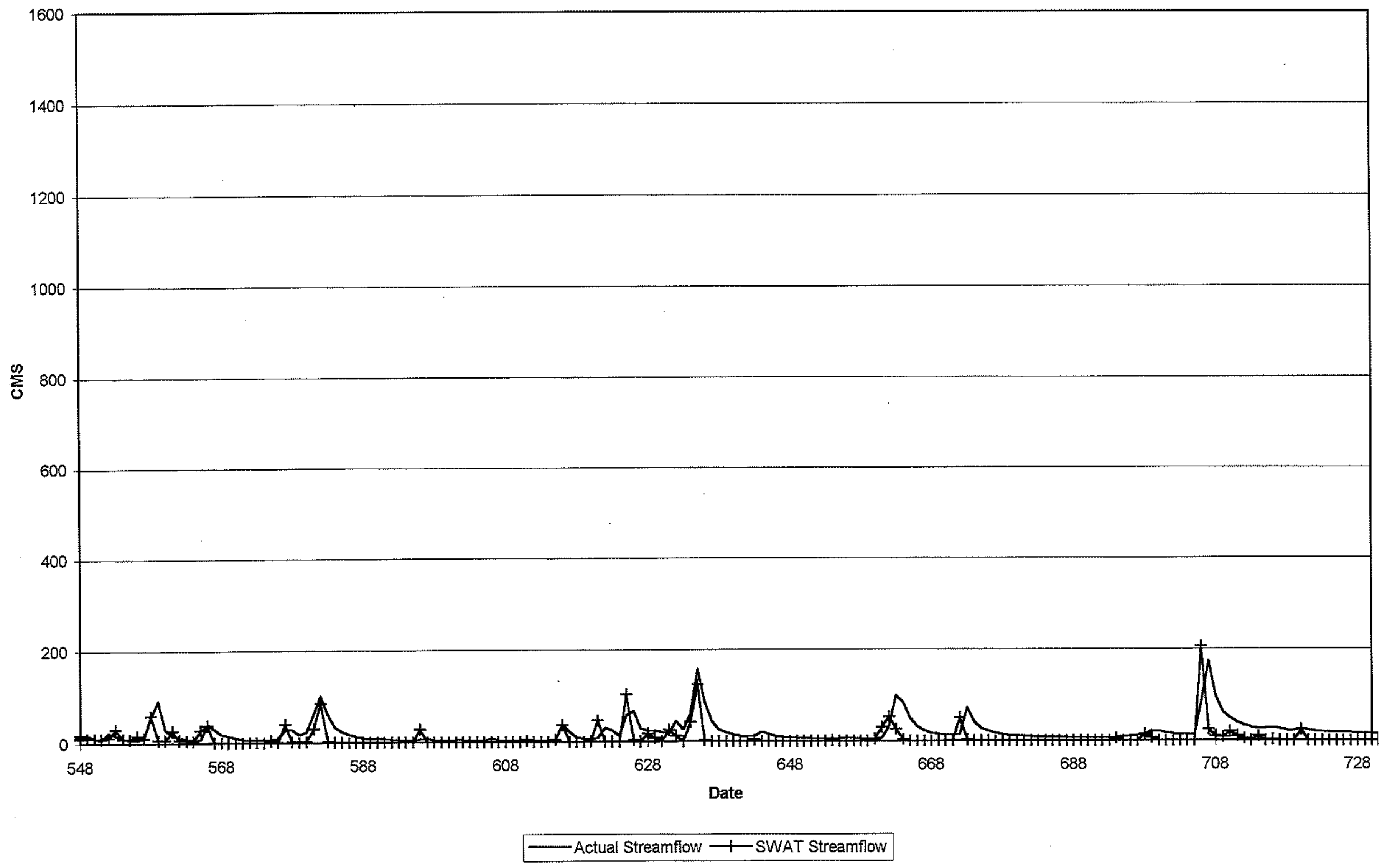
11-Digit Streamflow Comparison at Jackson, KY



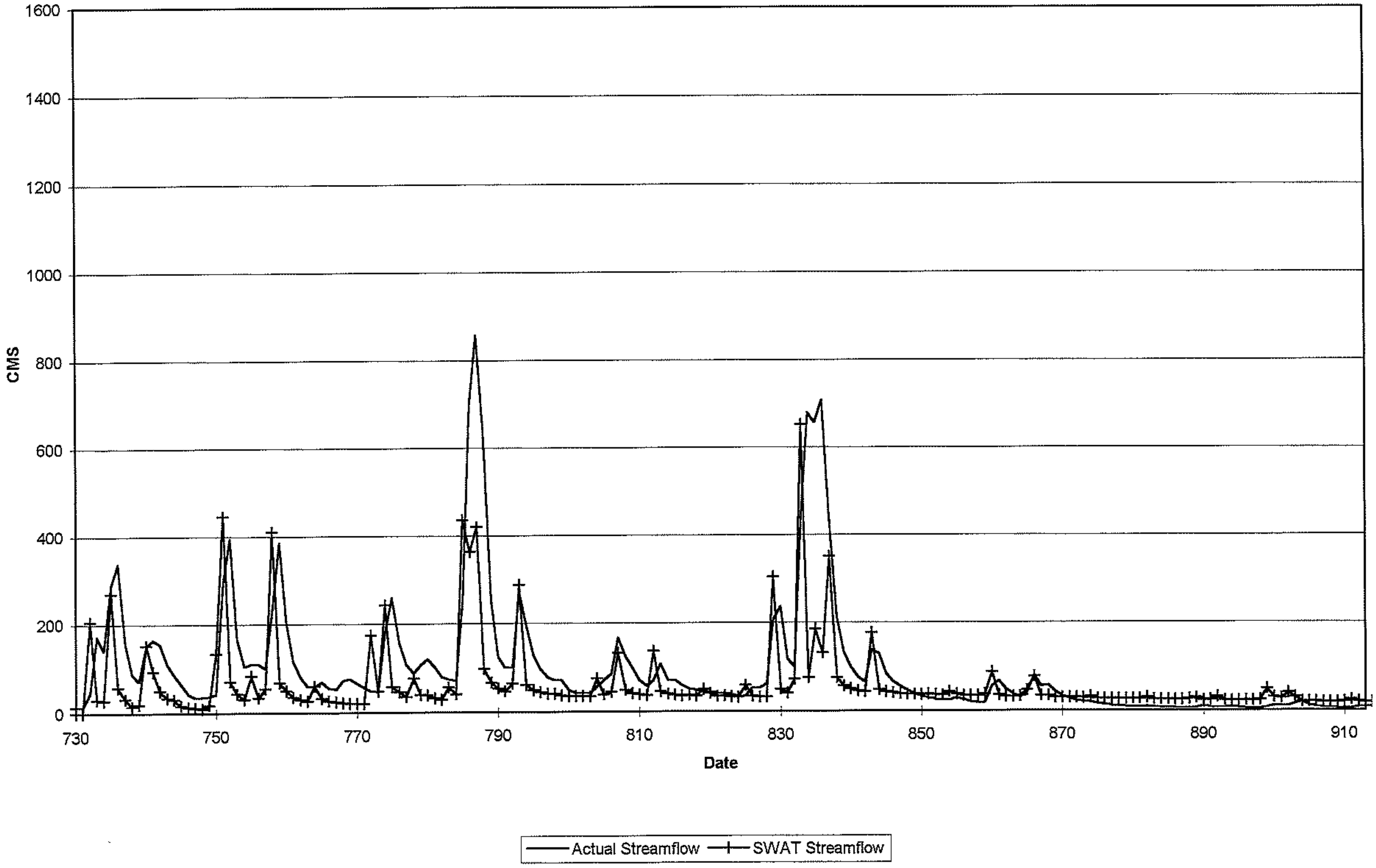
11-Digit Streamflow Comparison at Jackson, KY



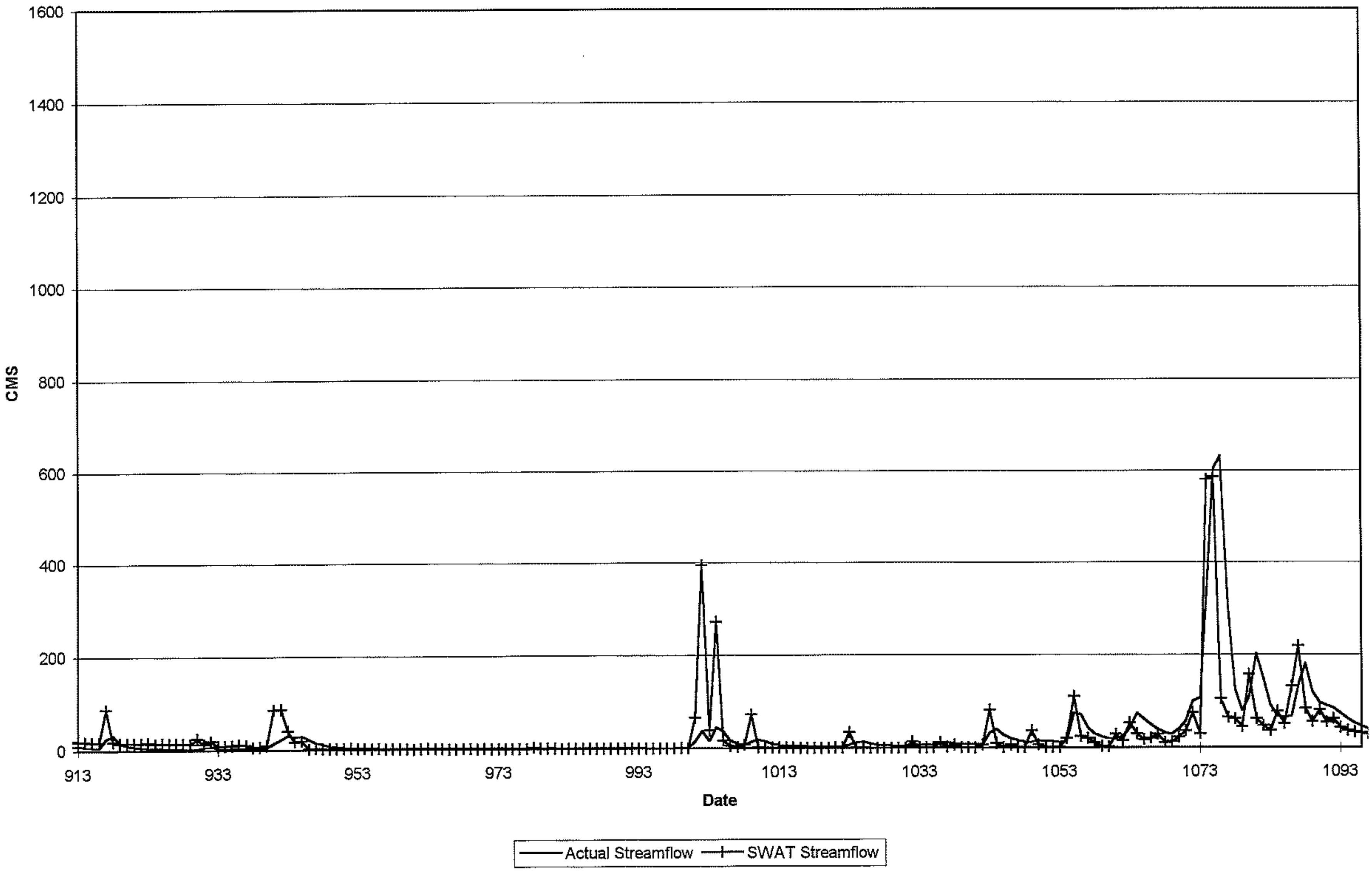
11-Digit Streamflow Comparison at Jackson, KY



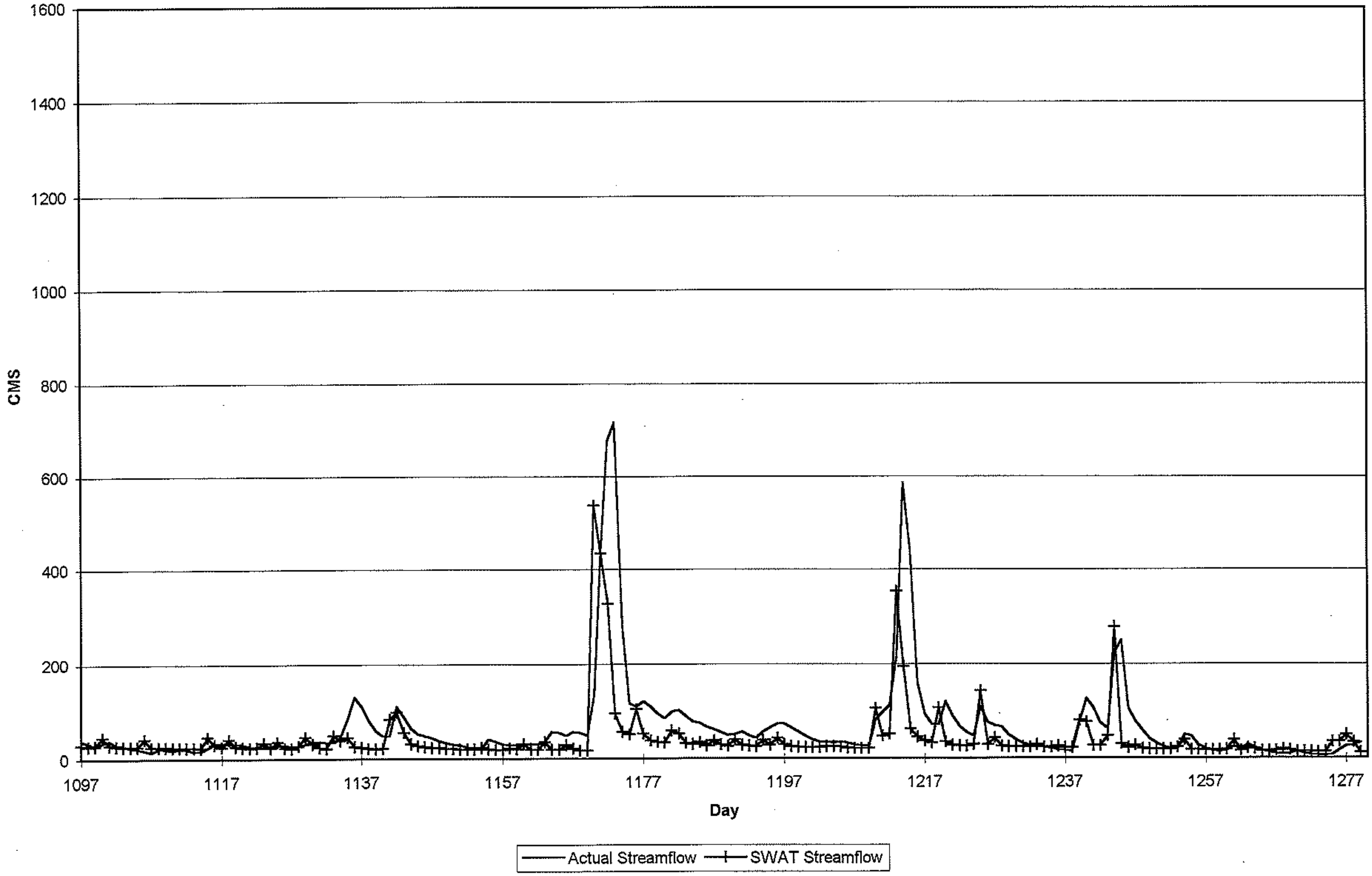
11-Digit Streamflow Comparison at Jackson, KY

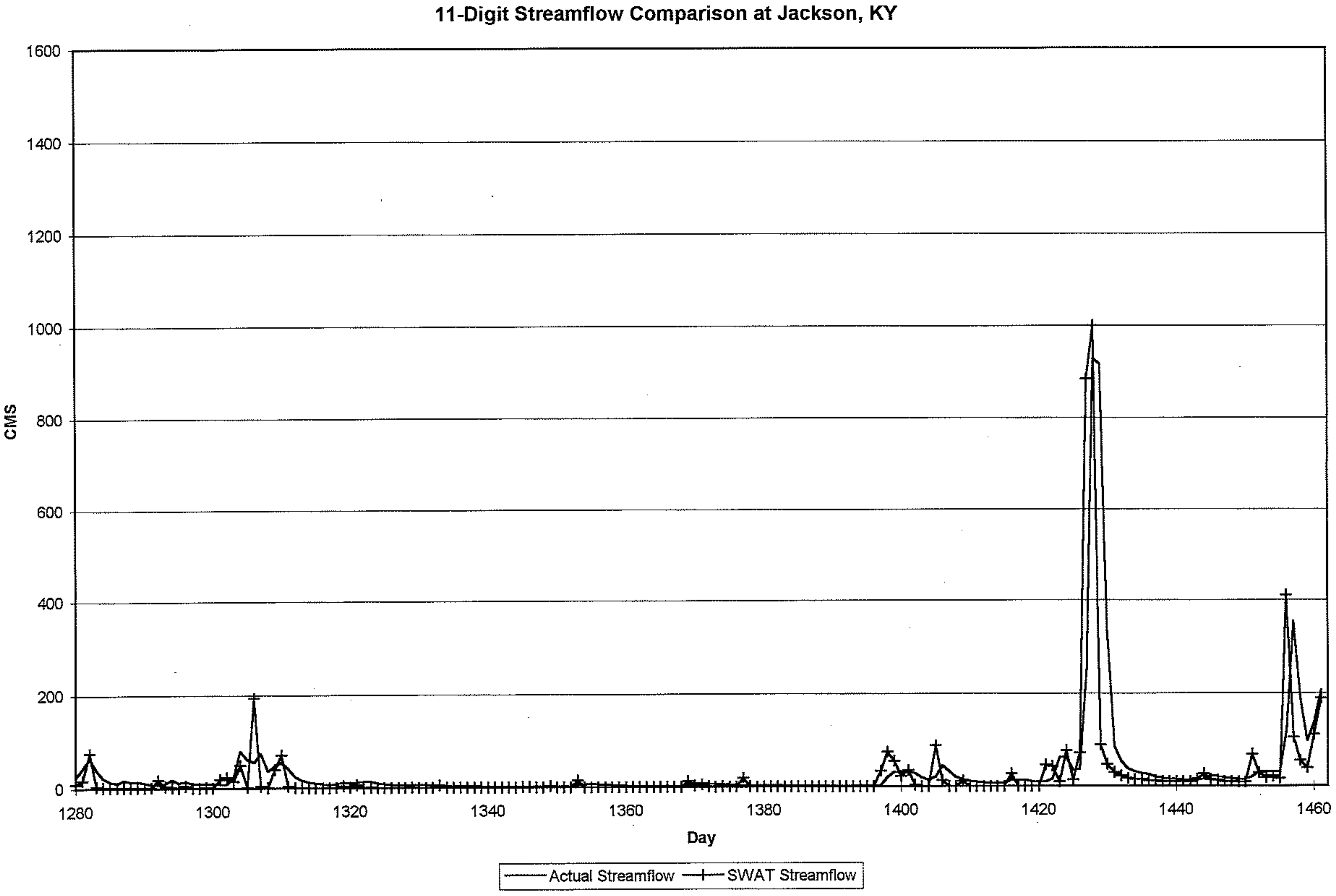


11-Digit Streamflow Comparison at Jackson, KY

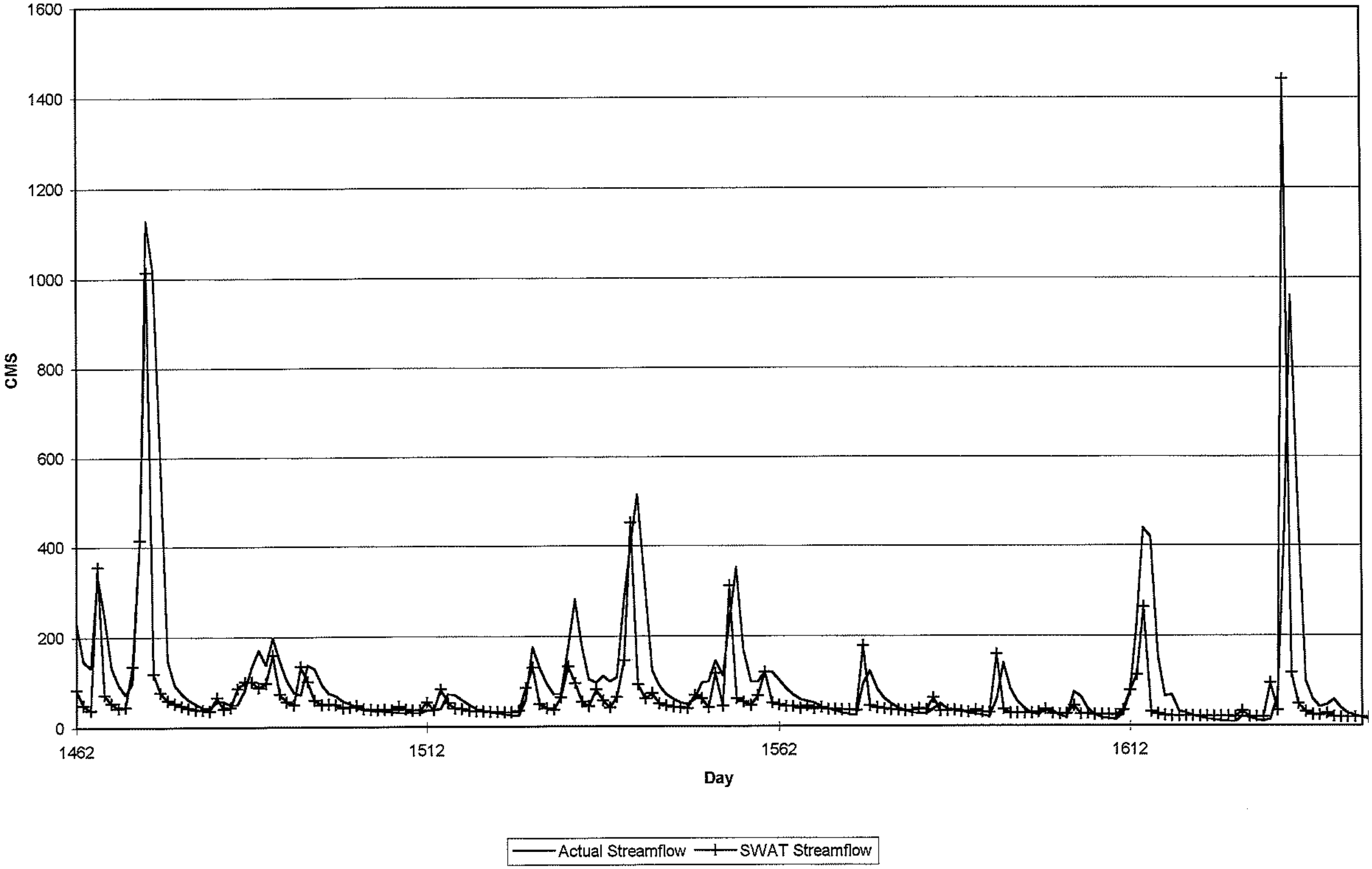


11-Digit Streamflow Comparison at Jackson, KY

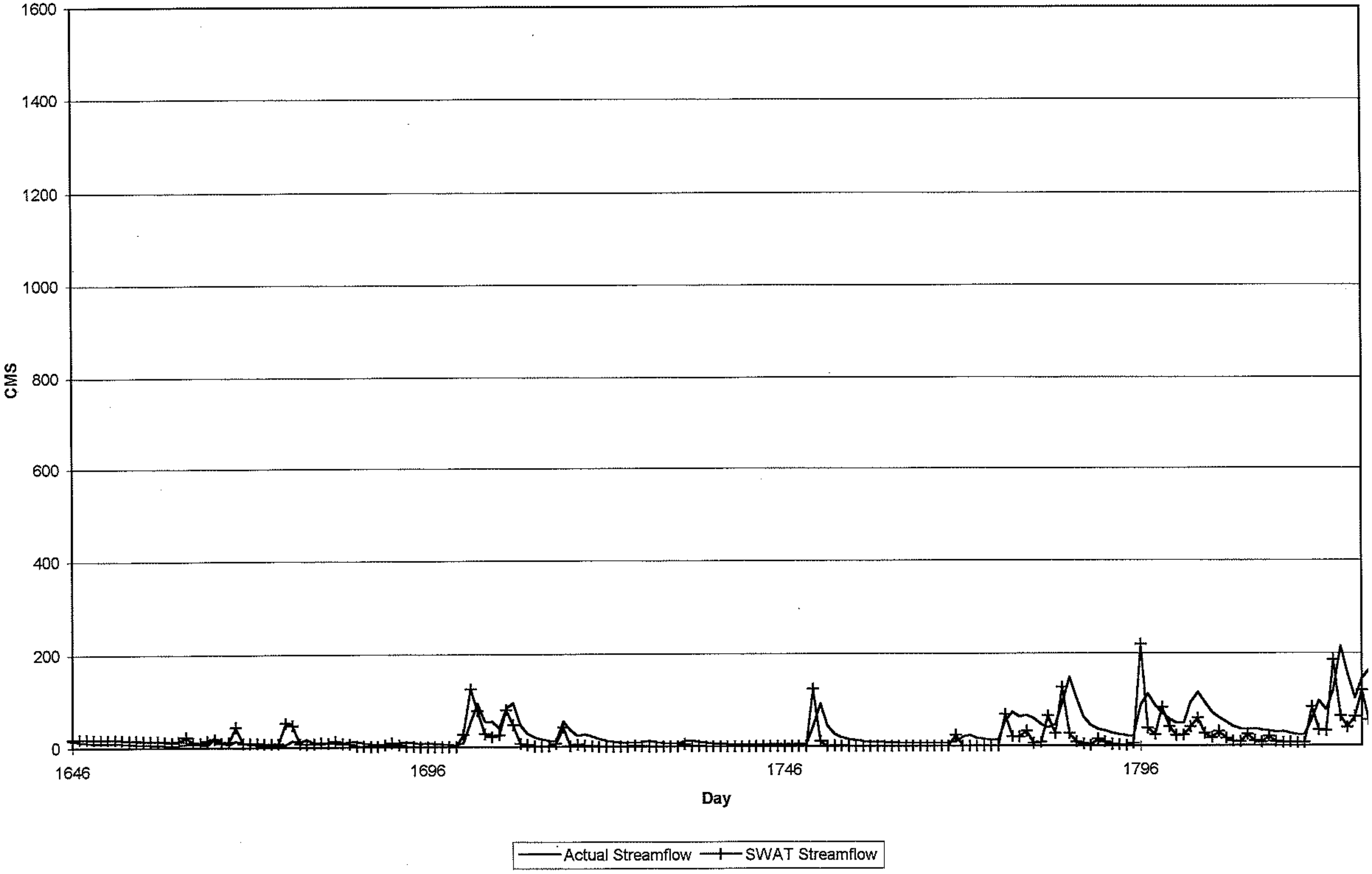



11-Digit Streamflow Comparison at Jackson, KY
CMS
1600
1400
1200
1000
800
600
400
200
0
1280
1300
1320
1340
1360
1380
1400
1420
1440
1460
Day
Actual Streamflow
SWAT Streamflow

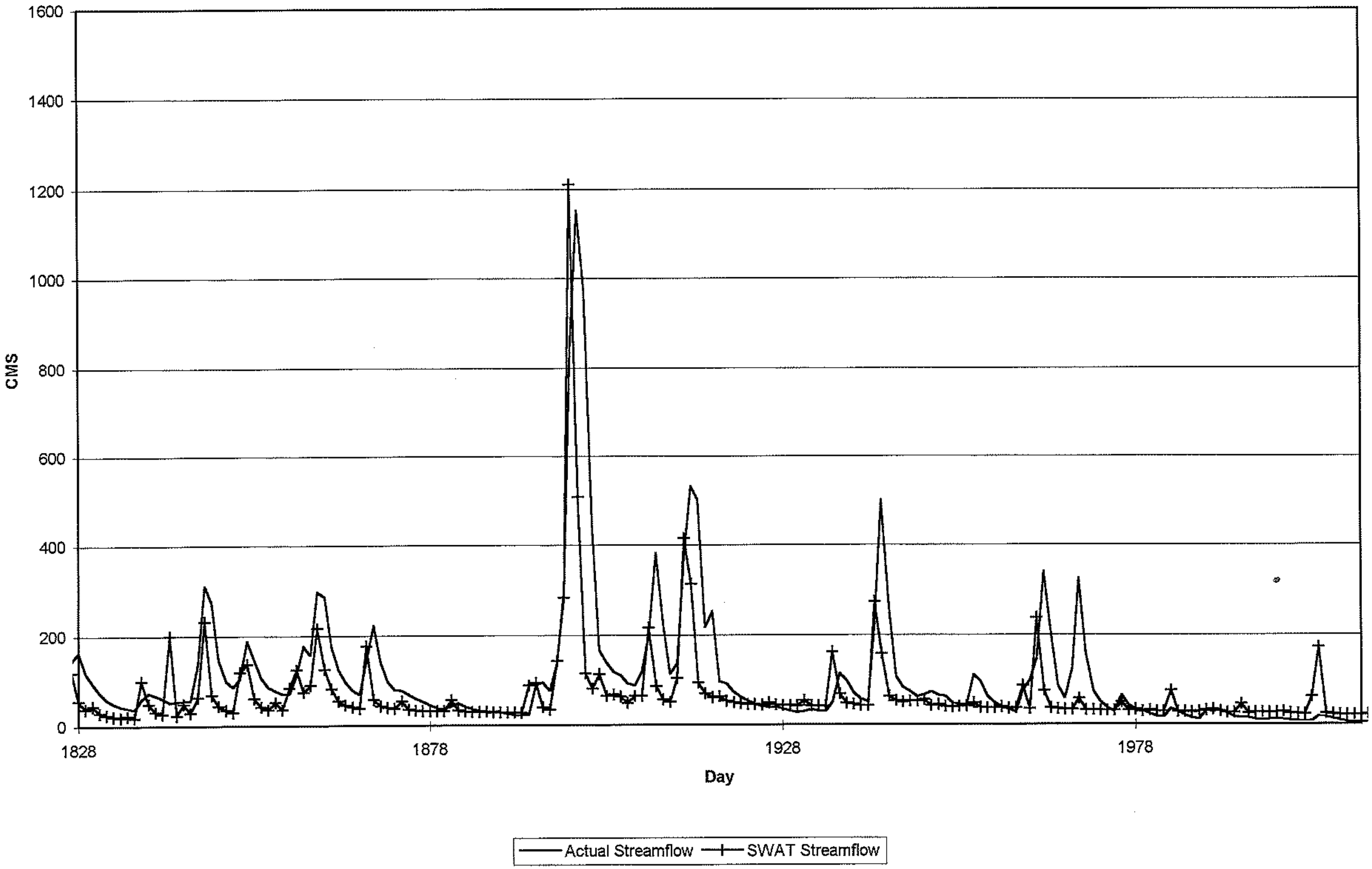
11-Digit Streamflow Comparison at Jackson, KY



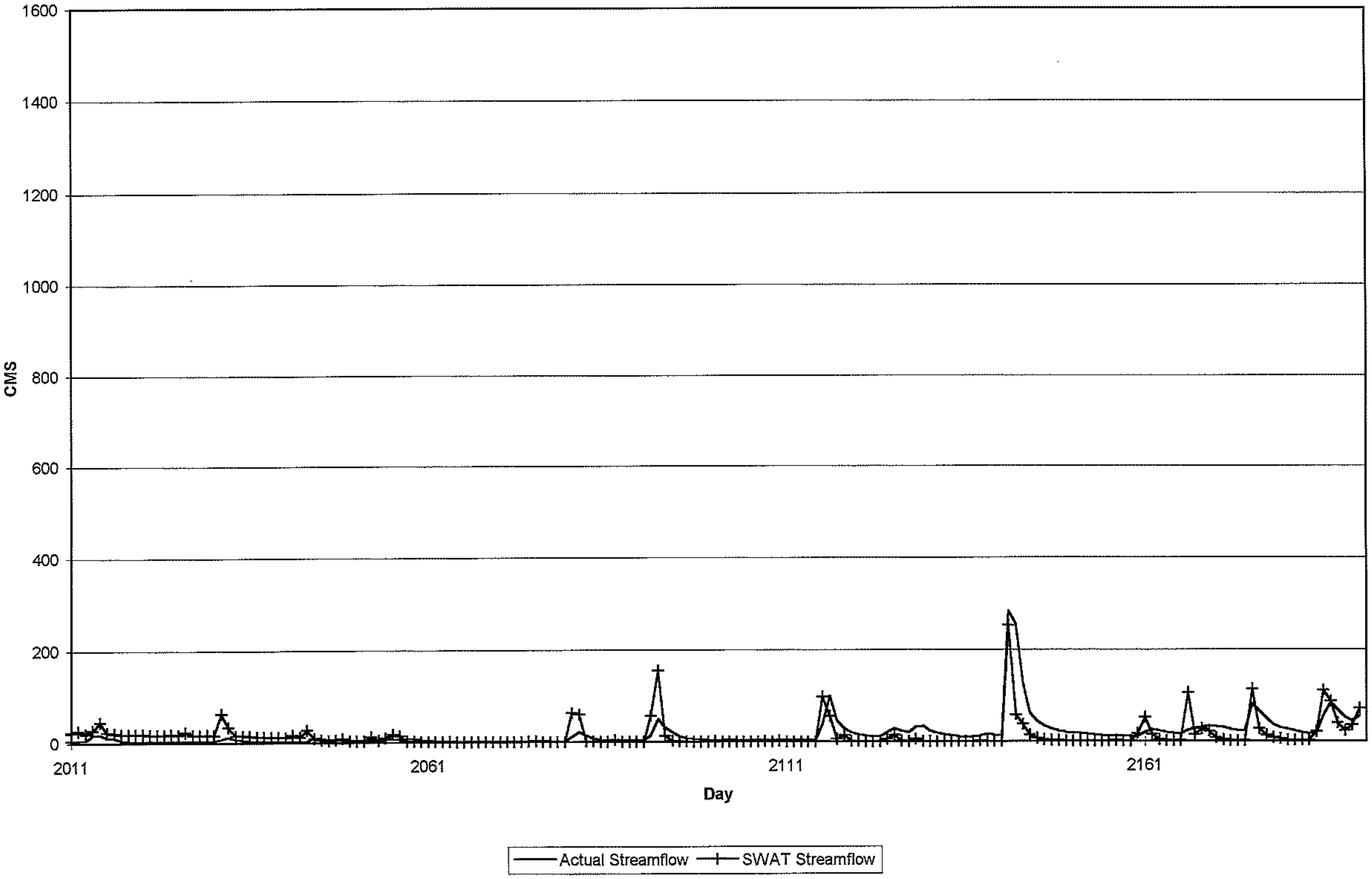
11-Digit Streamflow Comparison at Jackson, KY



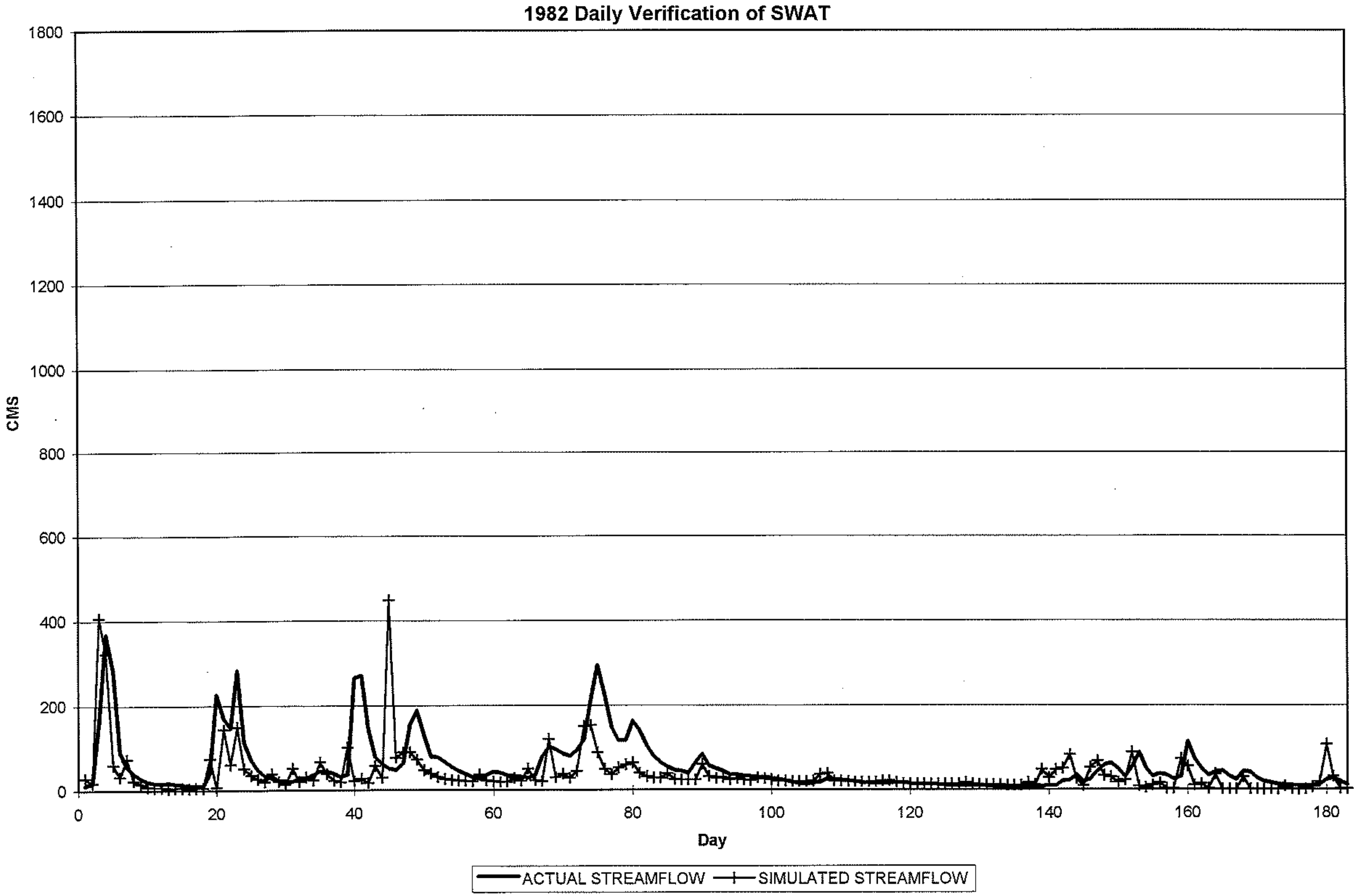
11-Digit Streamflow Comparison at Jackson, KY

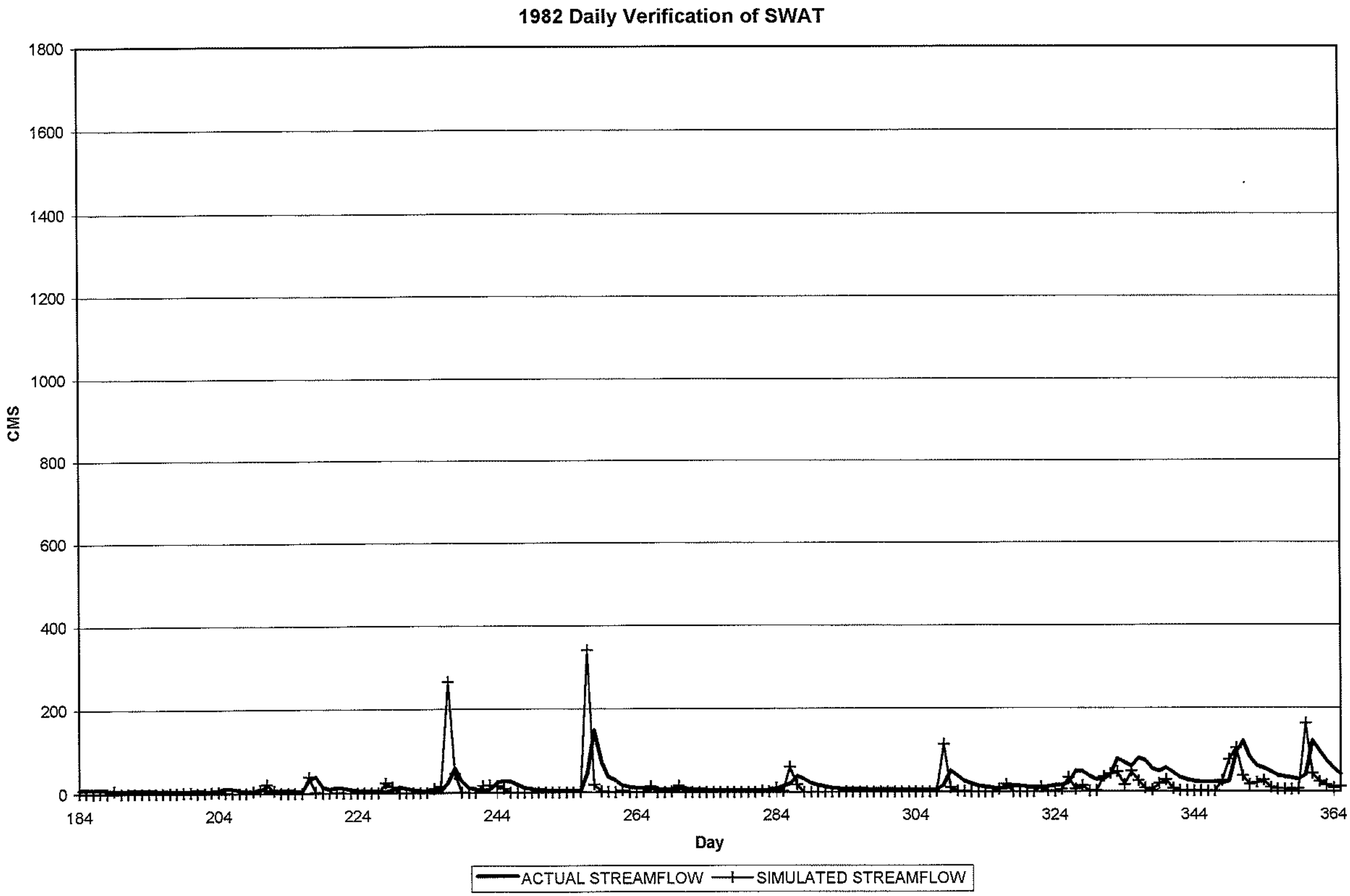


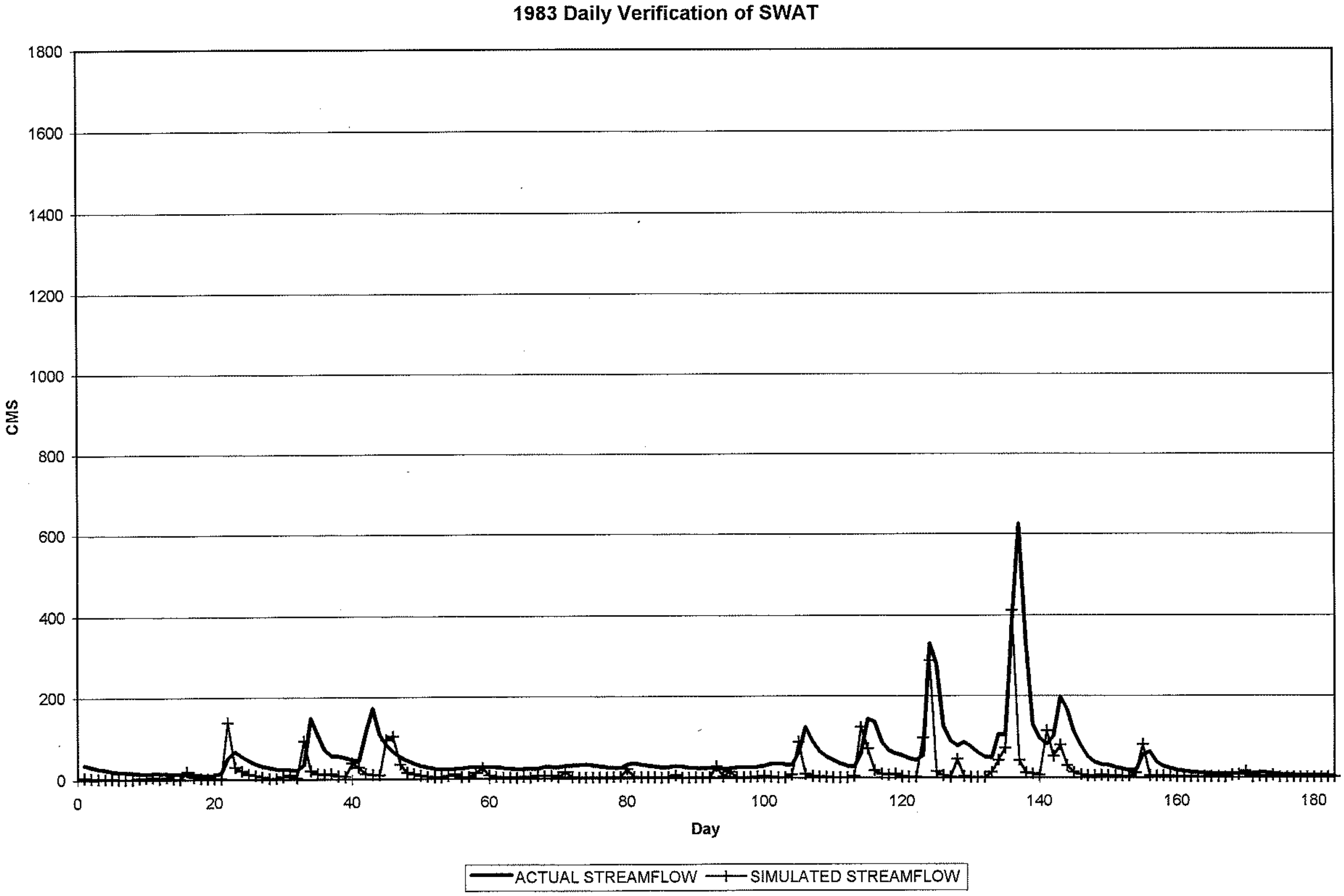
11-Digit Streamflow Comparison at Jackson, KY



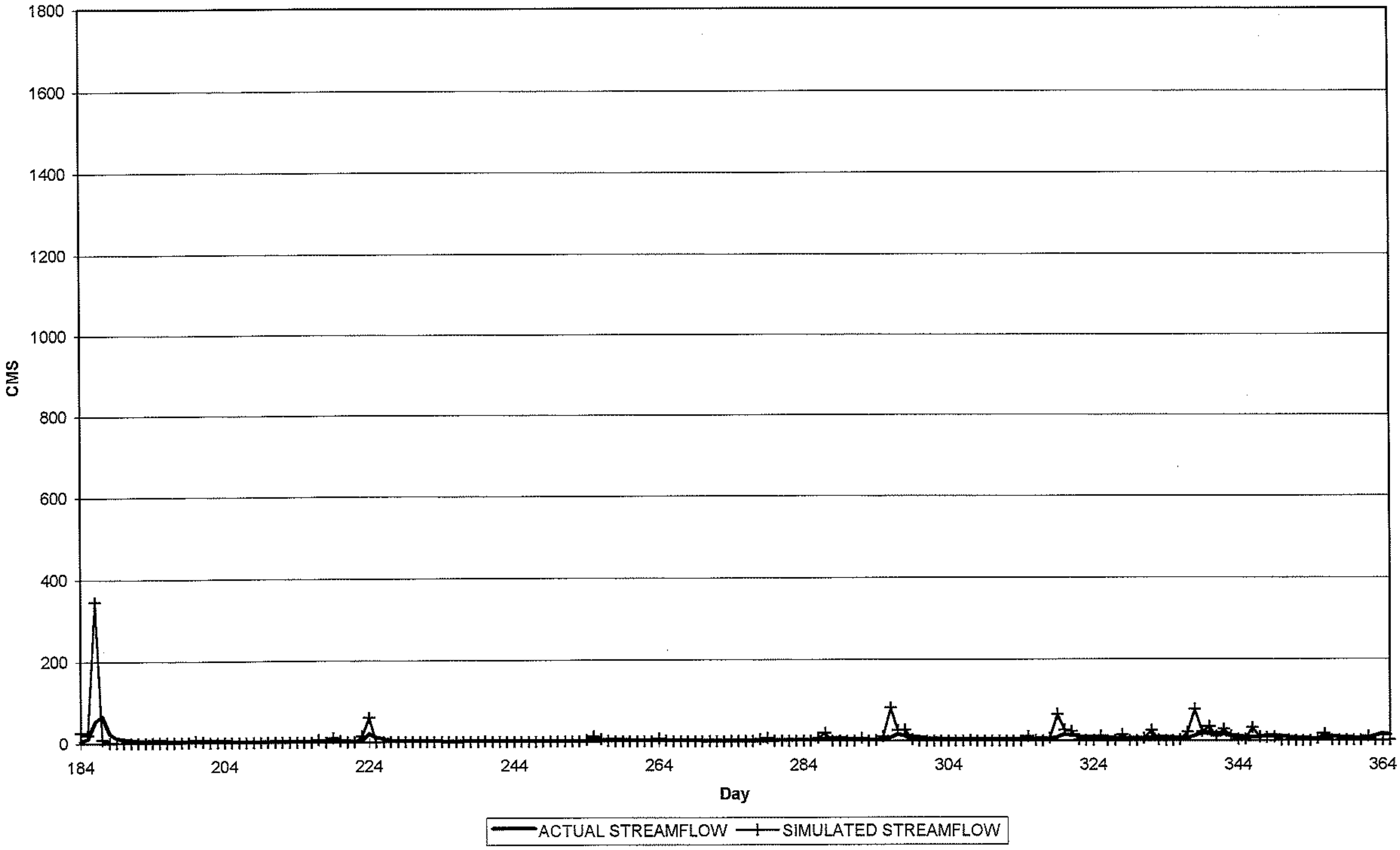
Appendix C5: Daily verification run of SWAT for 1982-1984 and 1988-1990.

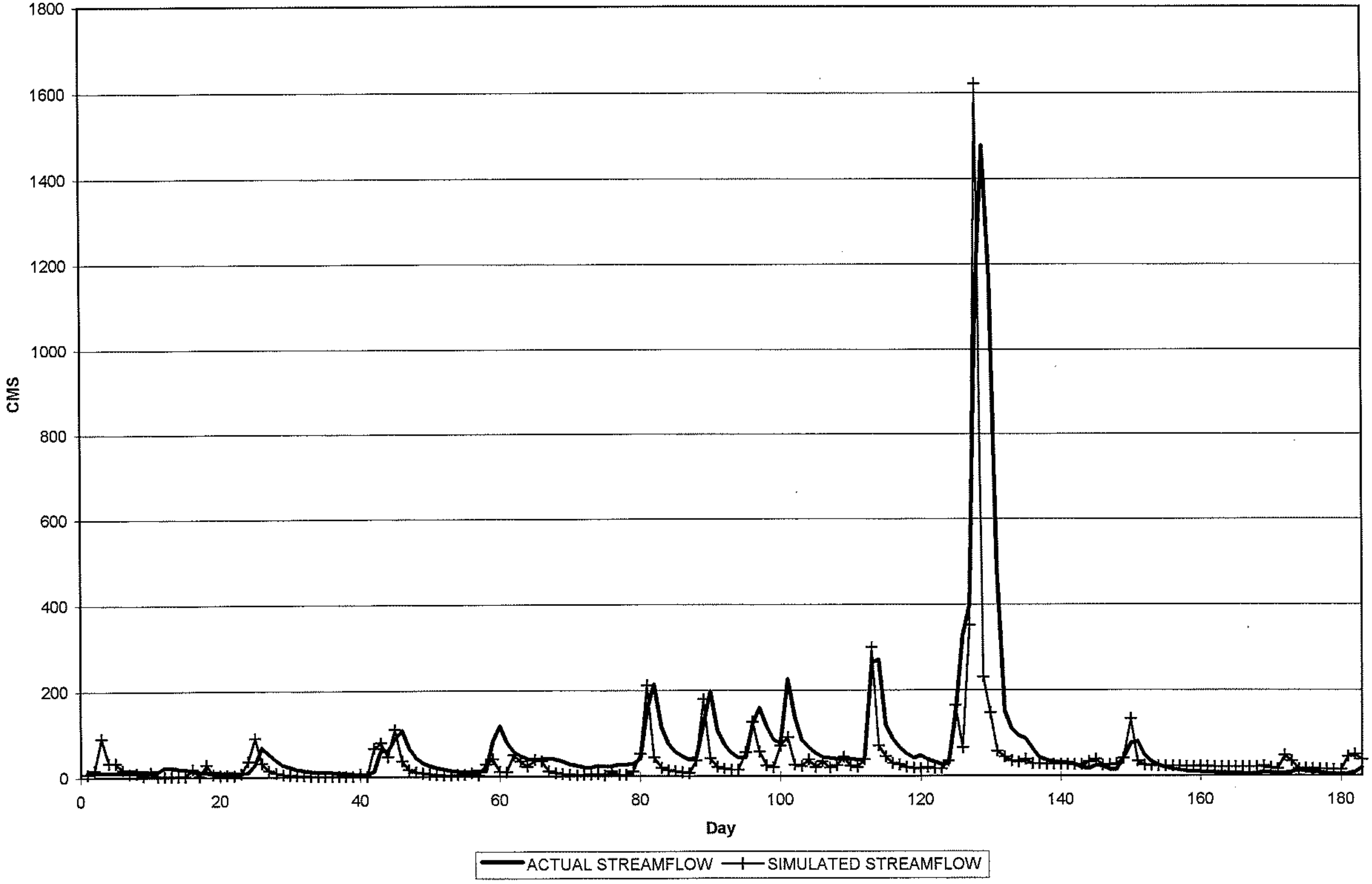

1982 Daily Verification of SWAT
CMS
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Day
ACTUAL STREAMFLOW
SIMULATED STREAMFLOW


1982 Daily Verification of SWAT


1983 Daily Verification of SWAT
CMS
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Day
ACTUAL STREAMFLOW
SIMULATED STREAMFLOW

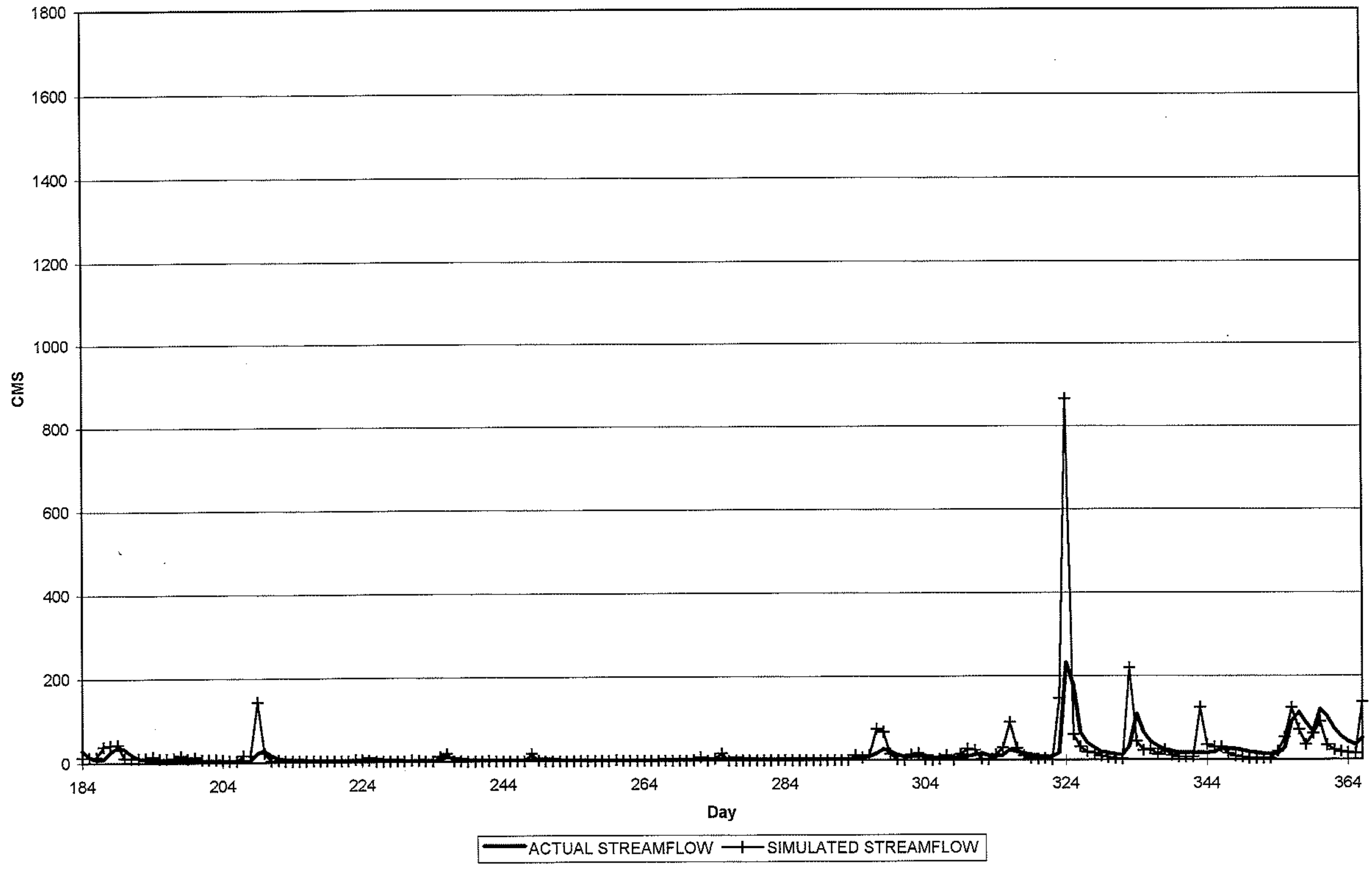
1983 Daily Verification of SWAT

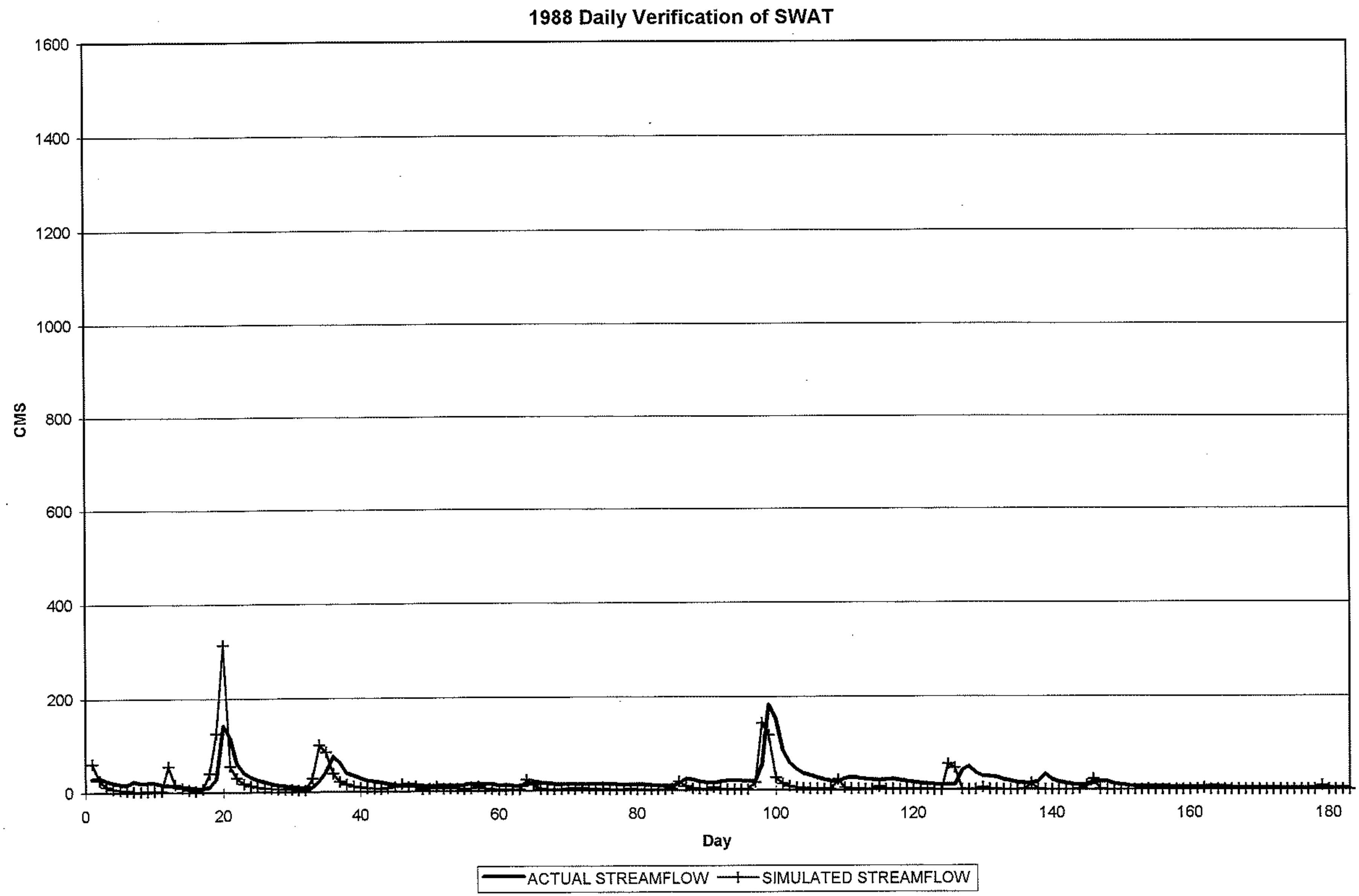




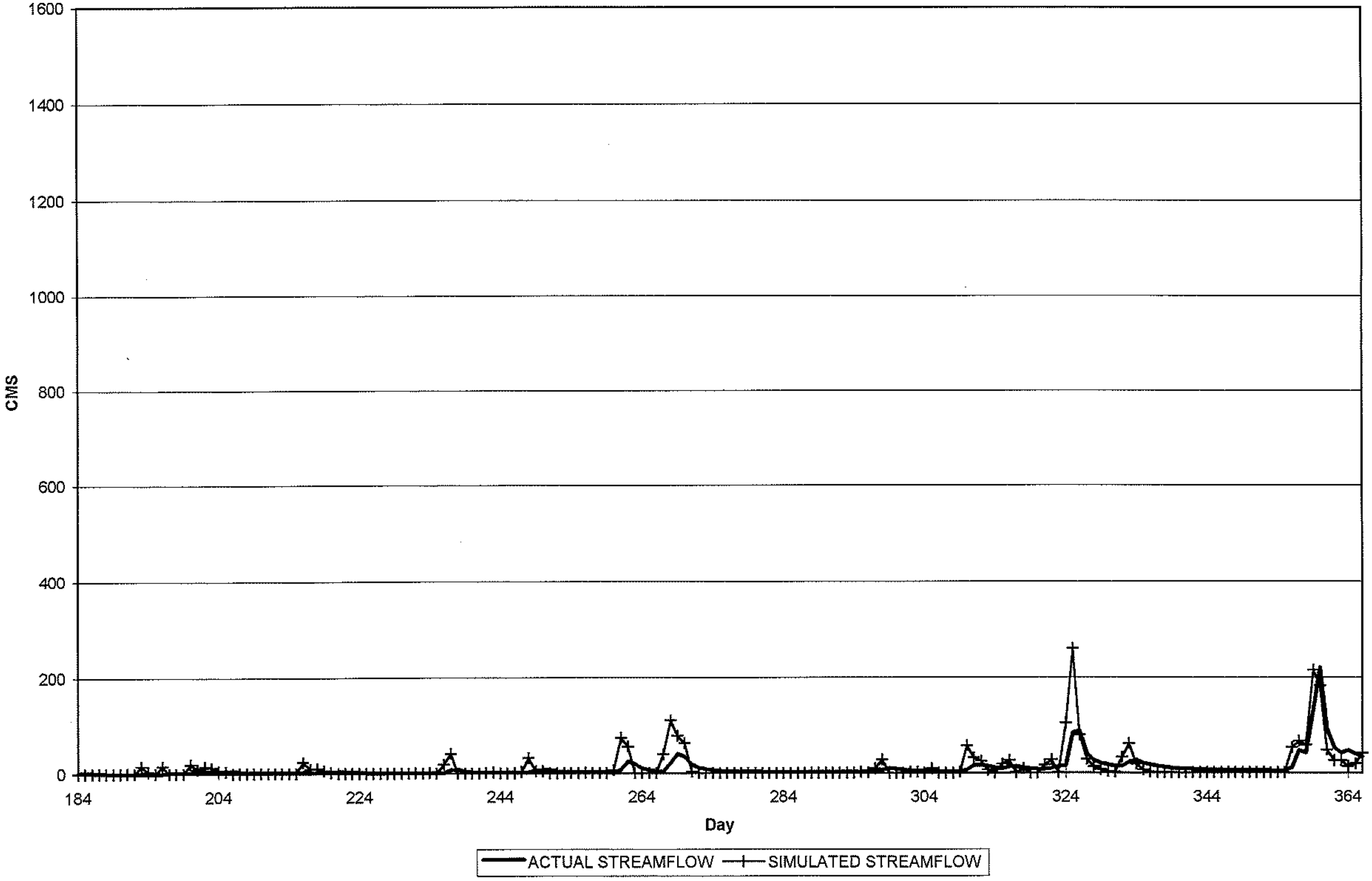
1984 Daily Verification of SWAT

1984 Daily Verification of SWAT

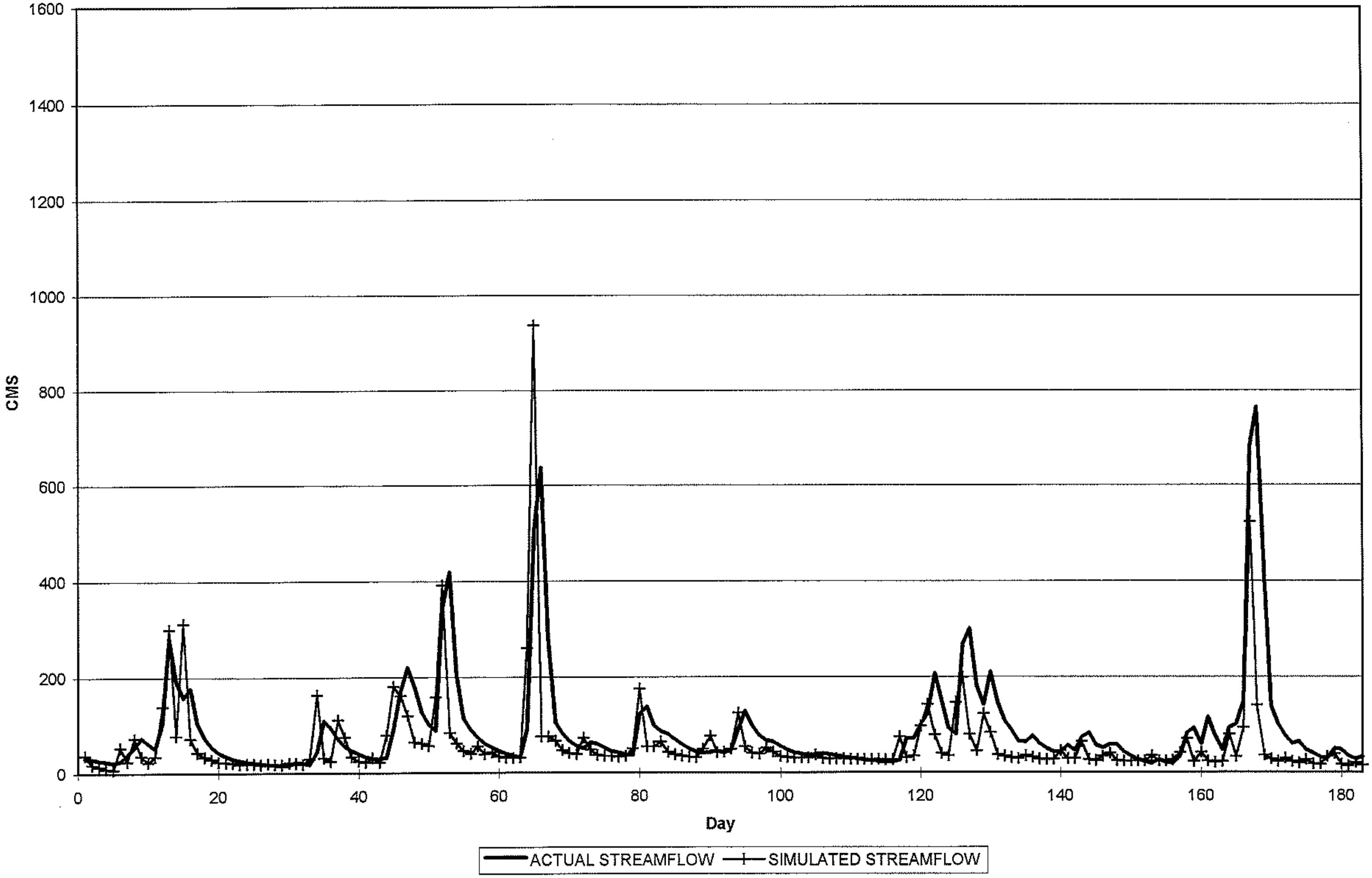



1988 Daily Verification of SWAT
CMS
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Day
ACTUAL STREAMFLOW
SIMULATED STREAMFLOW

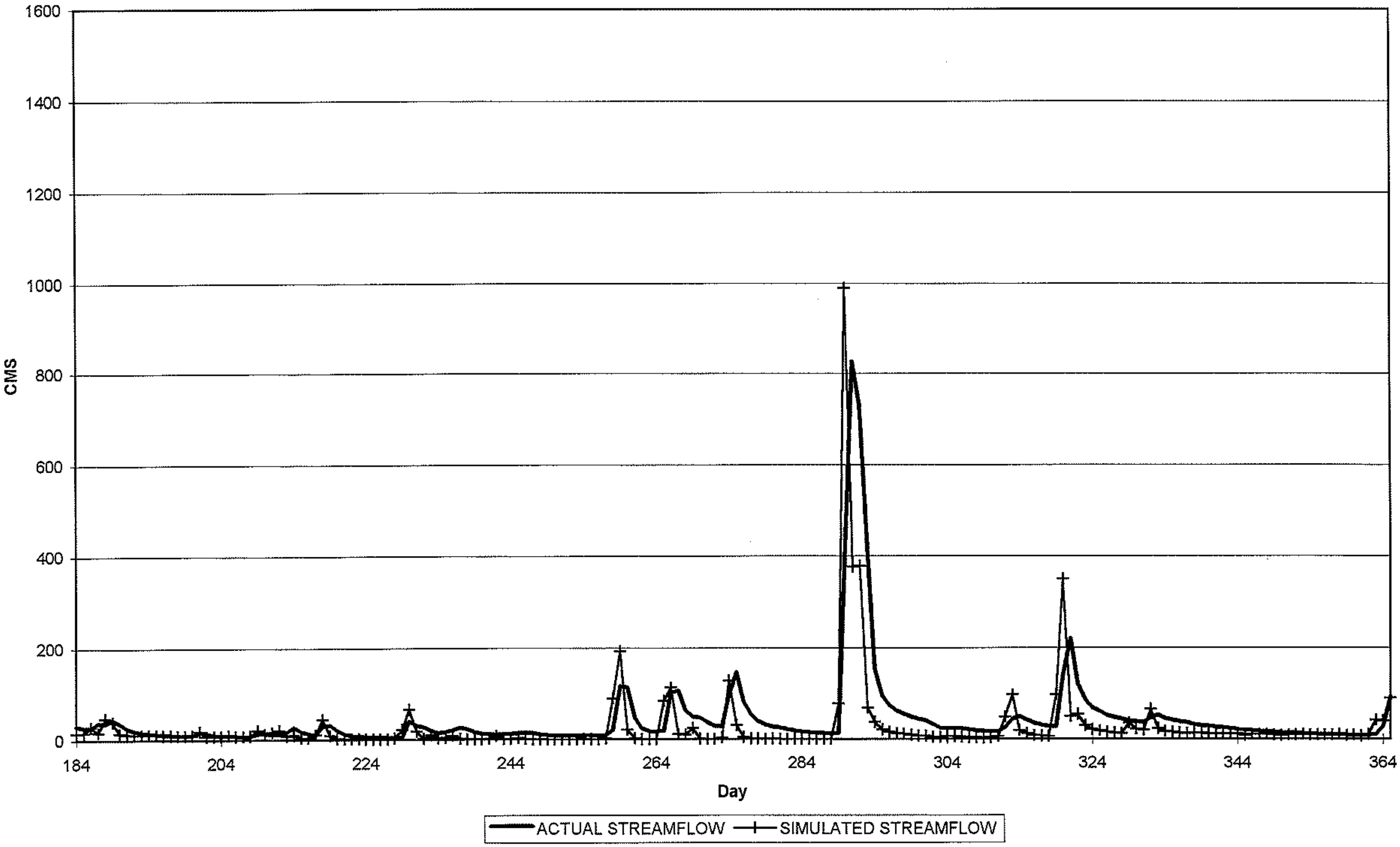
1988 Daily Verification of SWAT

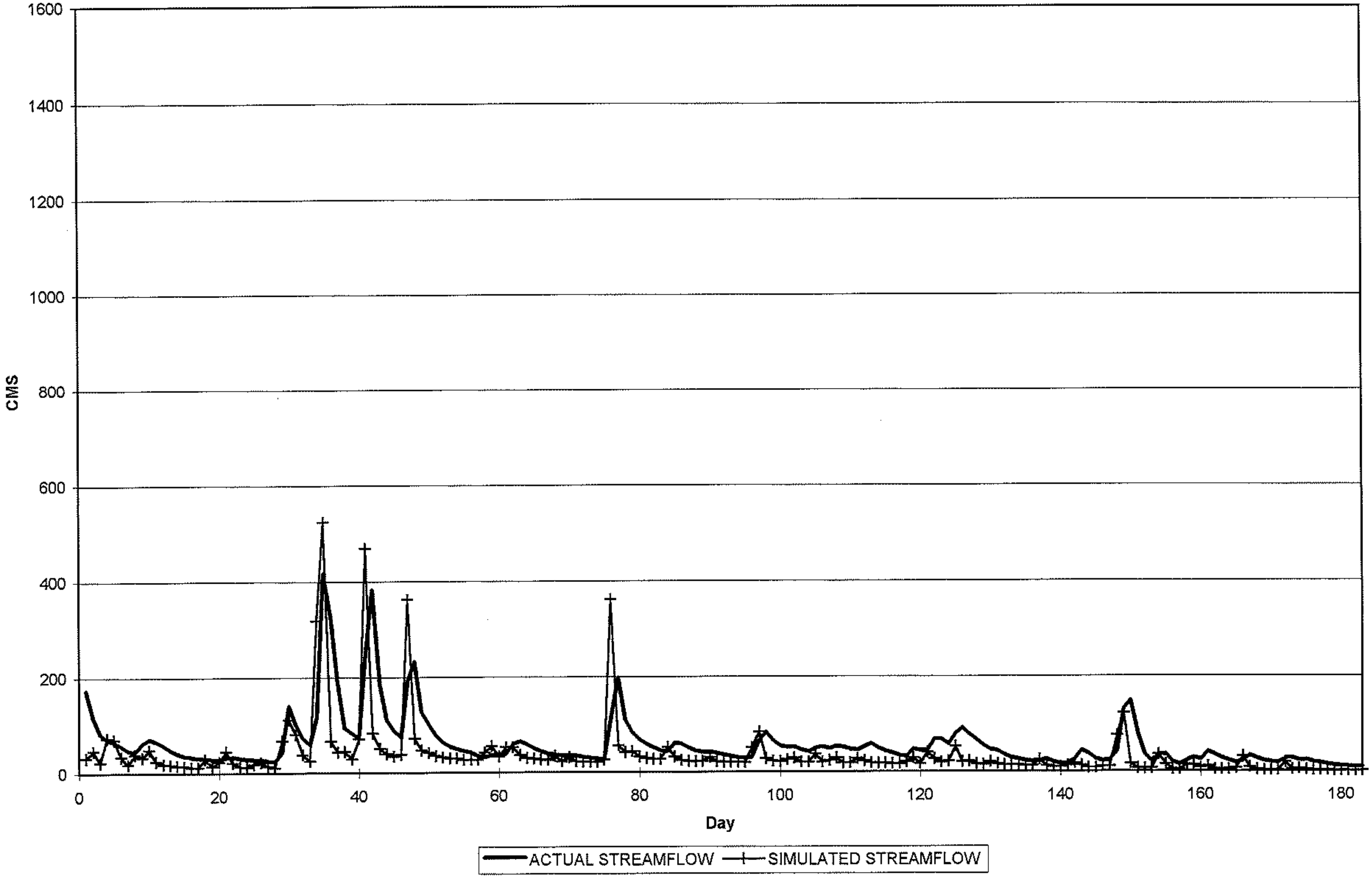


1989 Daily Verification of SWAT



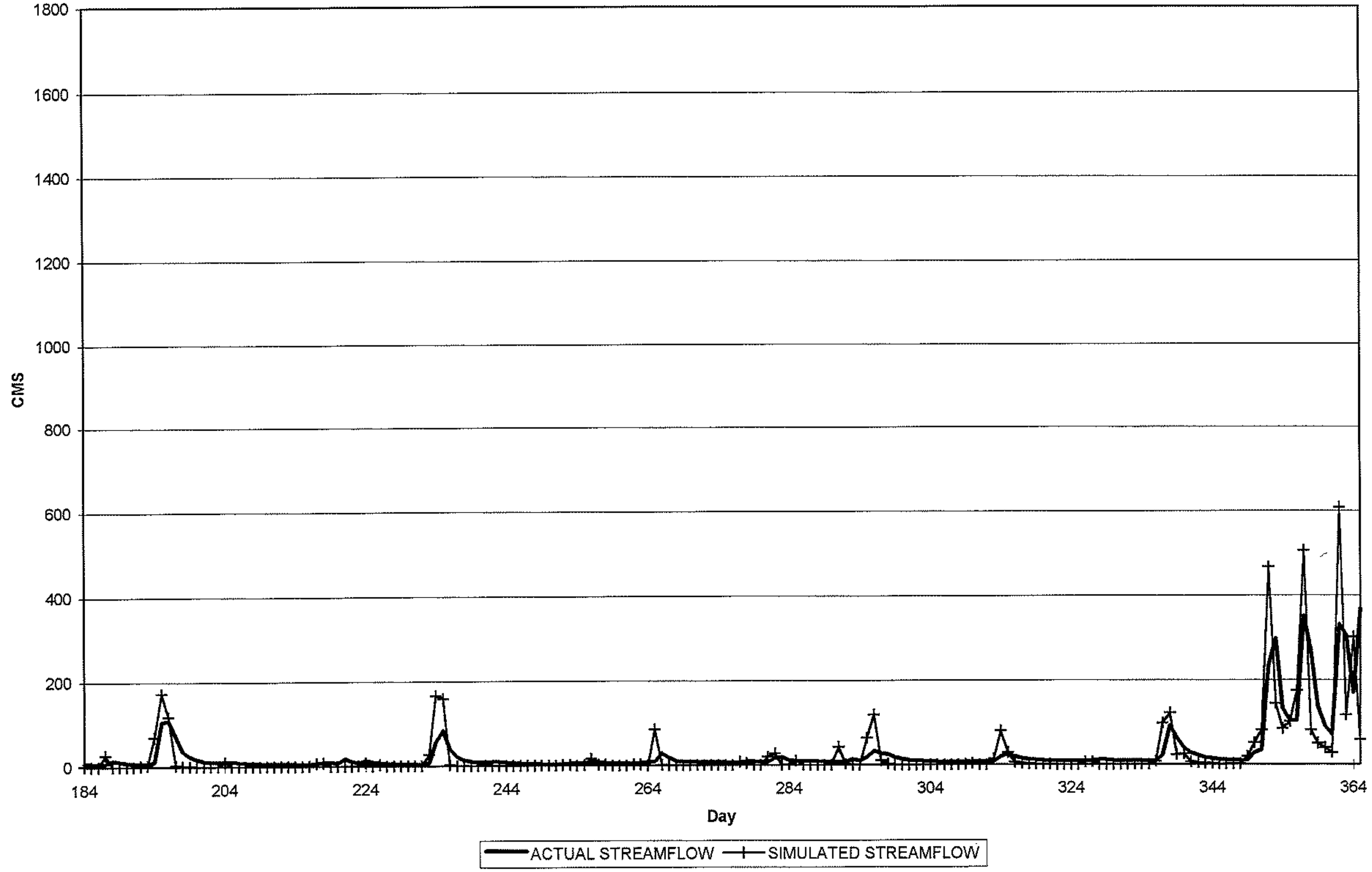
1989 Daily Verification of SWAT



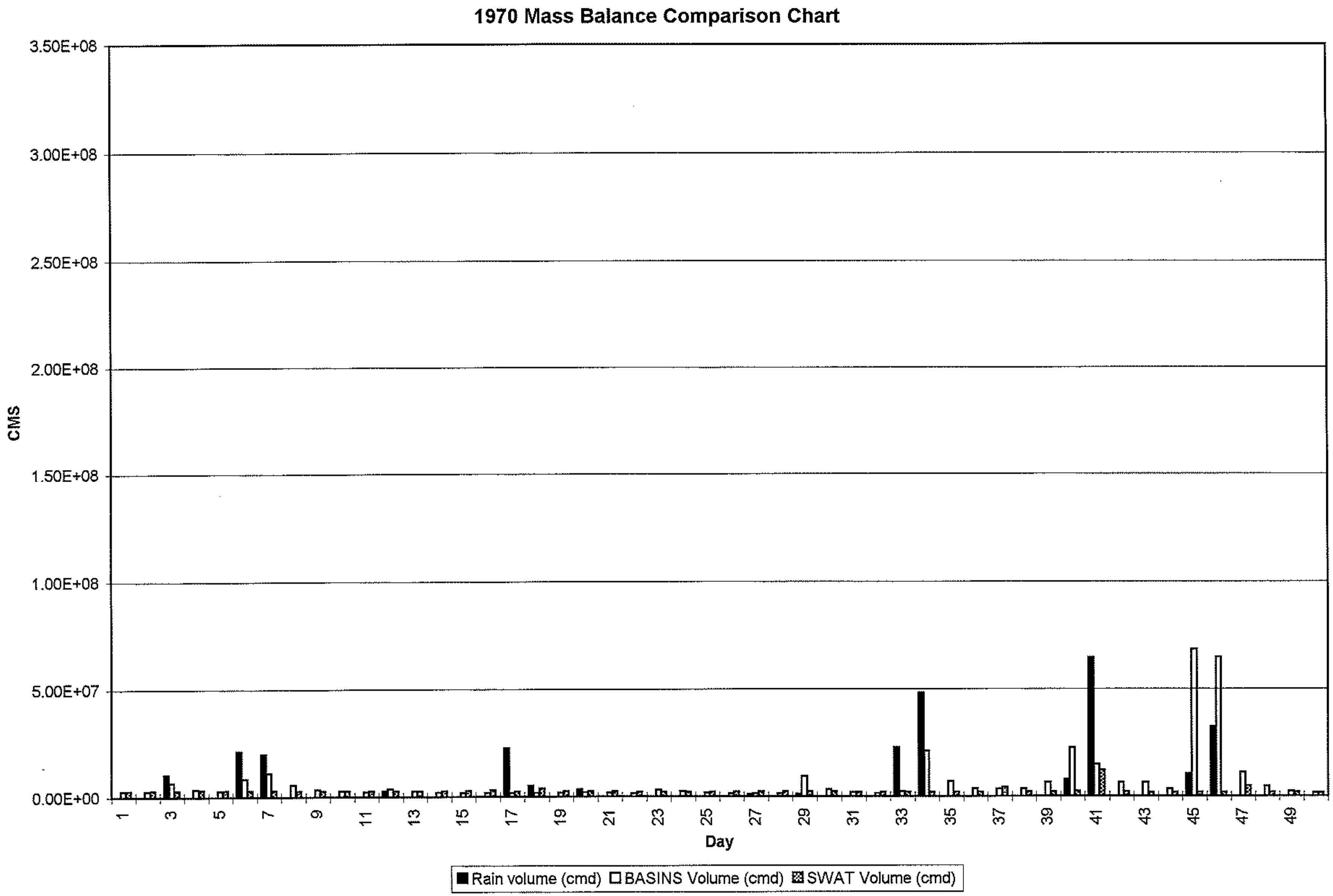


1990 Daily Verification of SWAT

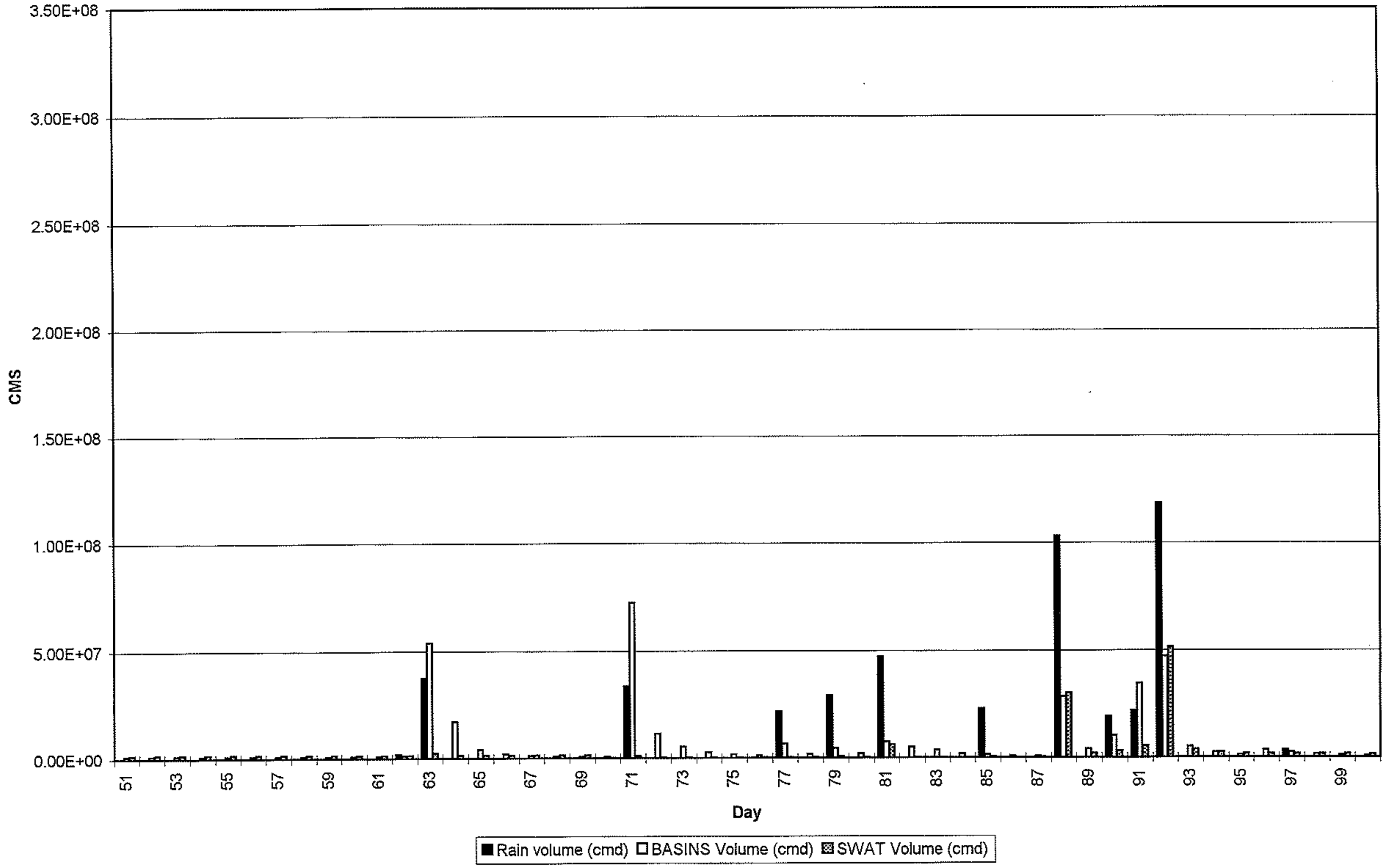
1990 Daily Verification of SWAT



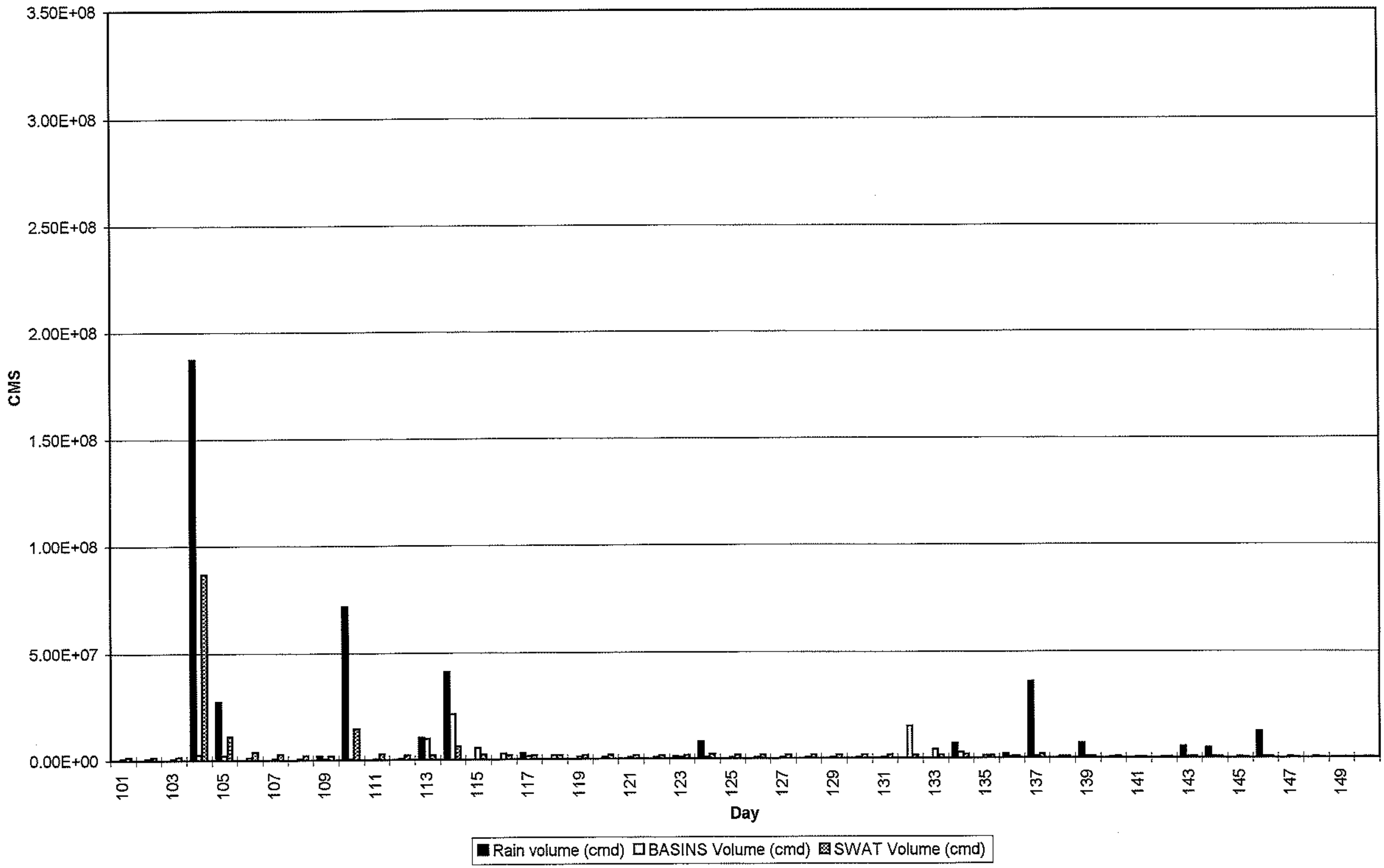
Appendix C6: Daily volumetric comparison of SWAT and BASINS to daily rainfall volume.


1970 Mass Balance Comparison Chart
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
CMS
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

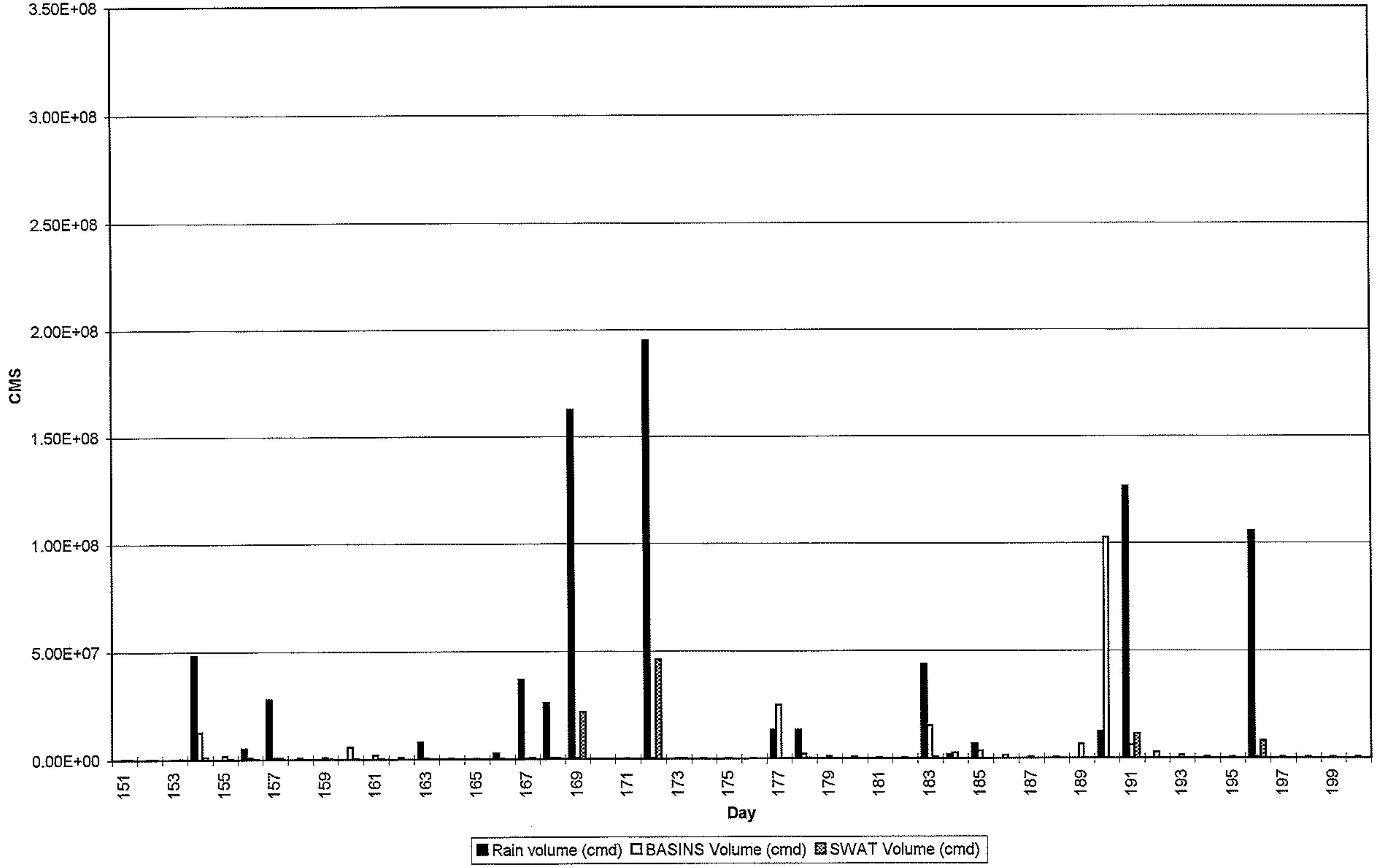
1970 Mass Balance Comparison Chart

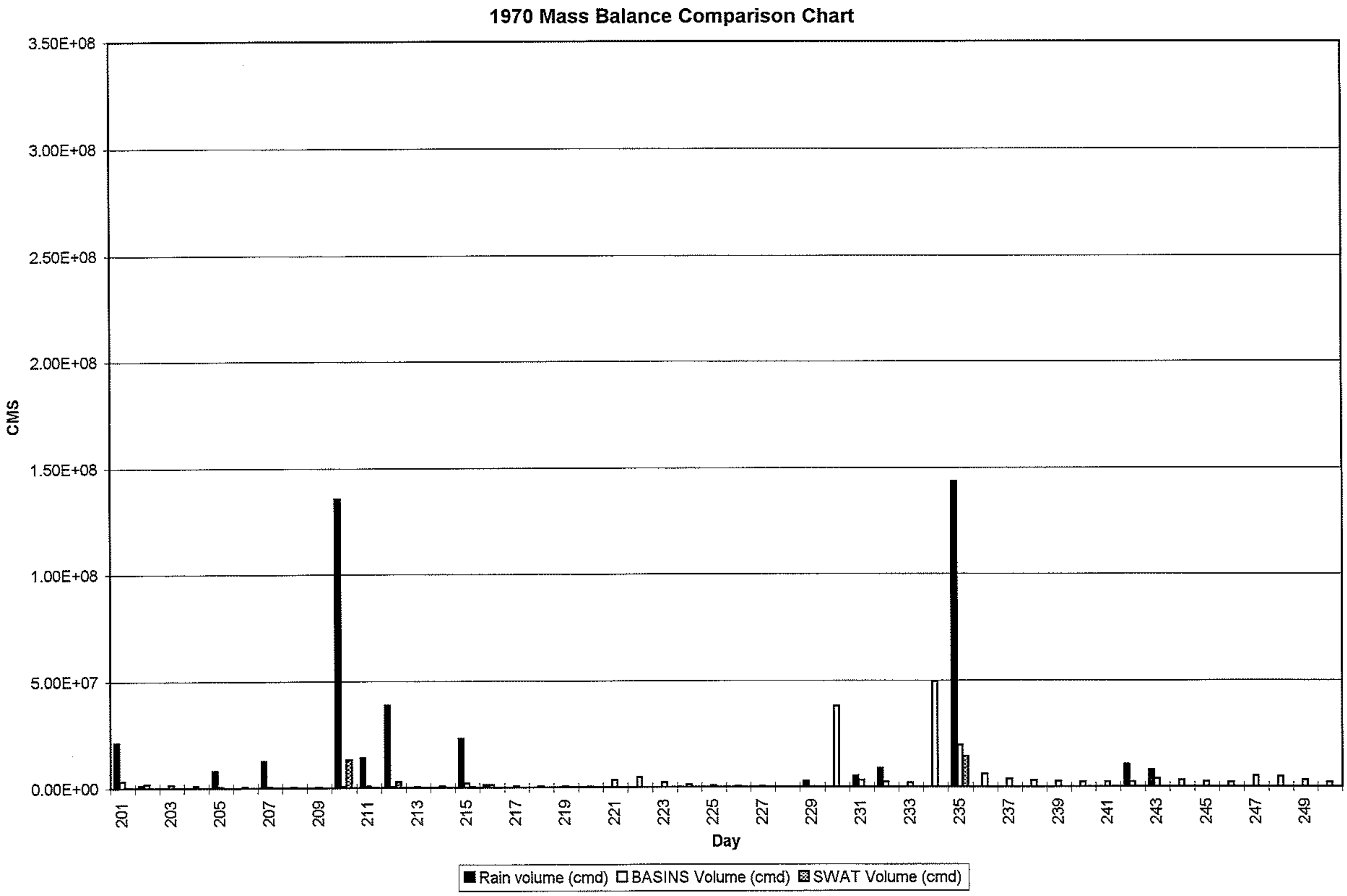


1970 Mass Balance Comparison Chart

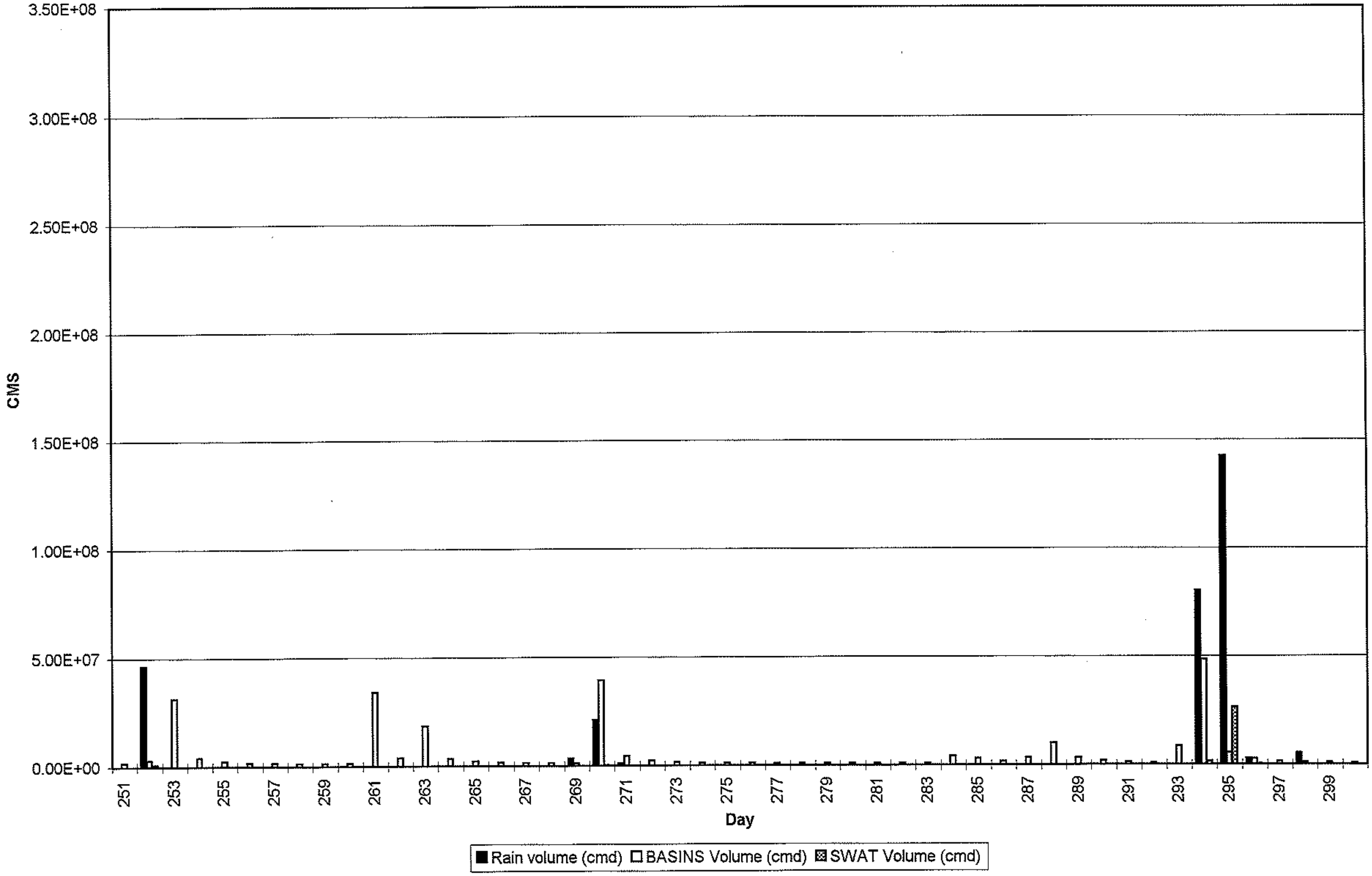


1970 Mass Balance Comparison Chart

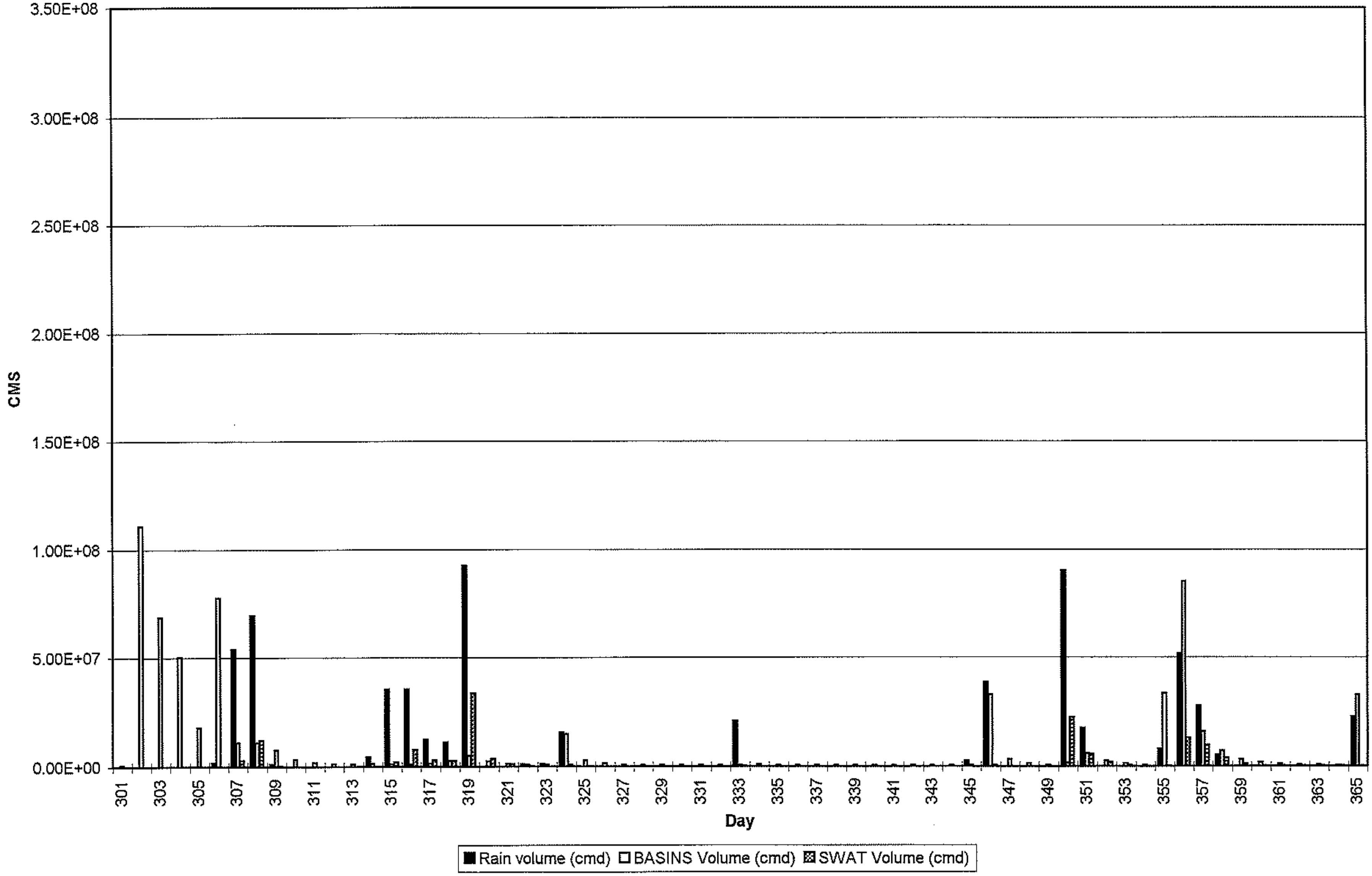



1970 Mass Balance Comparison Chart
CMS
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
201
203
205
207
209
211
213
215
217
219
221
223
225
227
229
231
233
235
237
239
241
243
245
247
249
Day
■ Rain volume (cmd)
☐ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

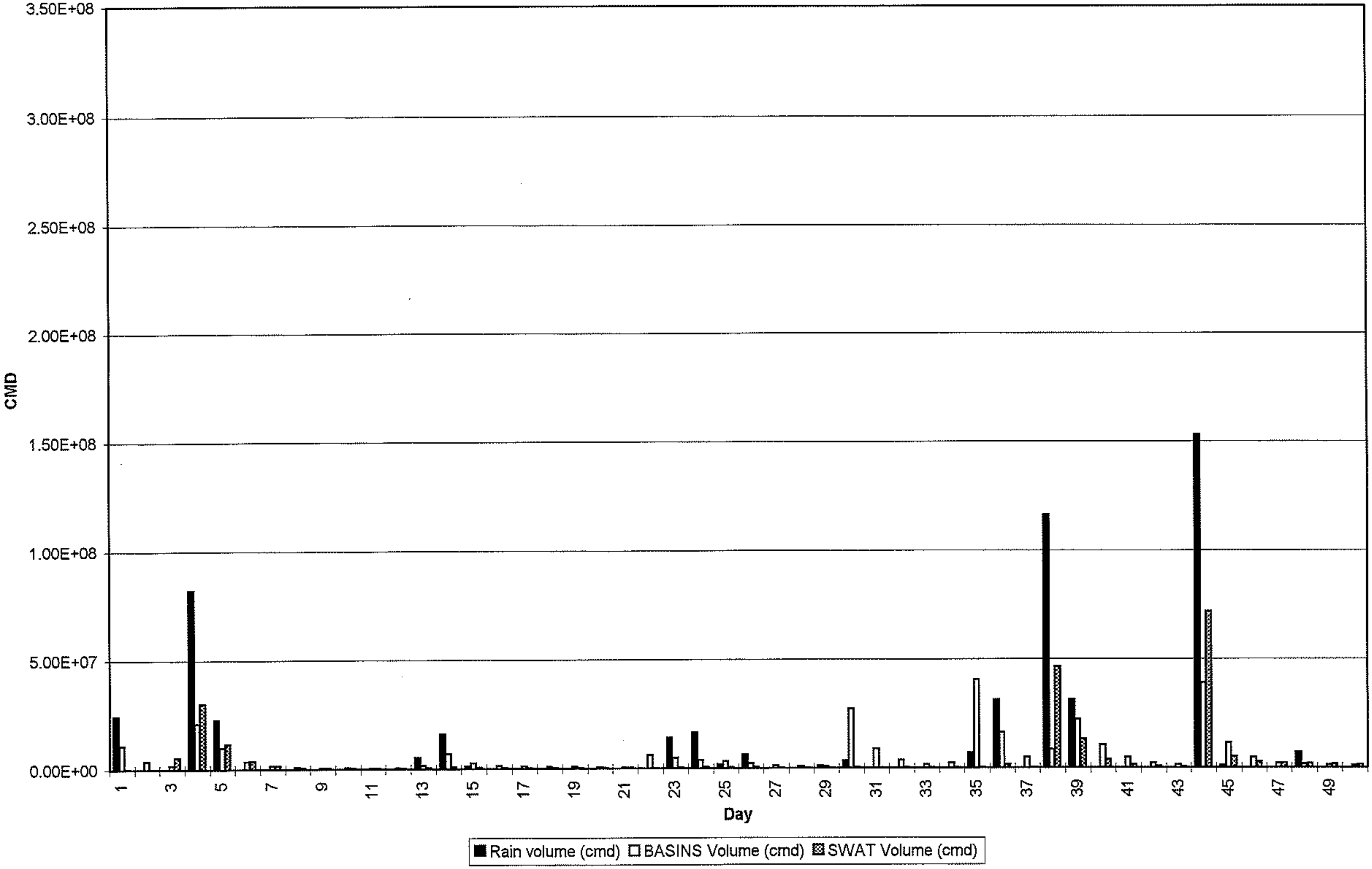
1970 Mass Balance Comparison Chart

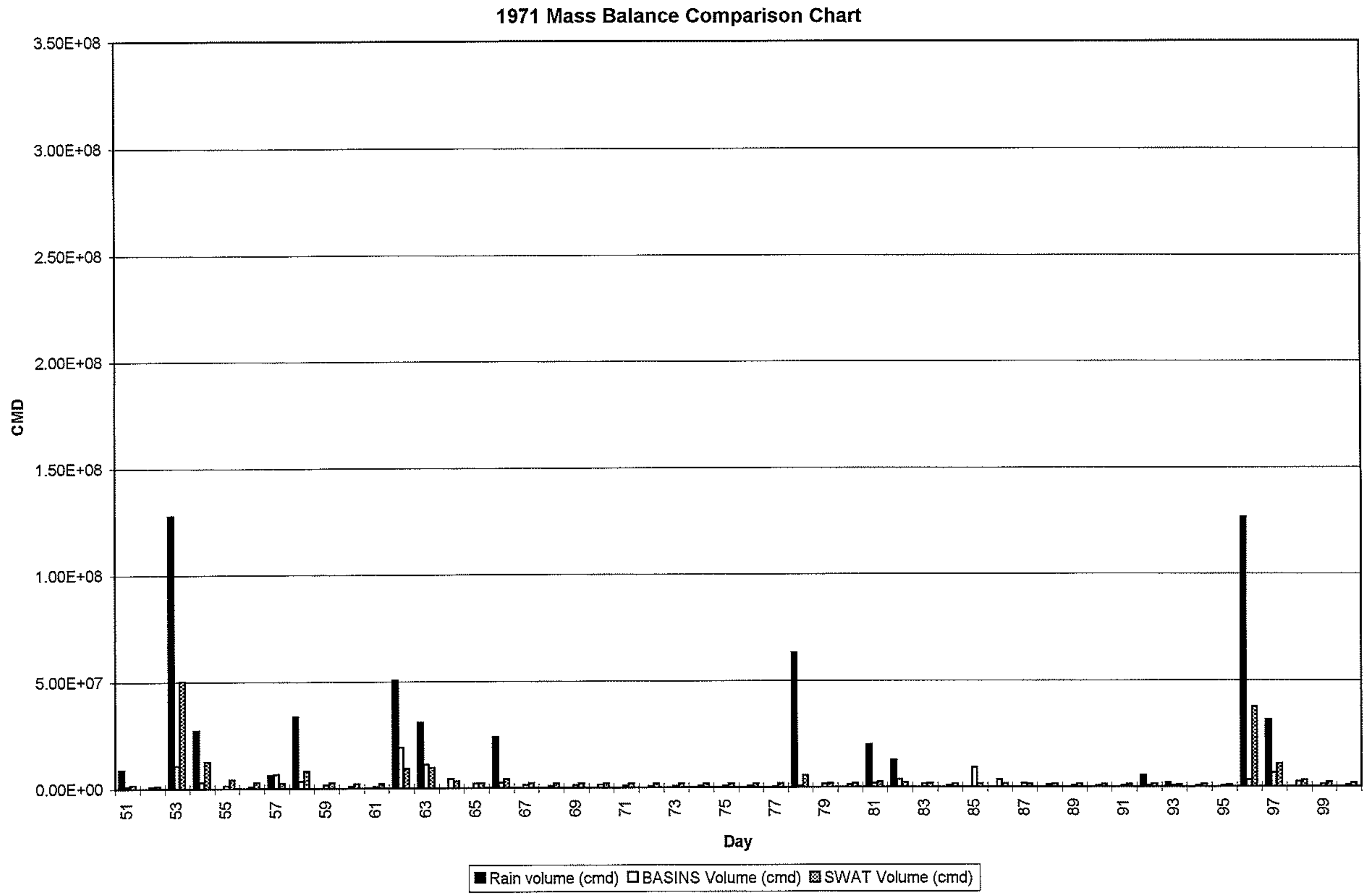


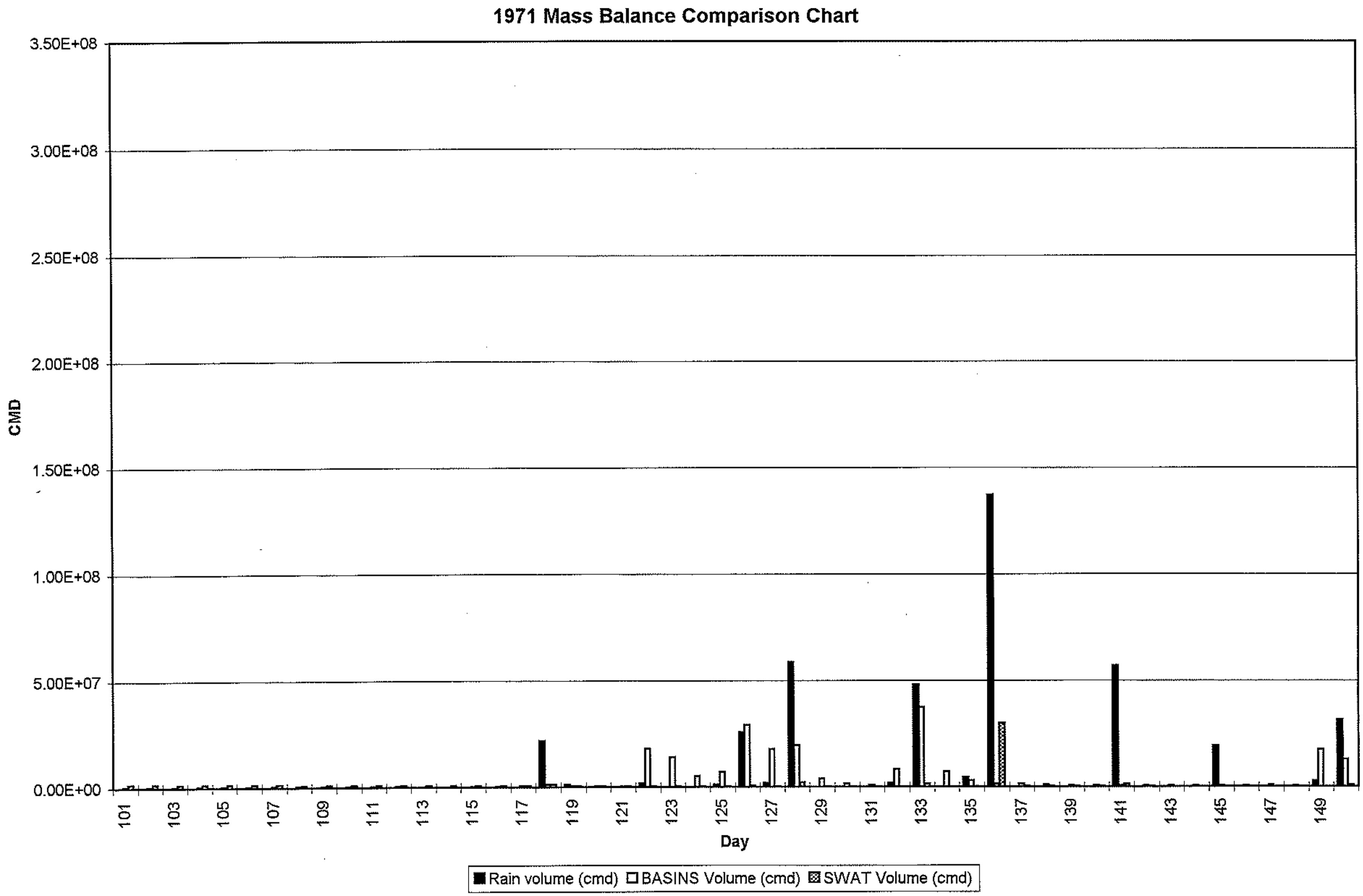
1970 Mass Balance Comparison Chart



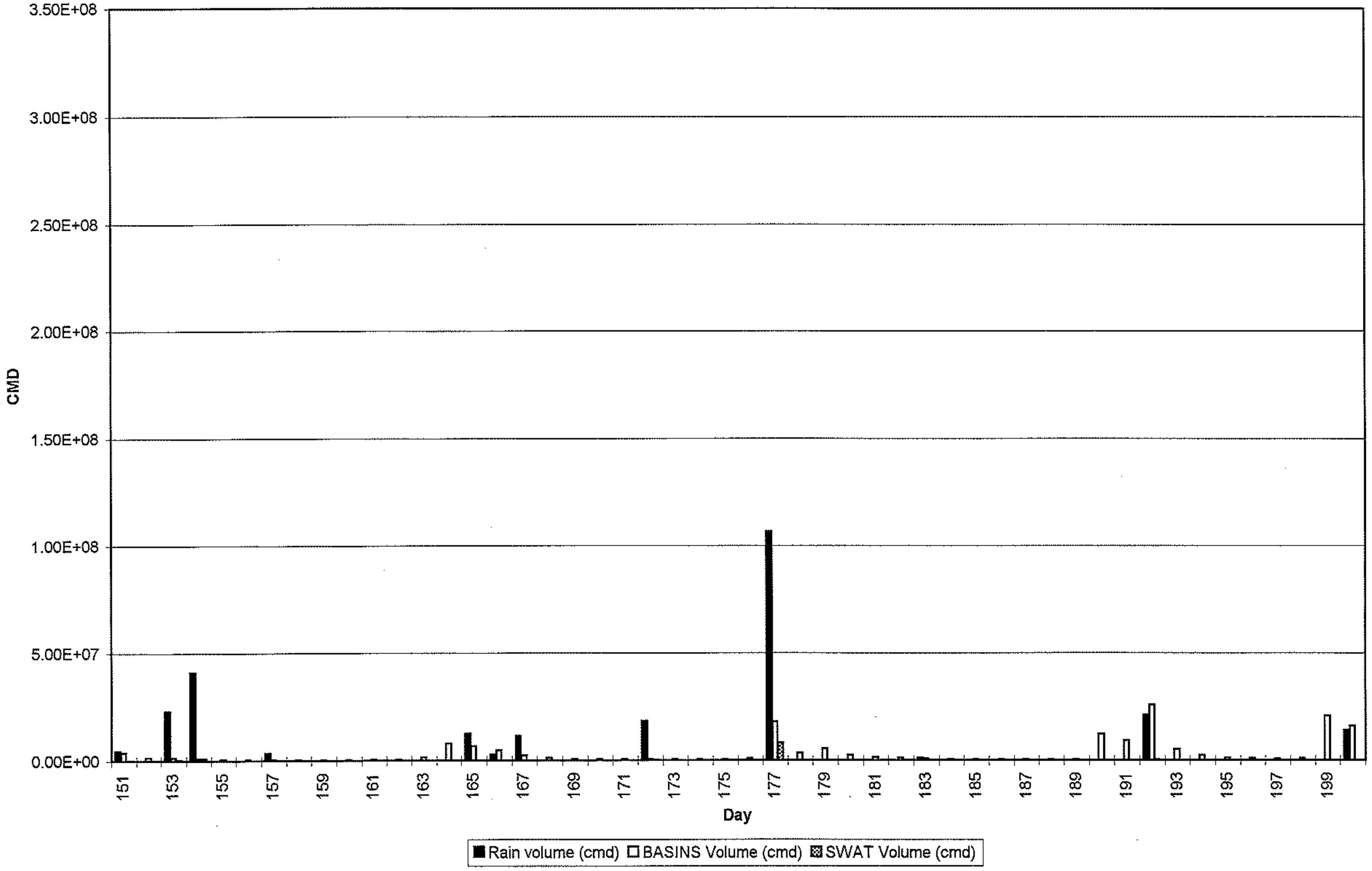
1971 Mass Balance Comparison Chart



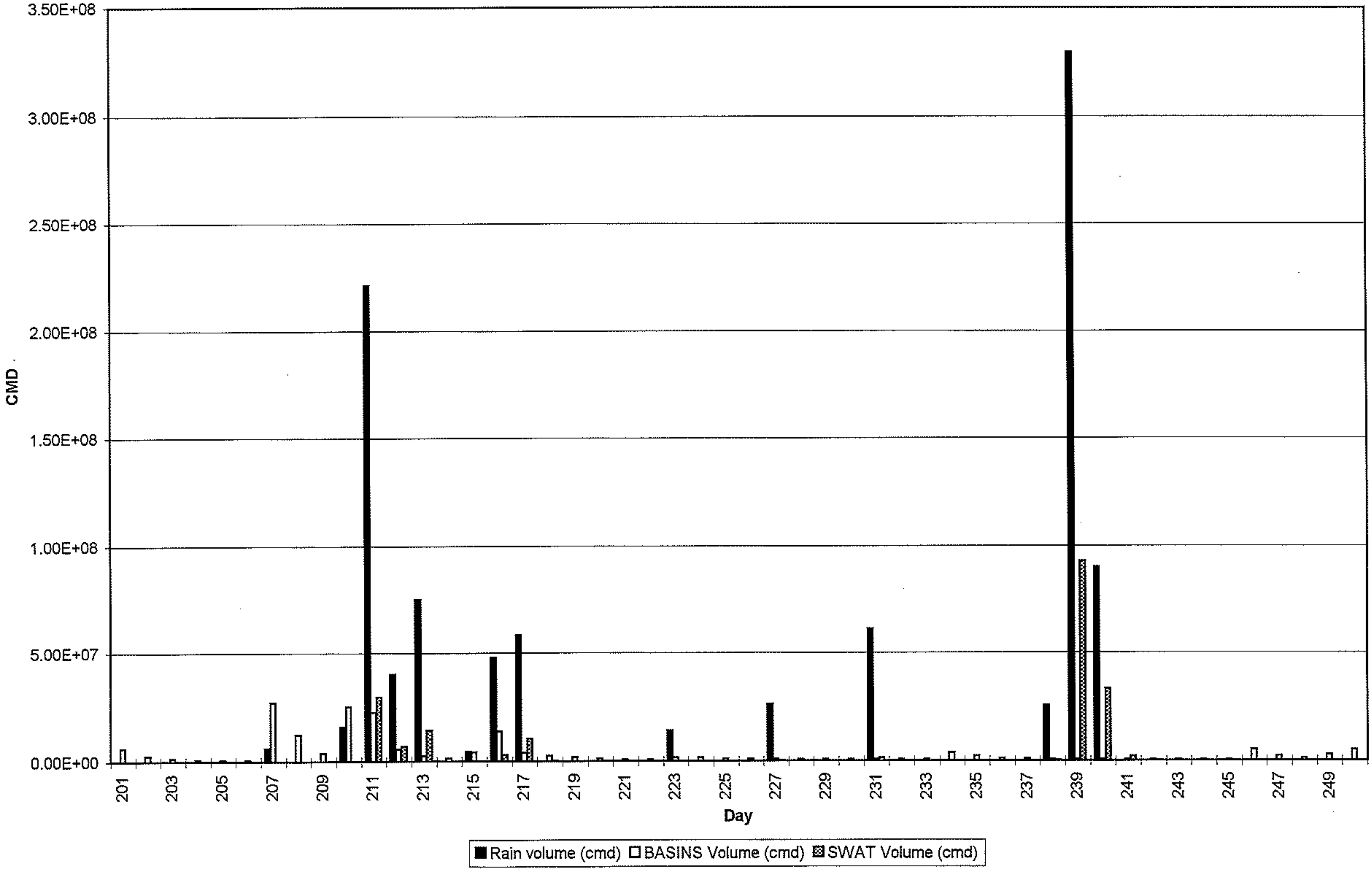

1971 Mass Balance Comparison Chart
CMD
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)


1971 Mass Balance Comparison Chart
CMD
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
101
103
105
107
109
111
113
115
117
119
121
123
125
127
129
131
133
135
137
139
141
143
145
147
149
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

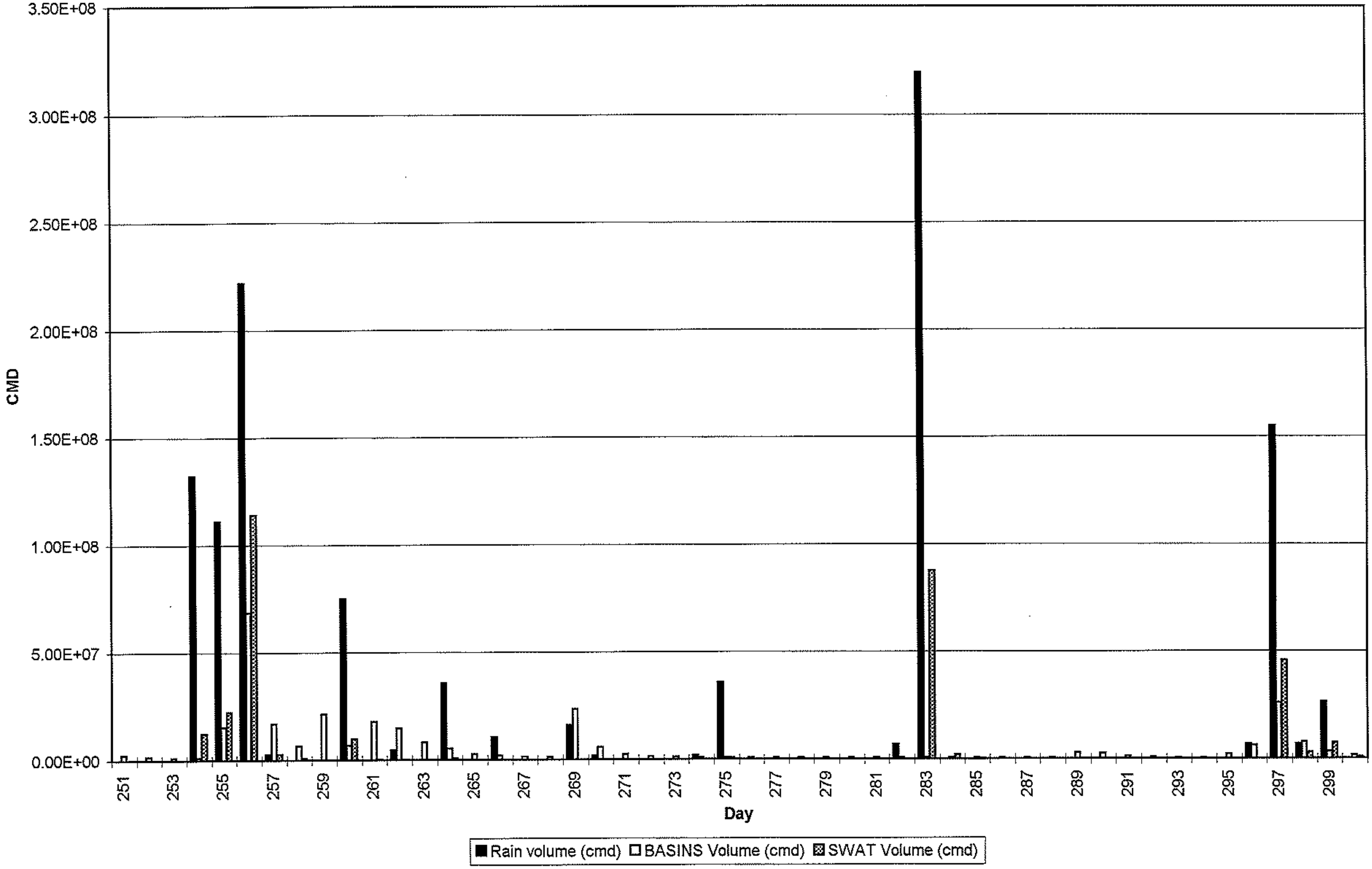
1971 Mass Balance Comparison Chart



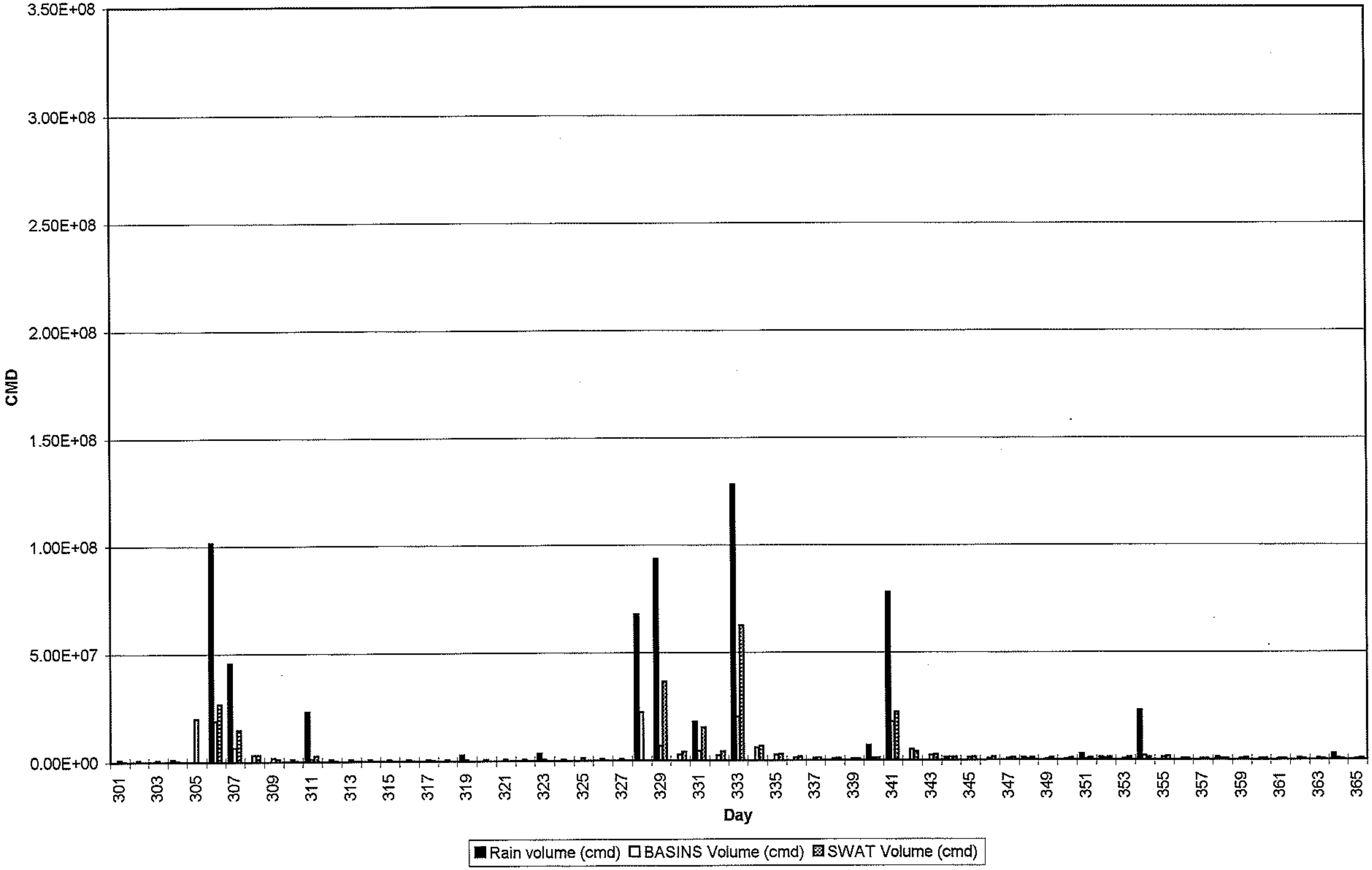
1971 Mass Balance Comparison Chart

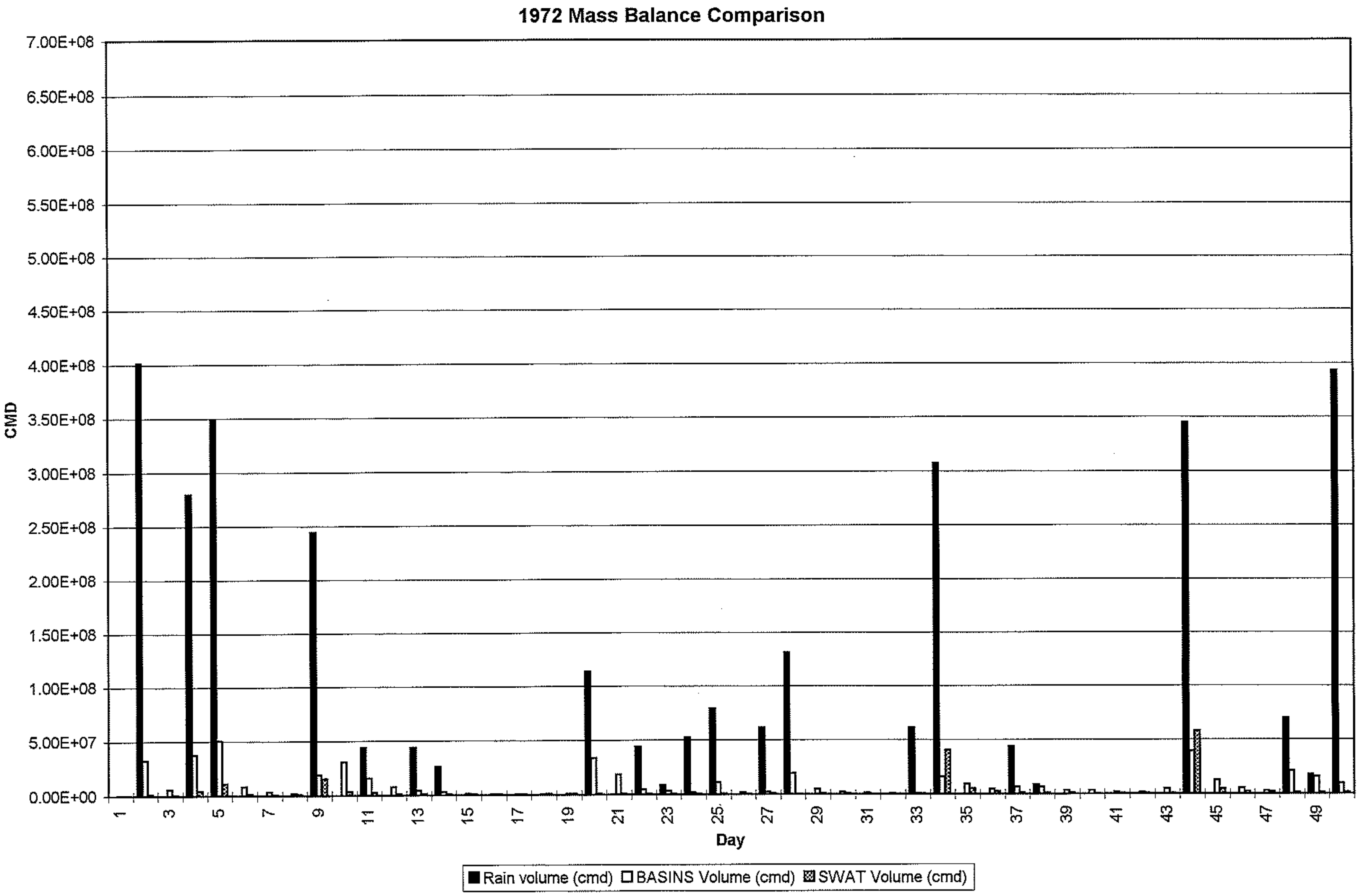


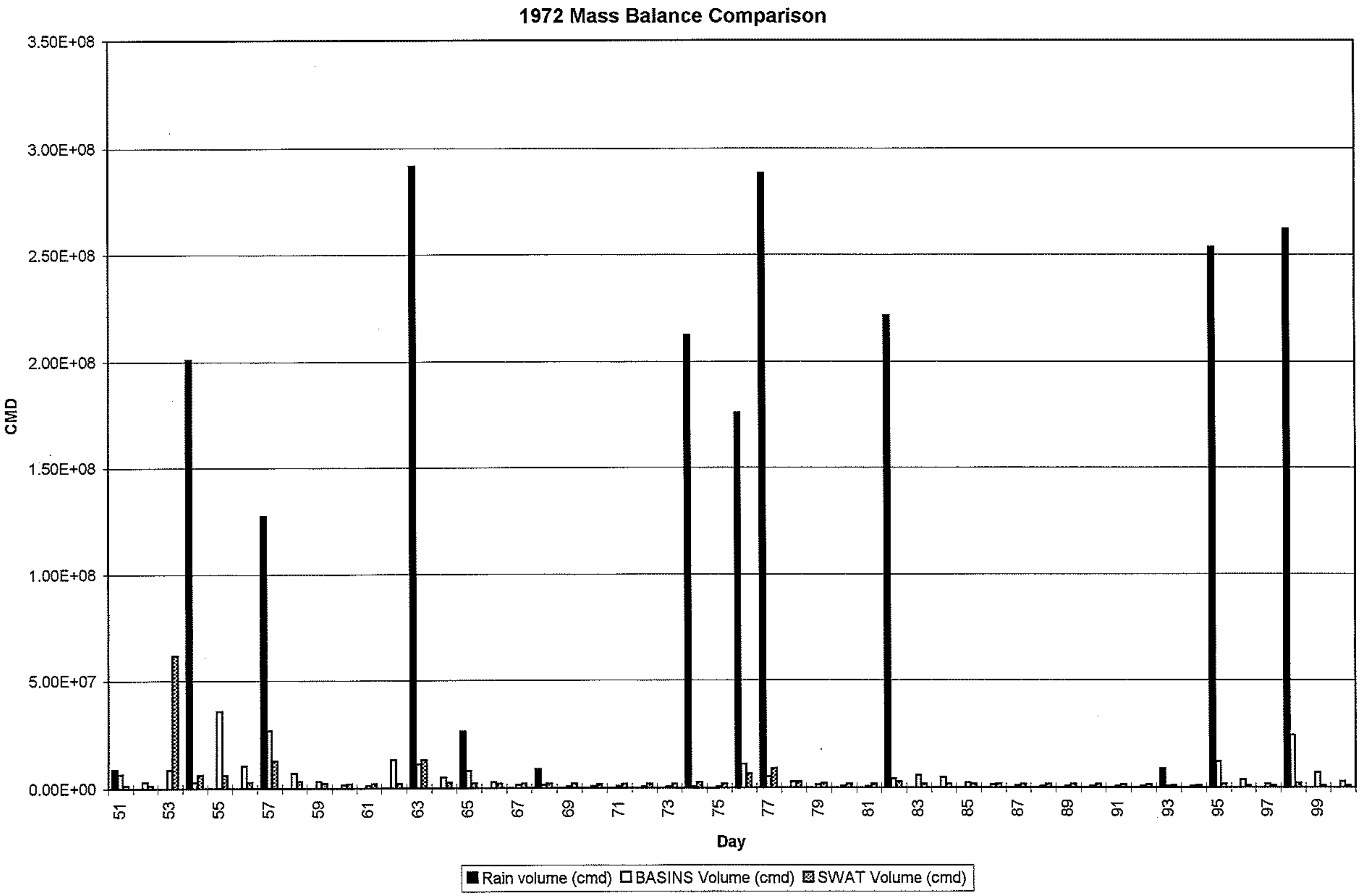
1971 Mass Balance Comparison Chart

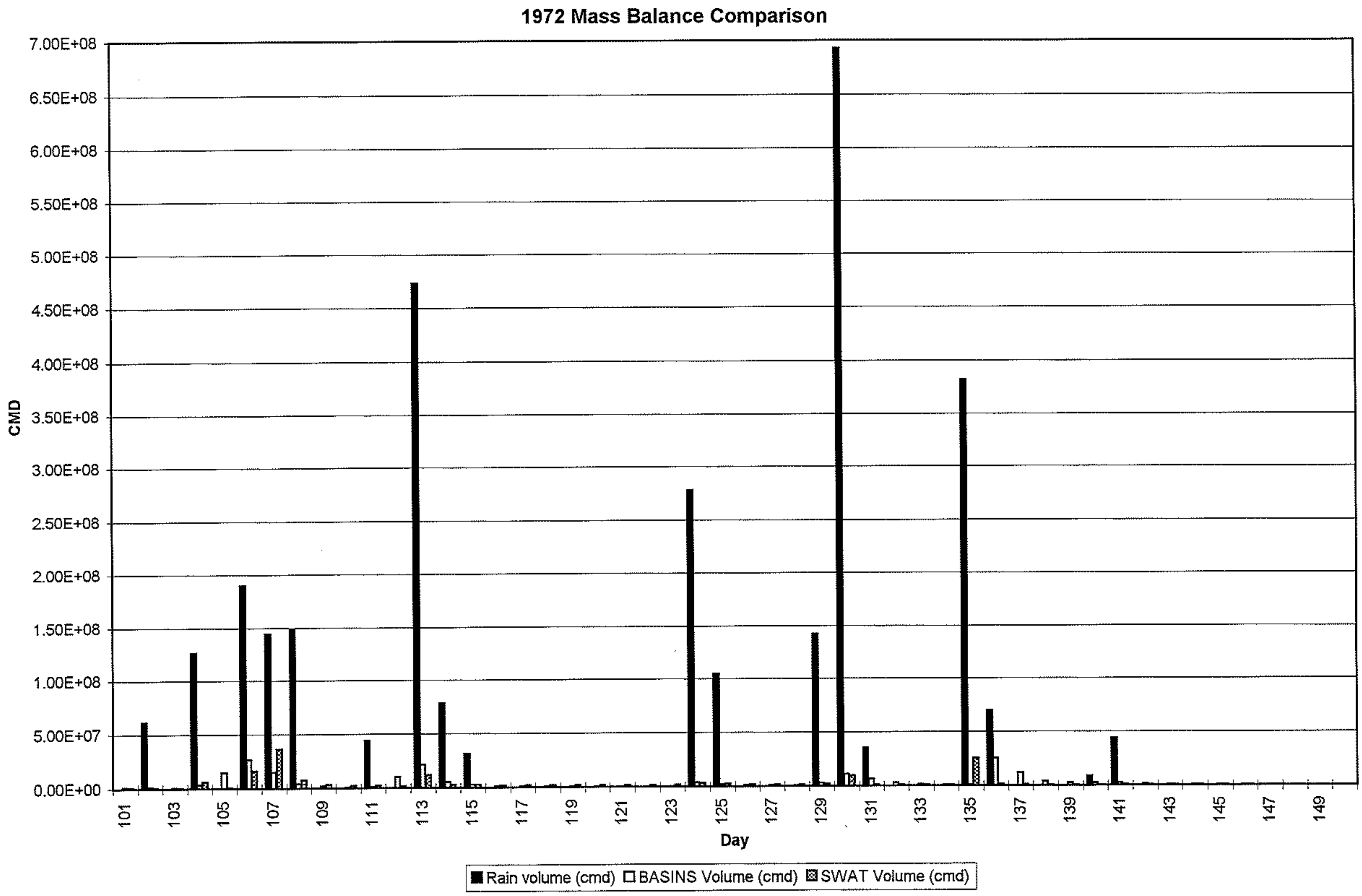


1971 Mass Balance Comparison Chart

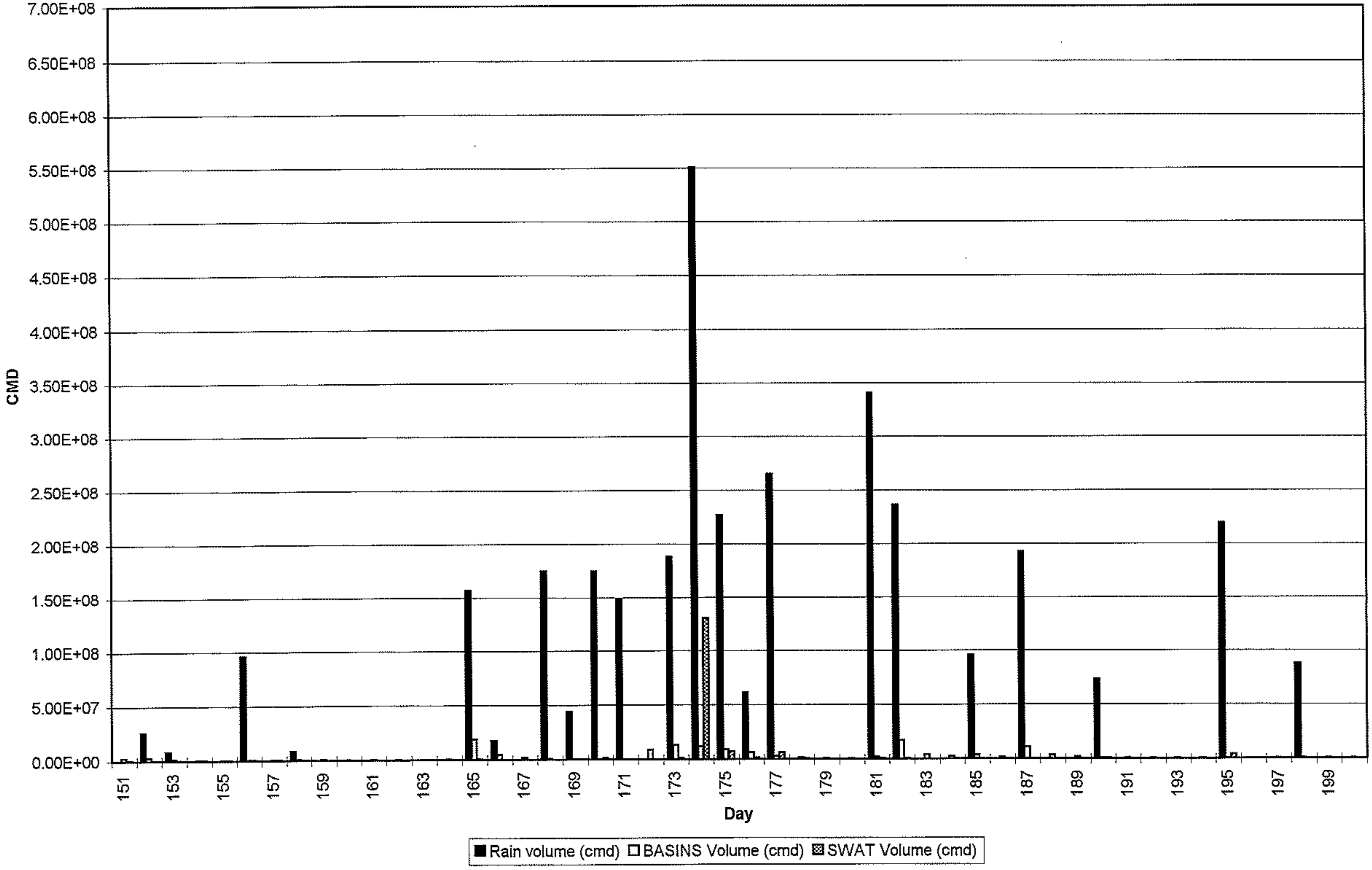



1972 Mass Balance Comparison
CMD
7.00E+08
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
Day
■ Rain volume (cmd)
☐ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

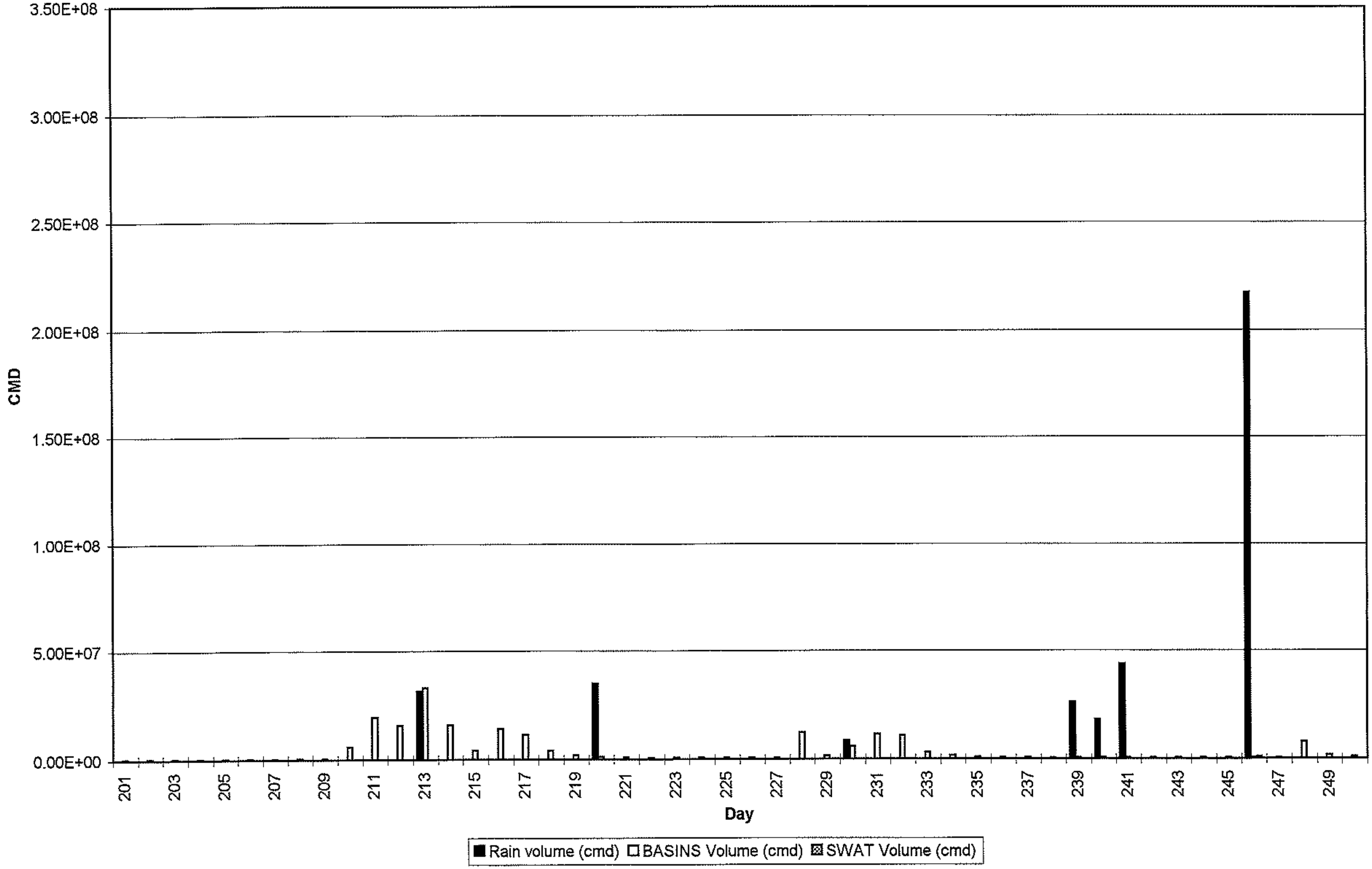

1972 Mass Balance Comparison
CMD
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
51
53
55
57
59
61
63
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

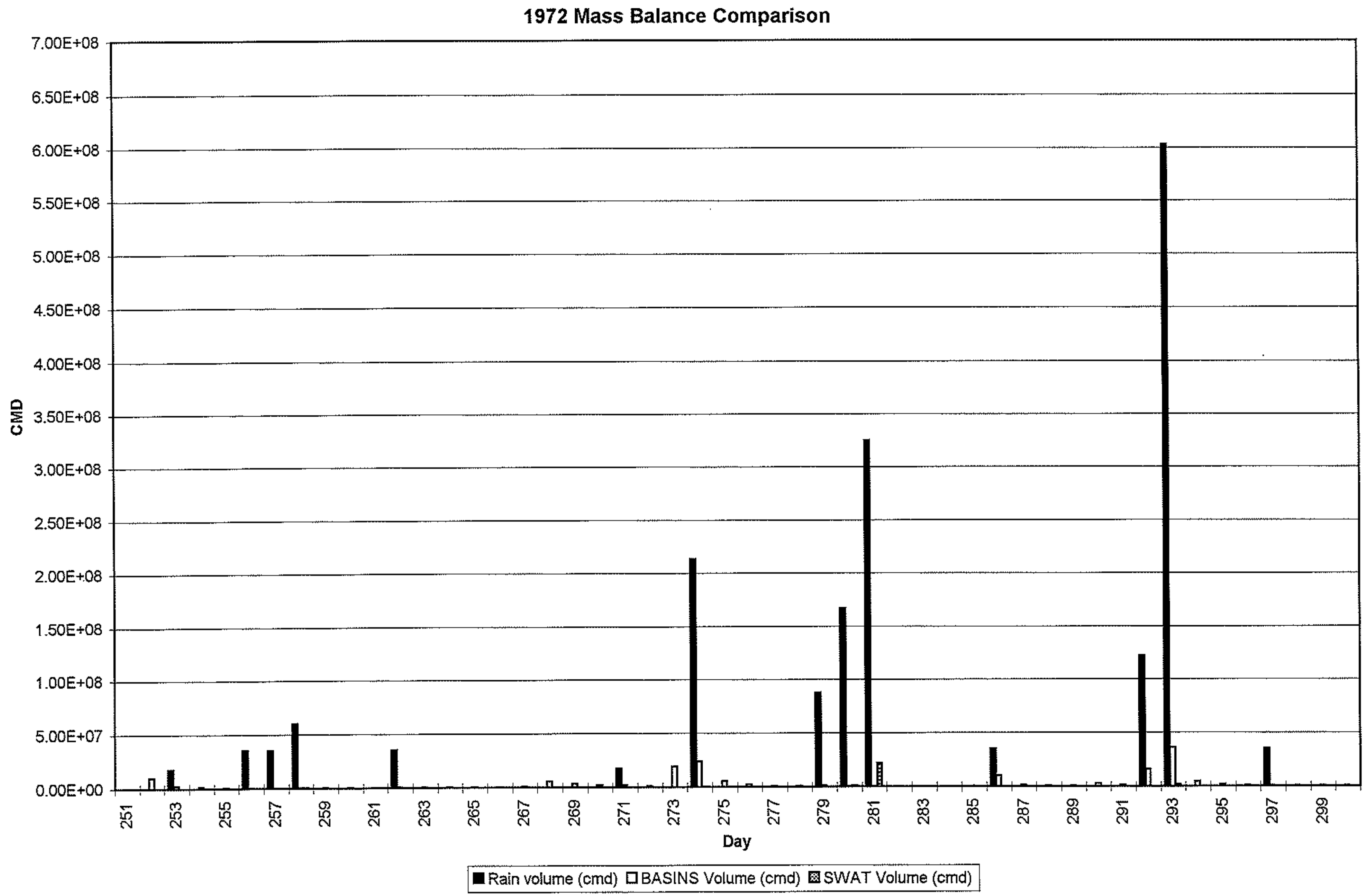

1972 Mass Balance Comparison
CMD
7.00E+08
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
101
103
105
107
109
111
113
115
117
119
121
123
125
127
129
131
133
135
137
139
141
143
145
147
149
Day
■ Rain volume (cmd)
☐ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

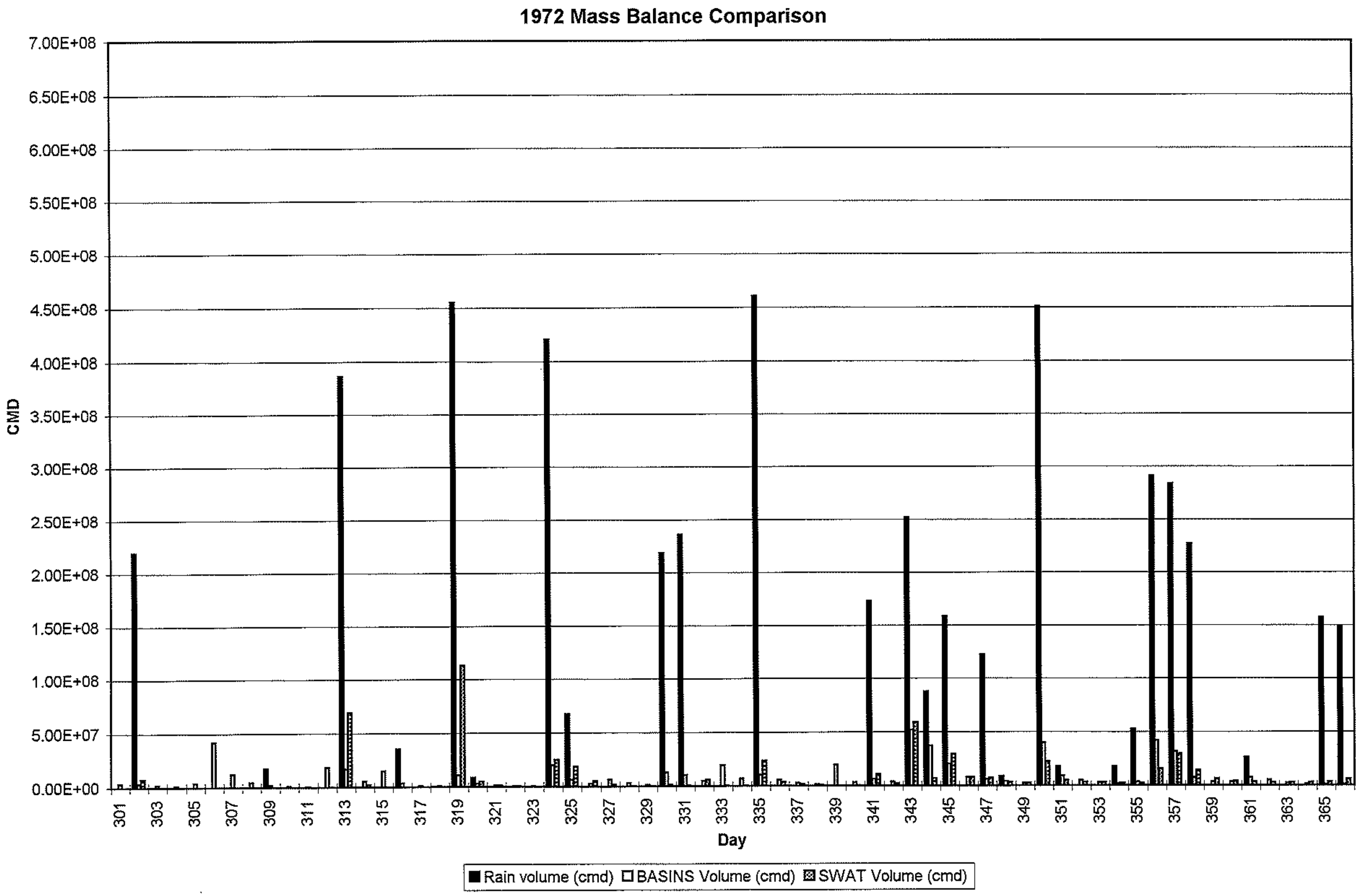
1972 Mass Balance Comparison

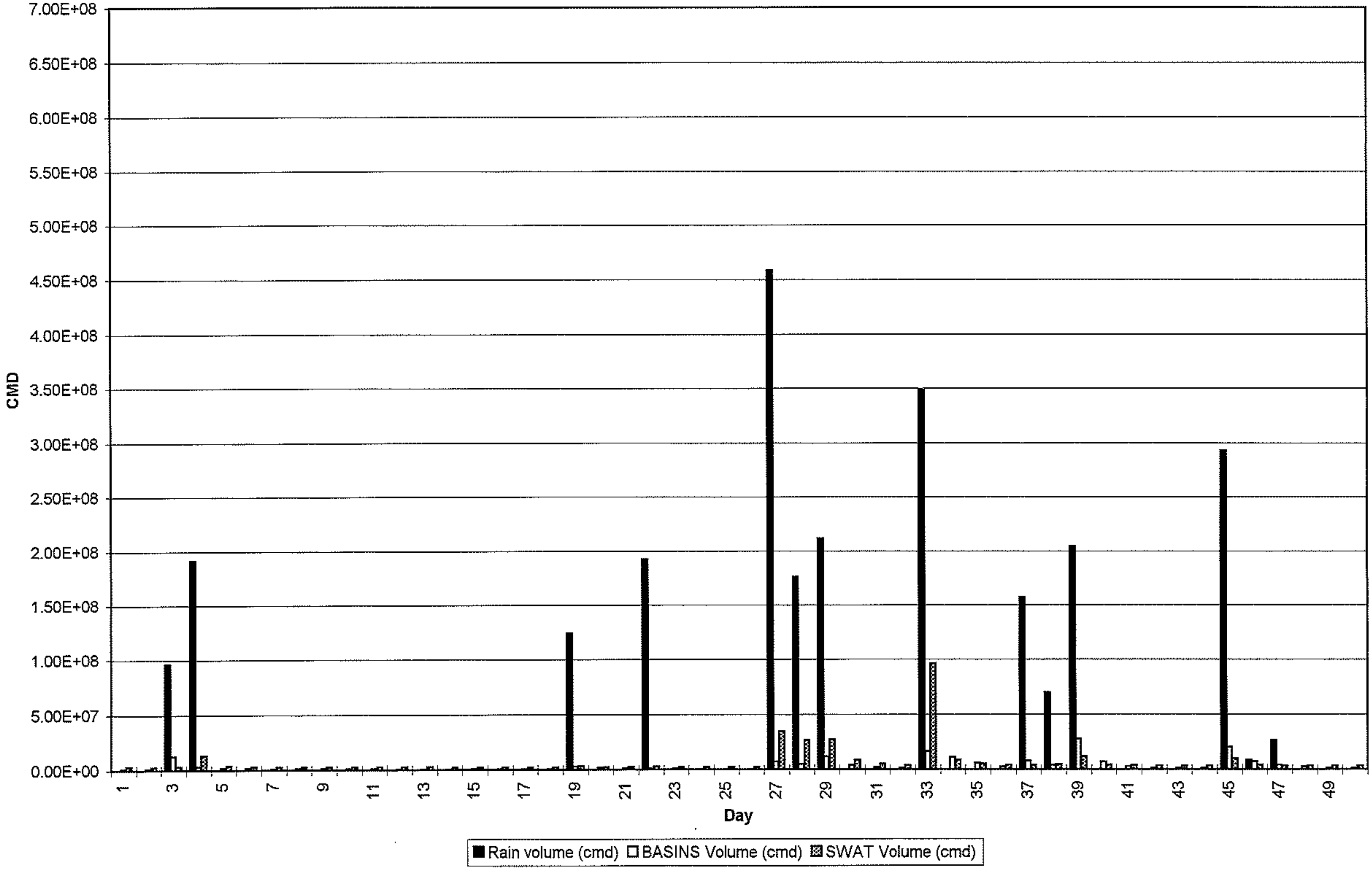


1972 Mass Balance Comparison



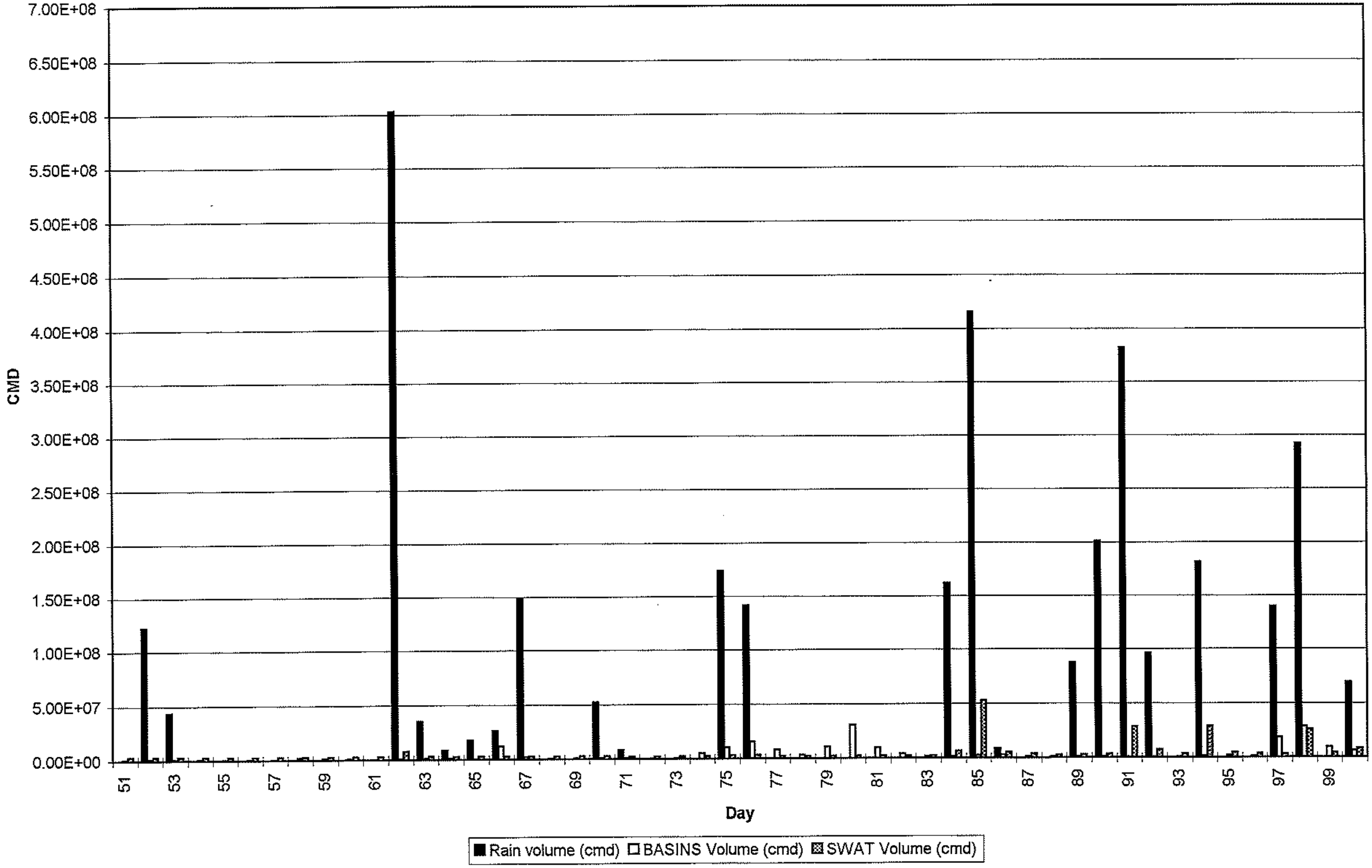

1972 Mass Balance Comparison
CMD
7.00E+08
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
251
253
255
257
259
261
263
265
267
269
271
273
275
277
279
281
283
285
287
289
291
293
295
297
299
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)


1972 Mass Balance Comparison
CMD
7.00E+08
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
301
303
305
307
309
311
313
315
317
319
321
323
325
327
329
331
333
335
337
339
341
343
345
347
349
351
353
355
357
359
361
363
365
Day
■ Rain volume (cmd) ☐ BASINS Volume (cmd) ▨ SWAT Volume (cmd)

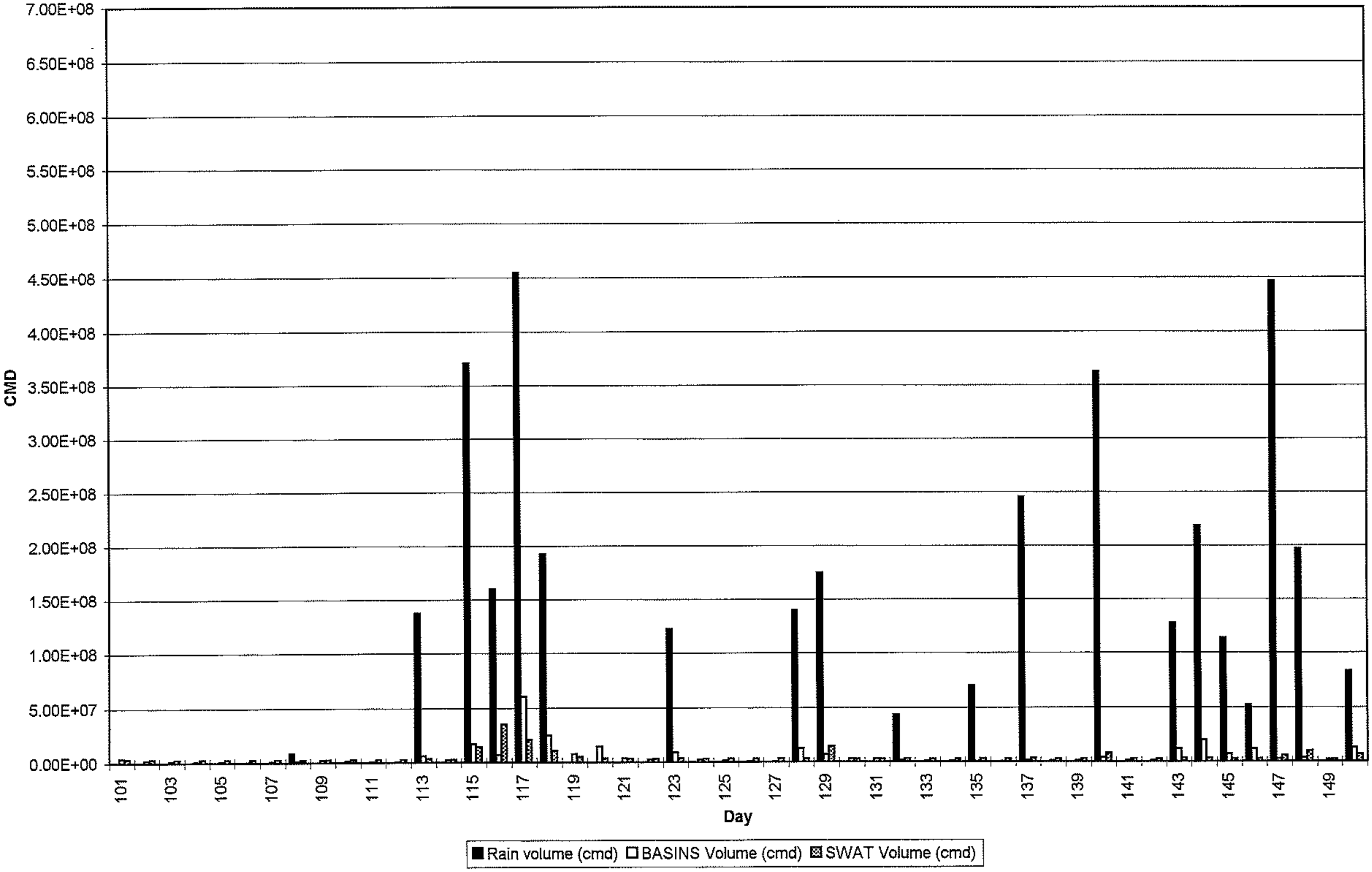


1973 Mass Balance Comparison

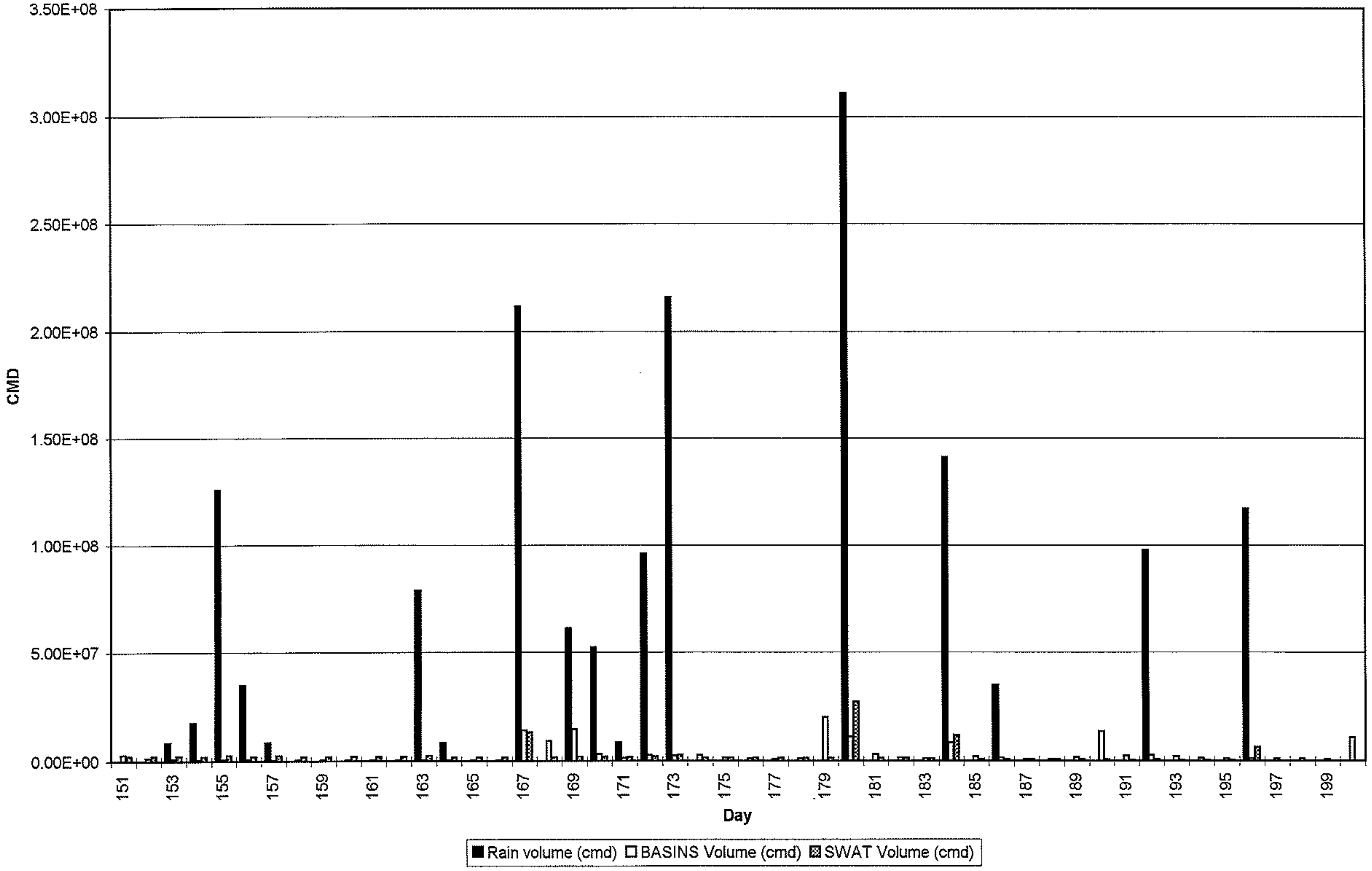
1973 Mass Balance Comparison



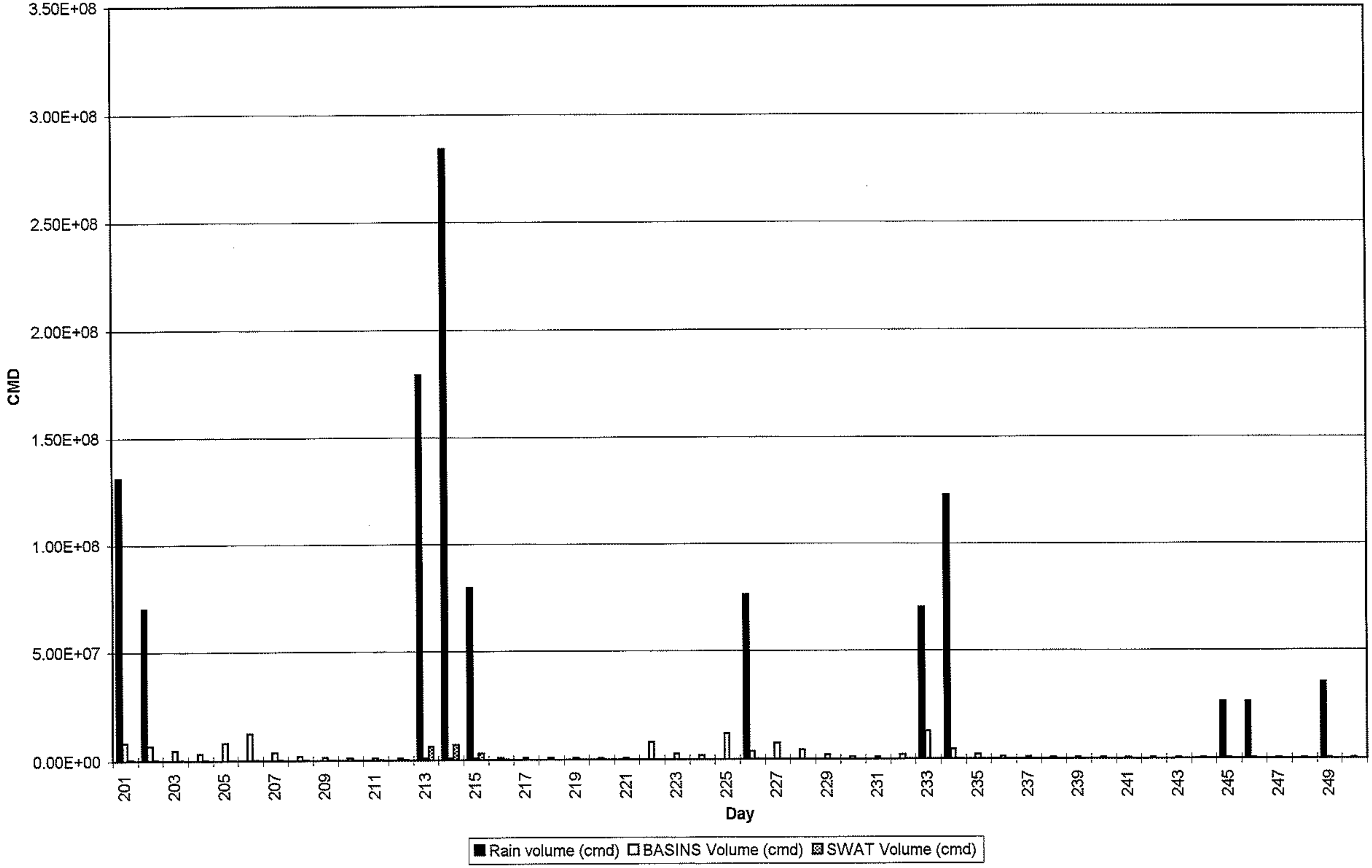
1973 Mass Balance Comparison

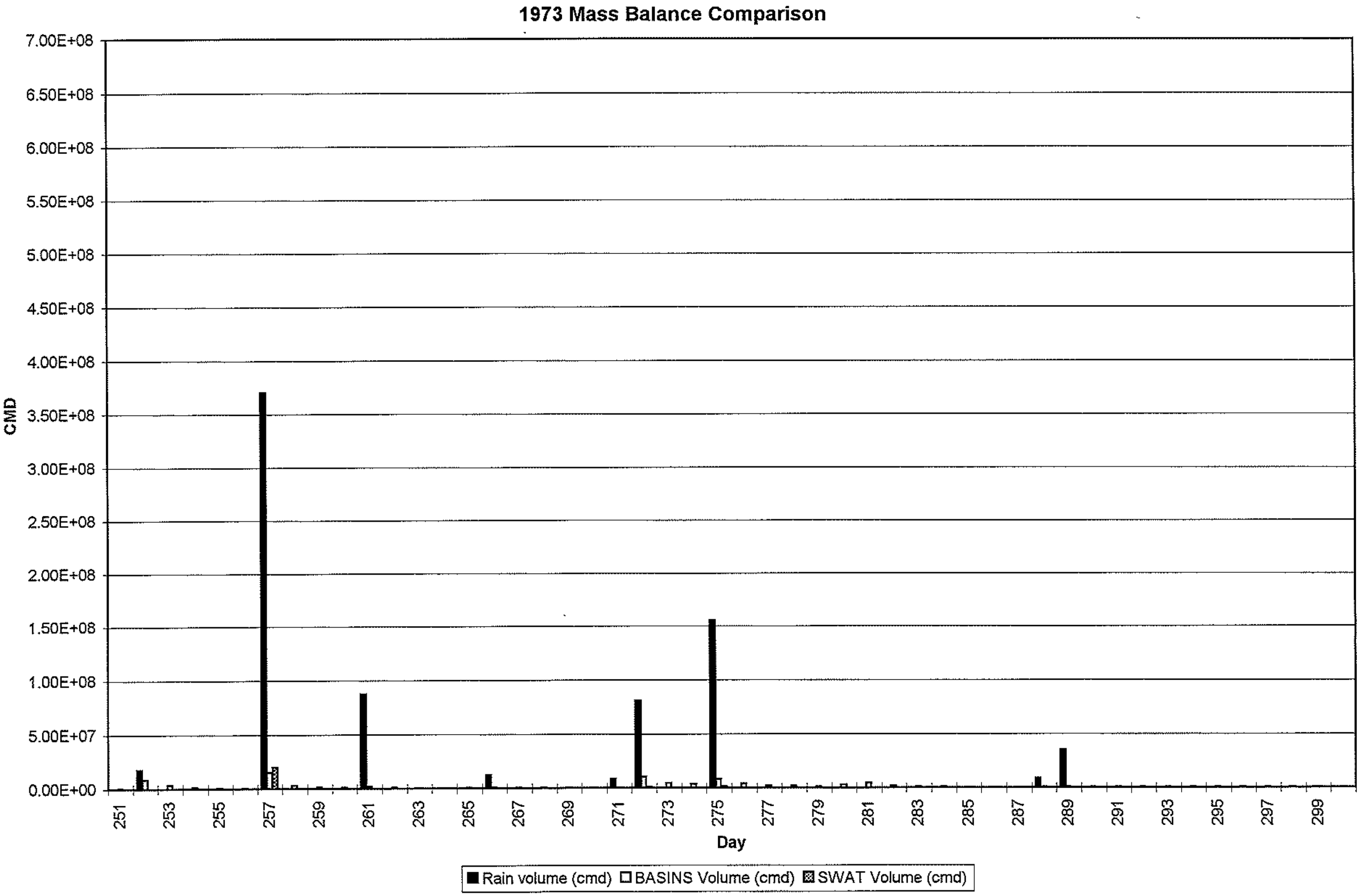


1973 Mass Balance Comparison

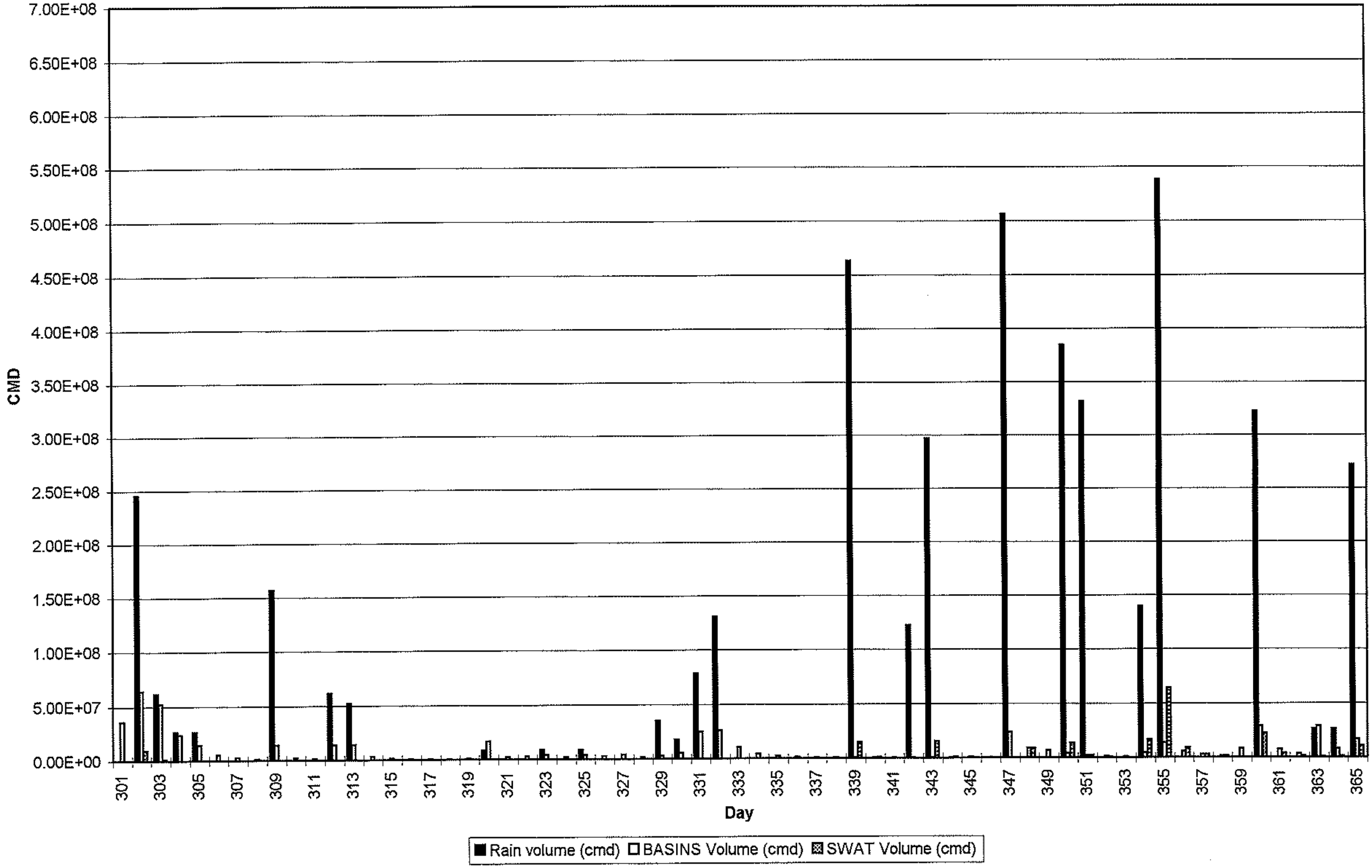


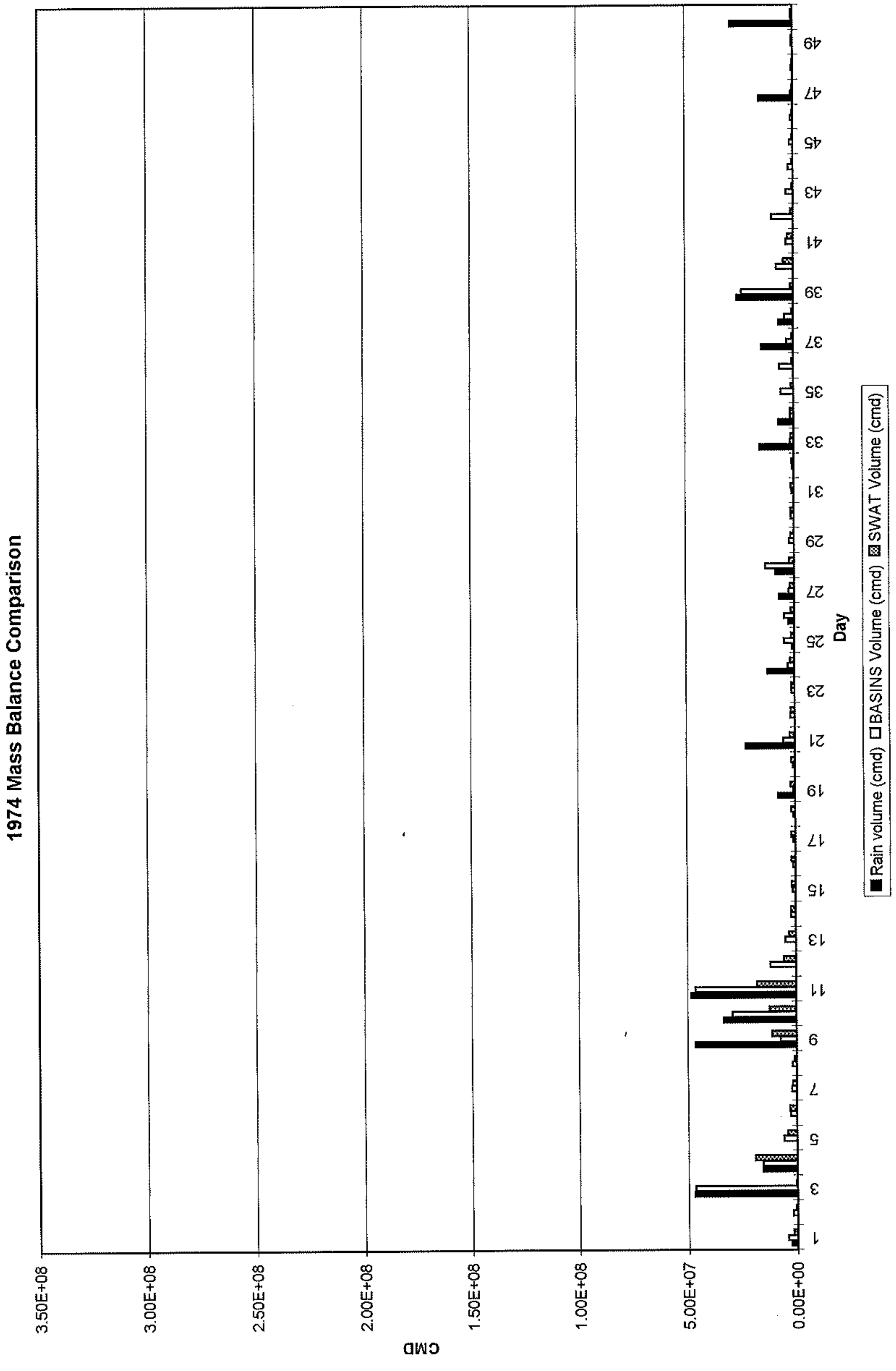
1973 Mass Balance Comparison



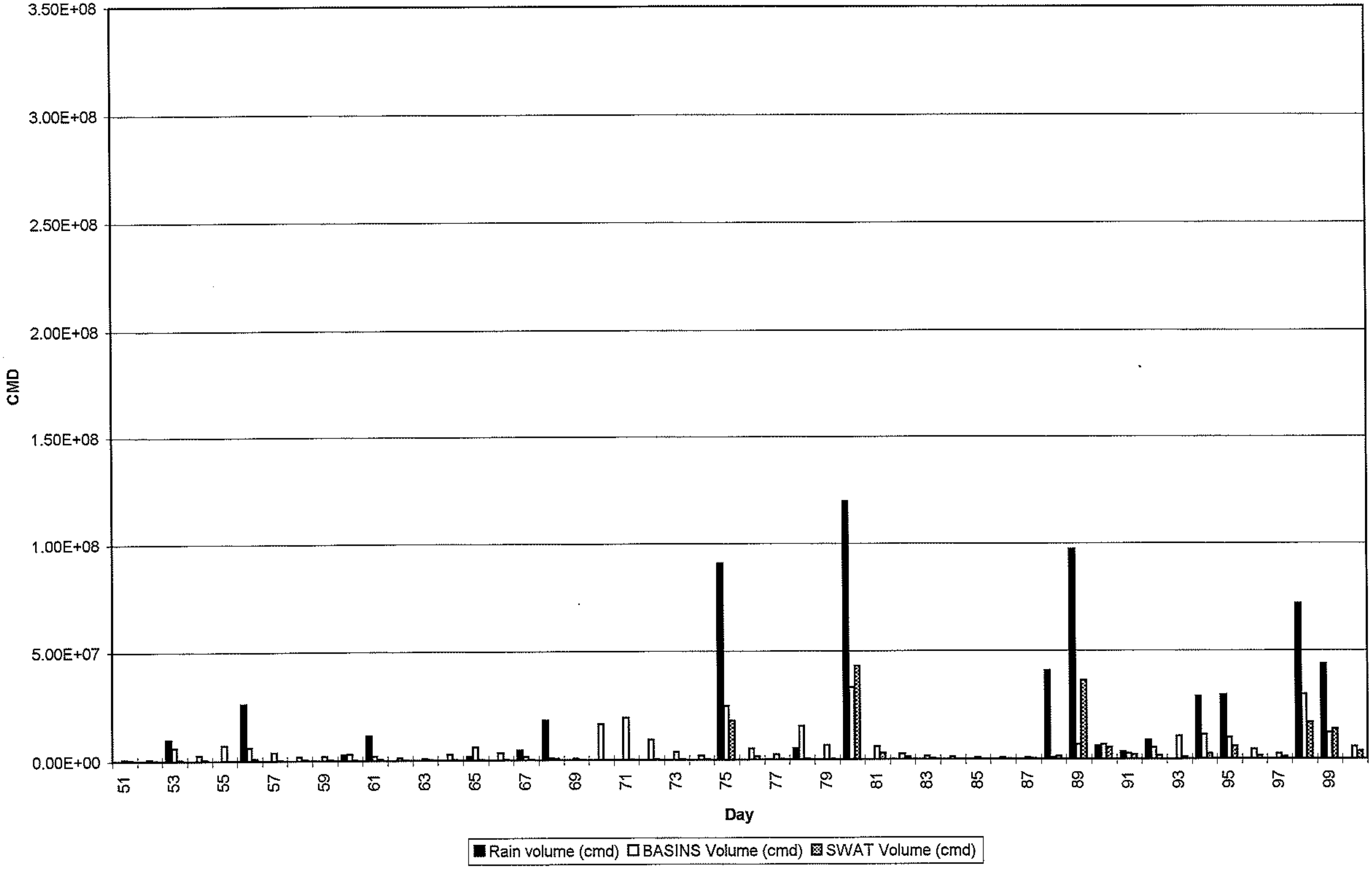

1973 Mass Balance Comparison
CMD
7.00E+08
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
251
253
255
257
259
261
263
265
267
269
271
273
275
277
279
281
283
285
287
289
291
293
295
297
299
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

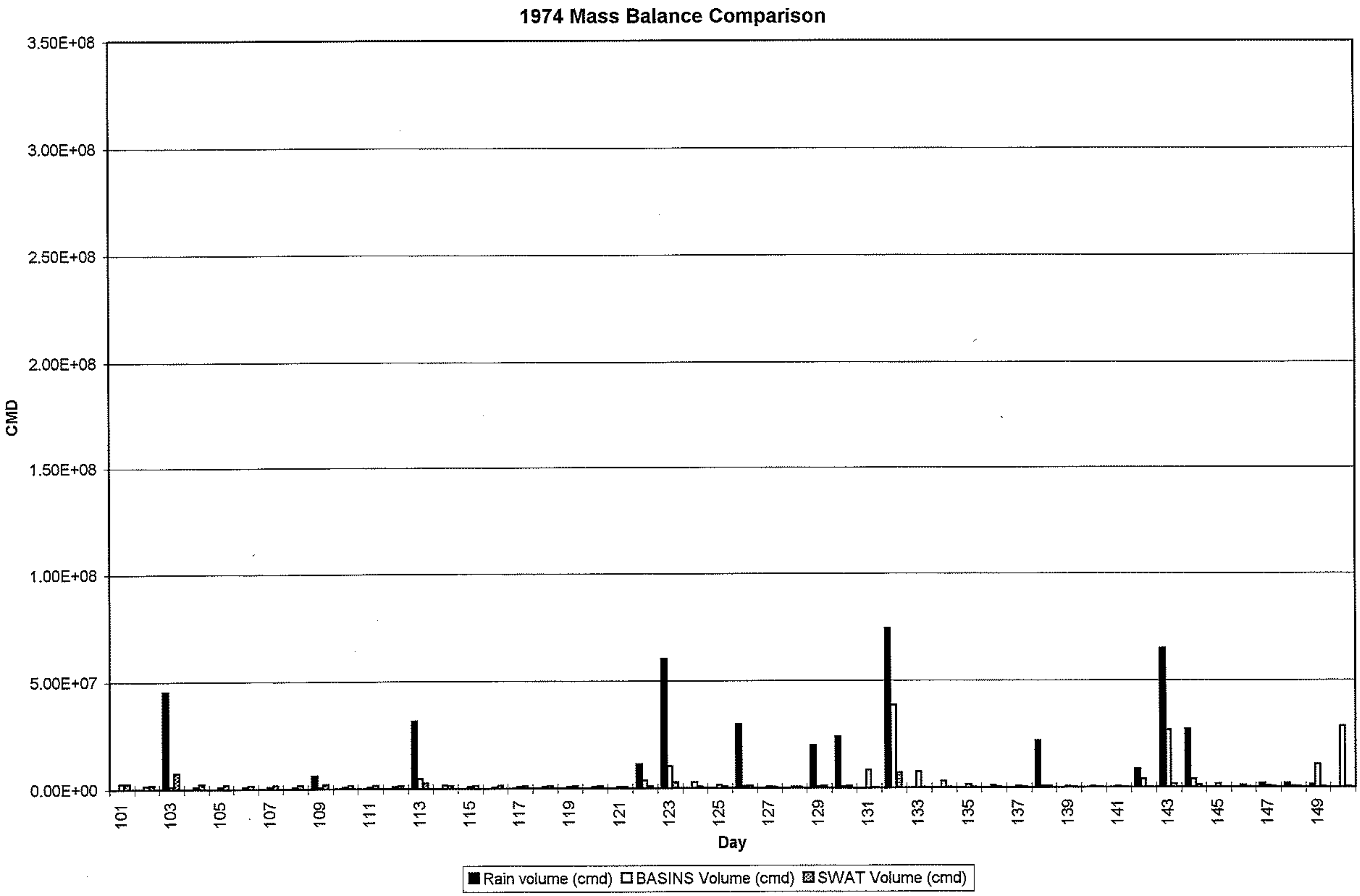
1973 Mass Balance Comparison



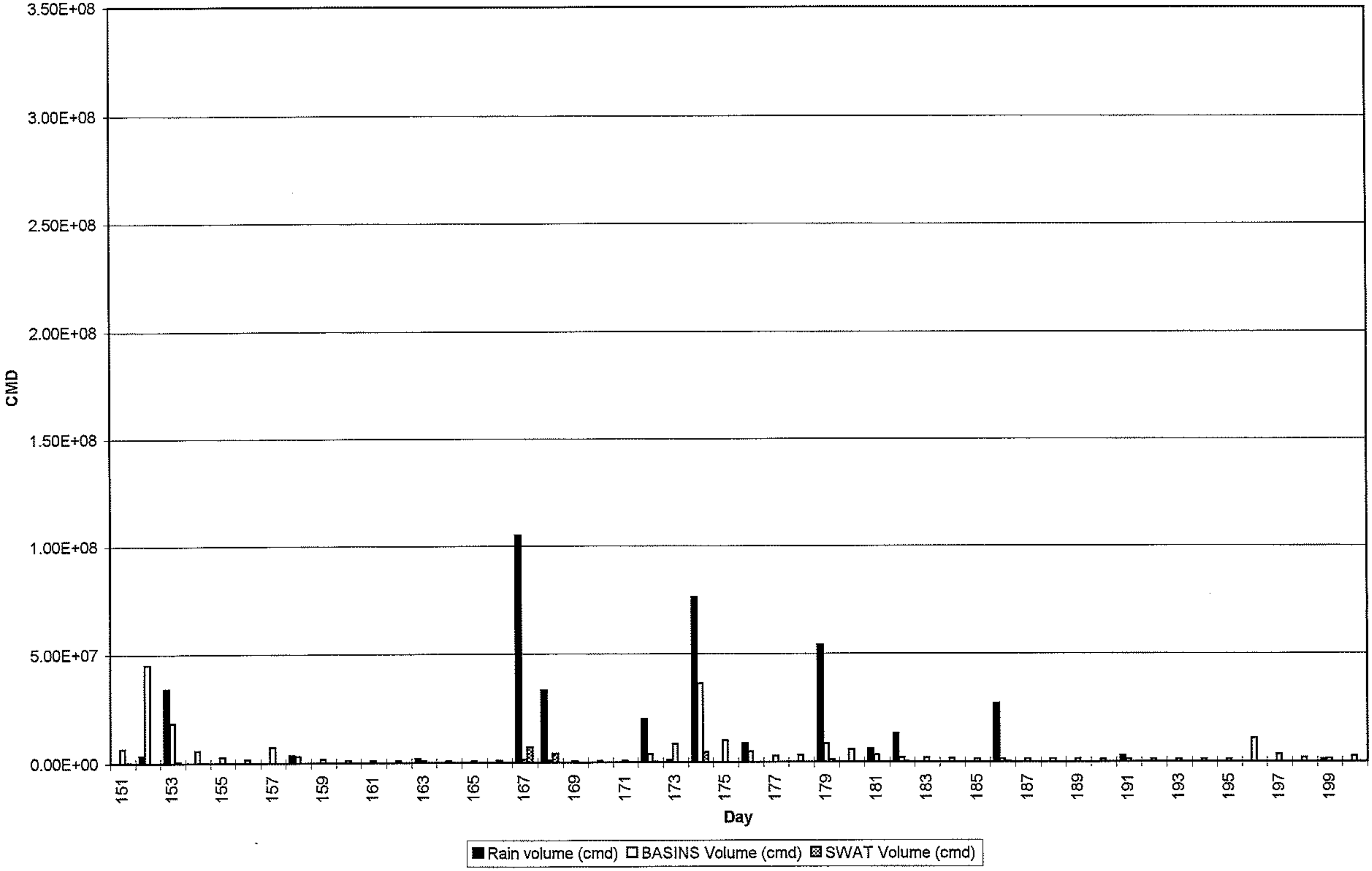

1974 Mass Balance Comparison
CMD
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
Day
■ Rain volume (cmd)
☐ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

1974 Mass Balance Comparison

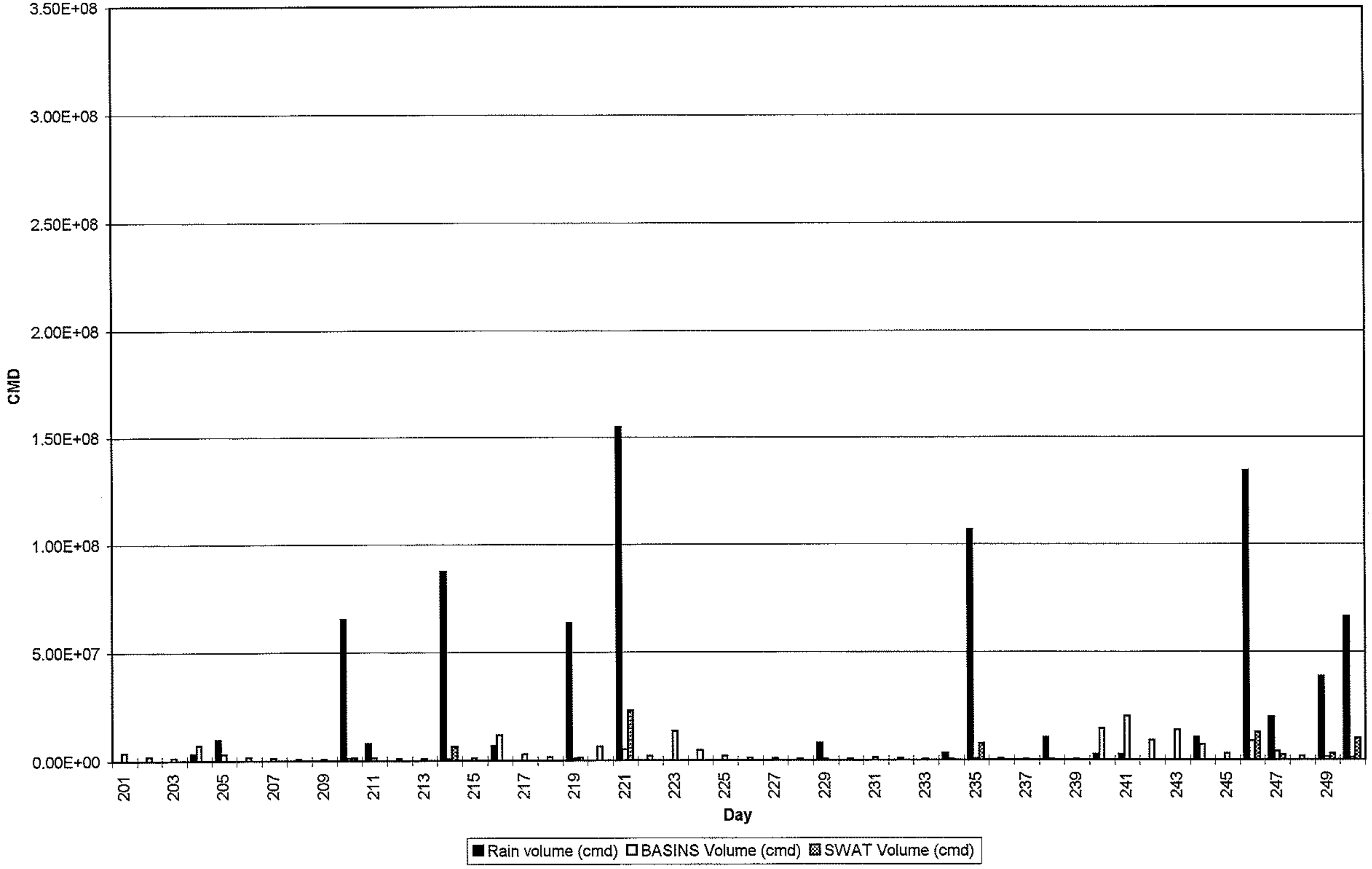




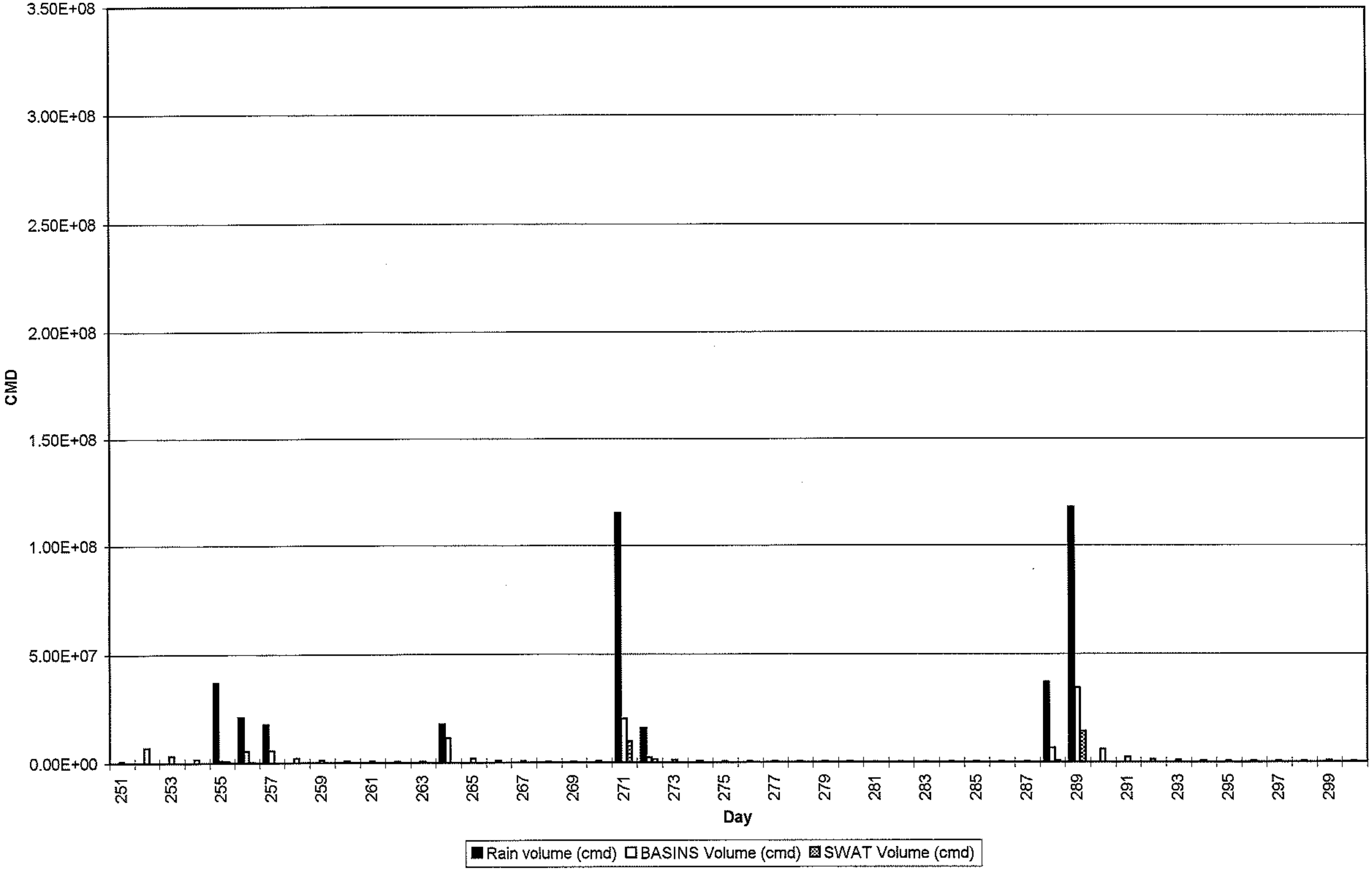
1974 Mass Balance Comparison


1974 Mass Balance Comparison

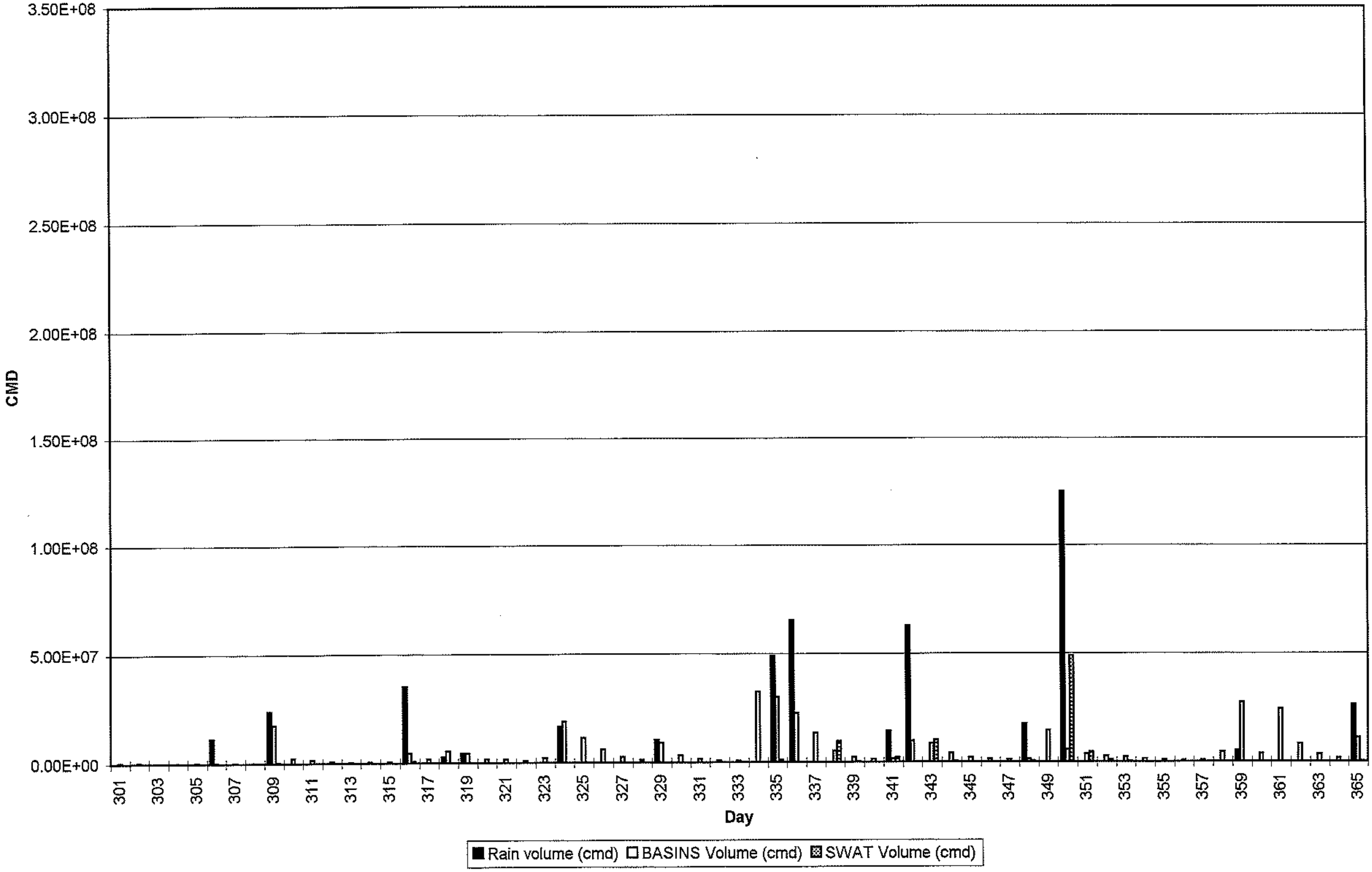
1974 Mass Balance Comparison

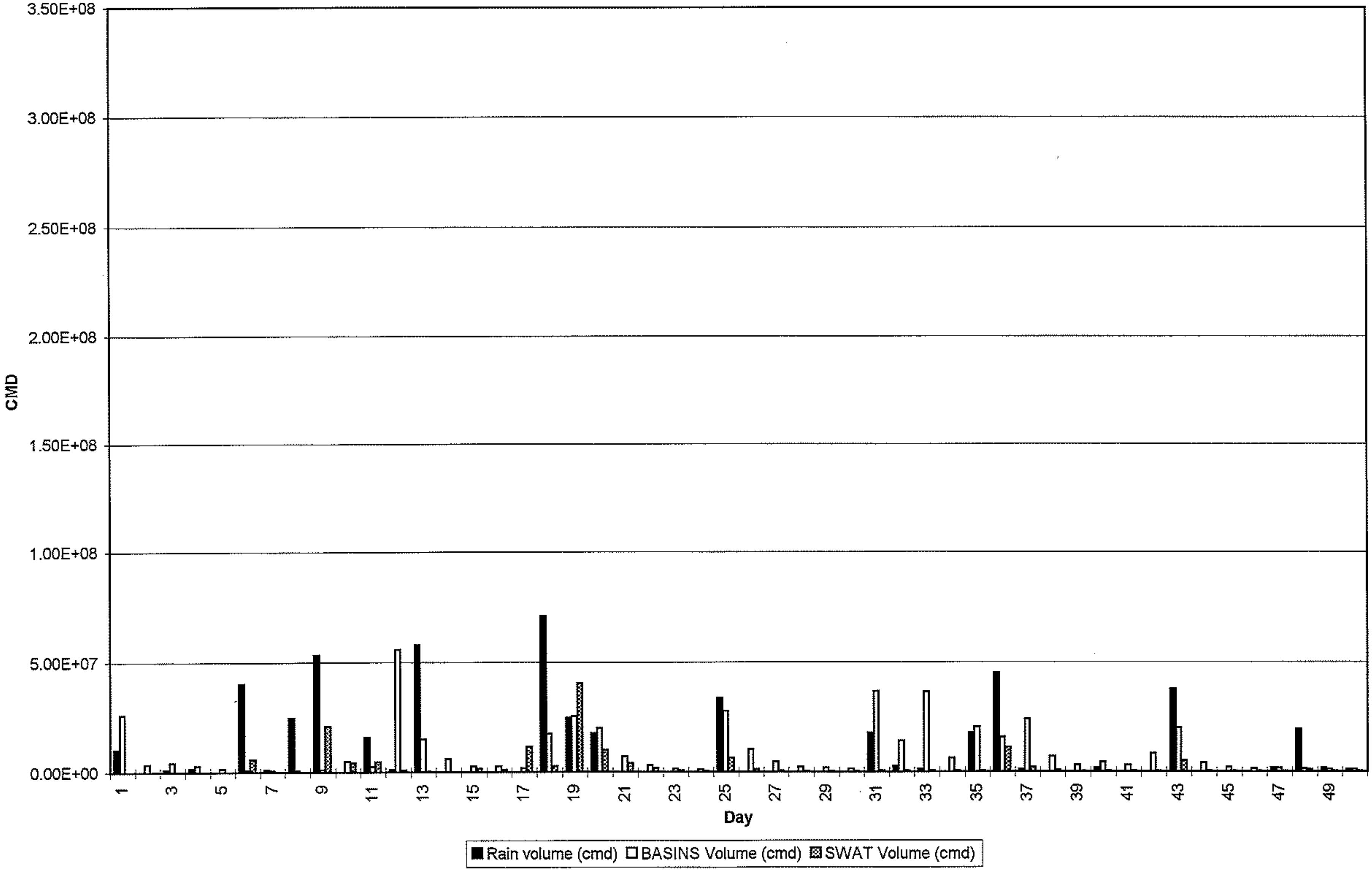


1974 Mass Balance Comparison



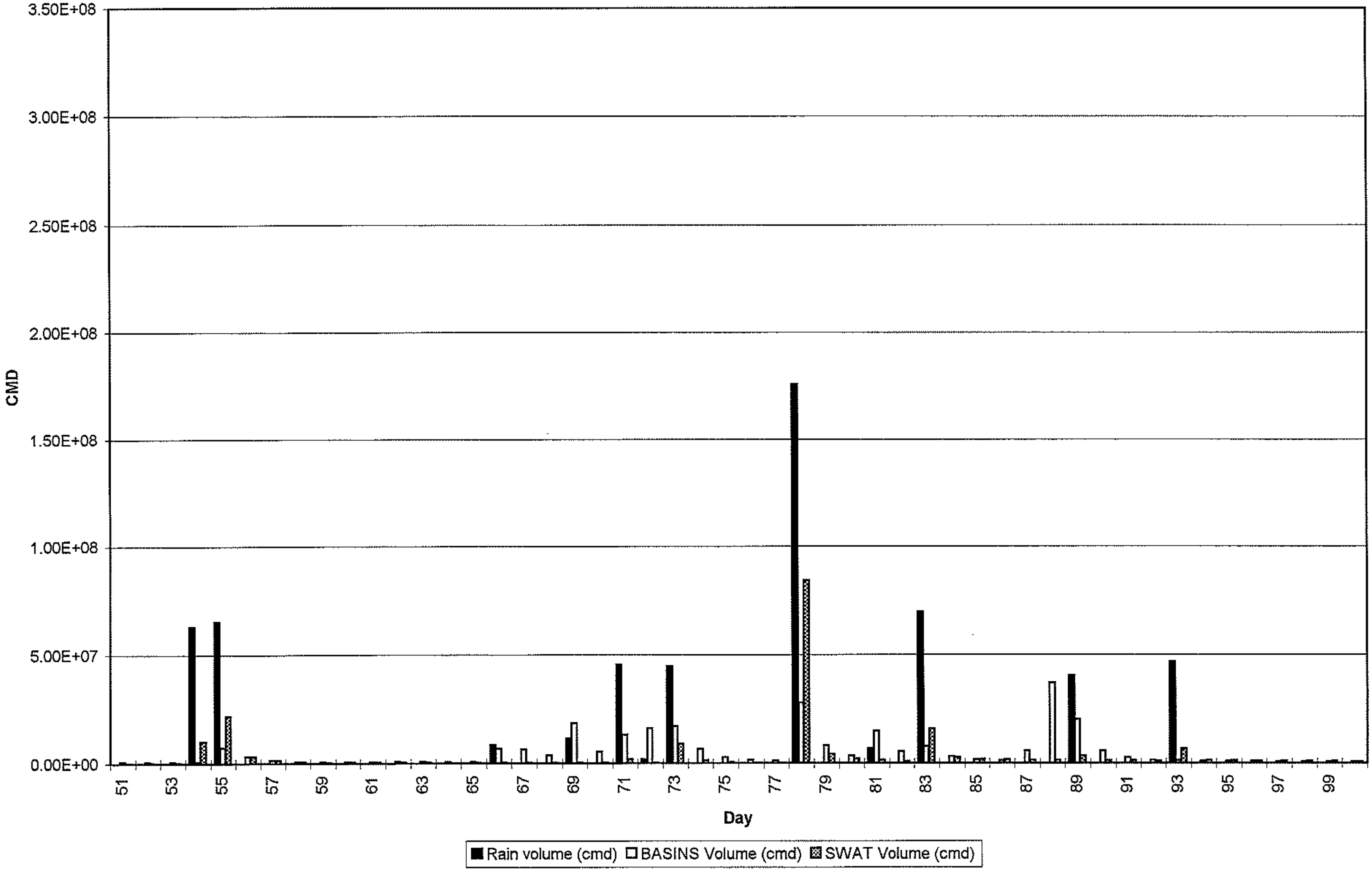
1974 Mass Balance Comparison

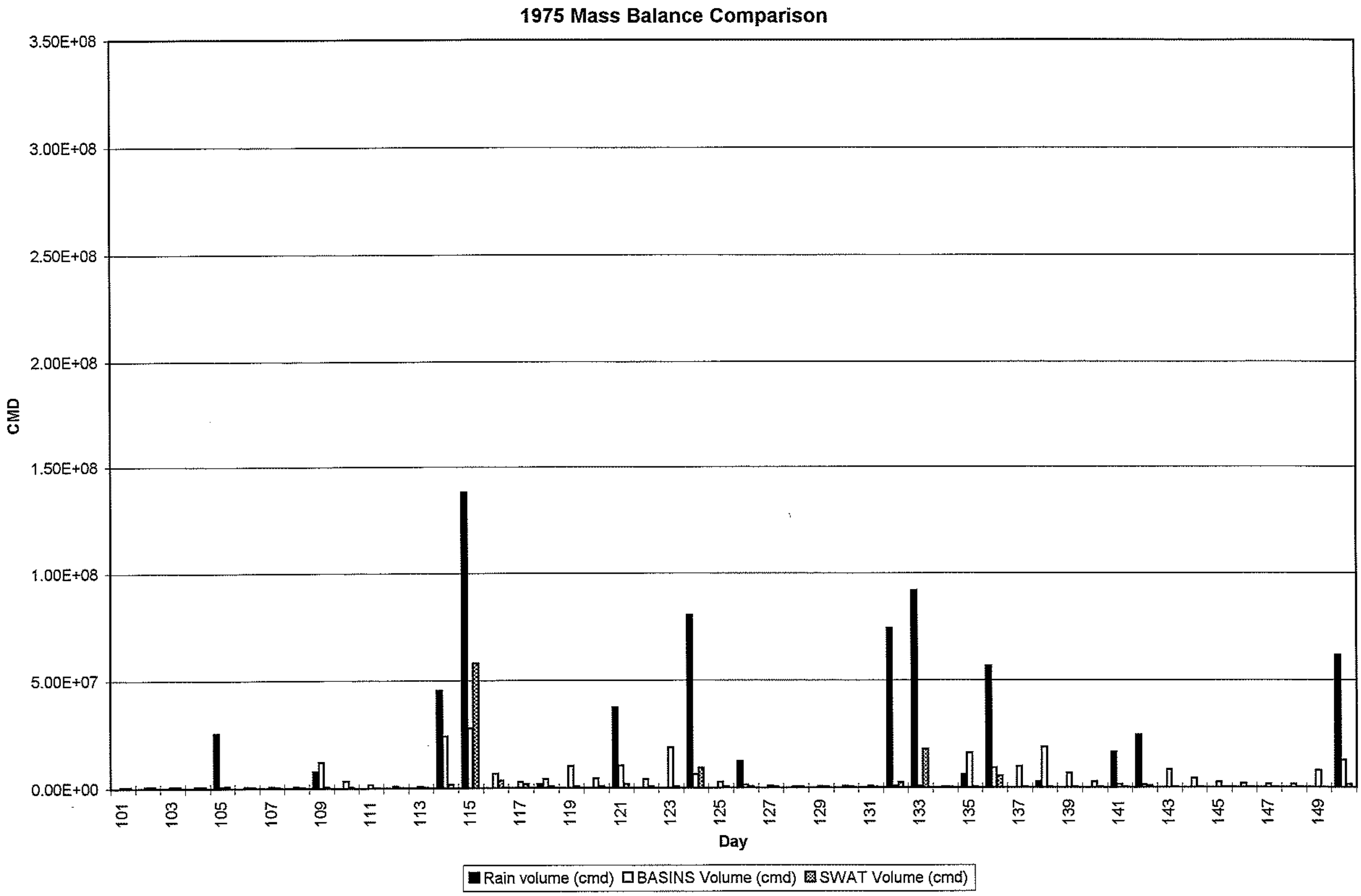




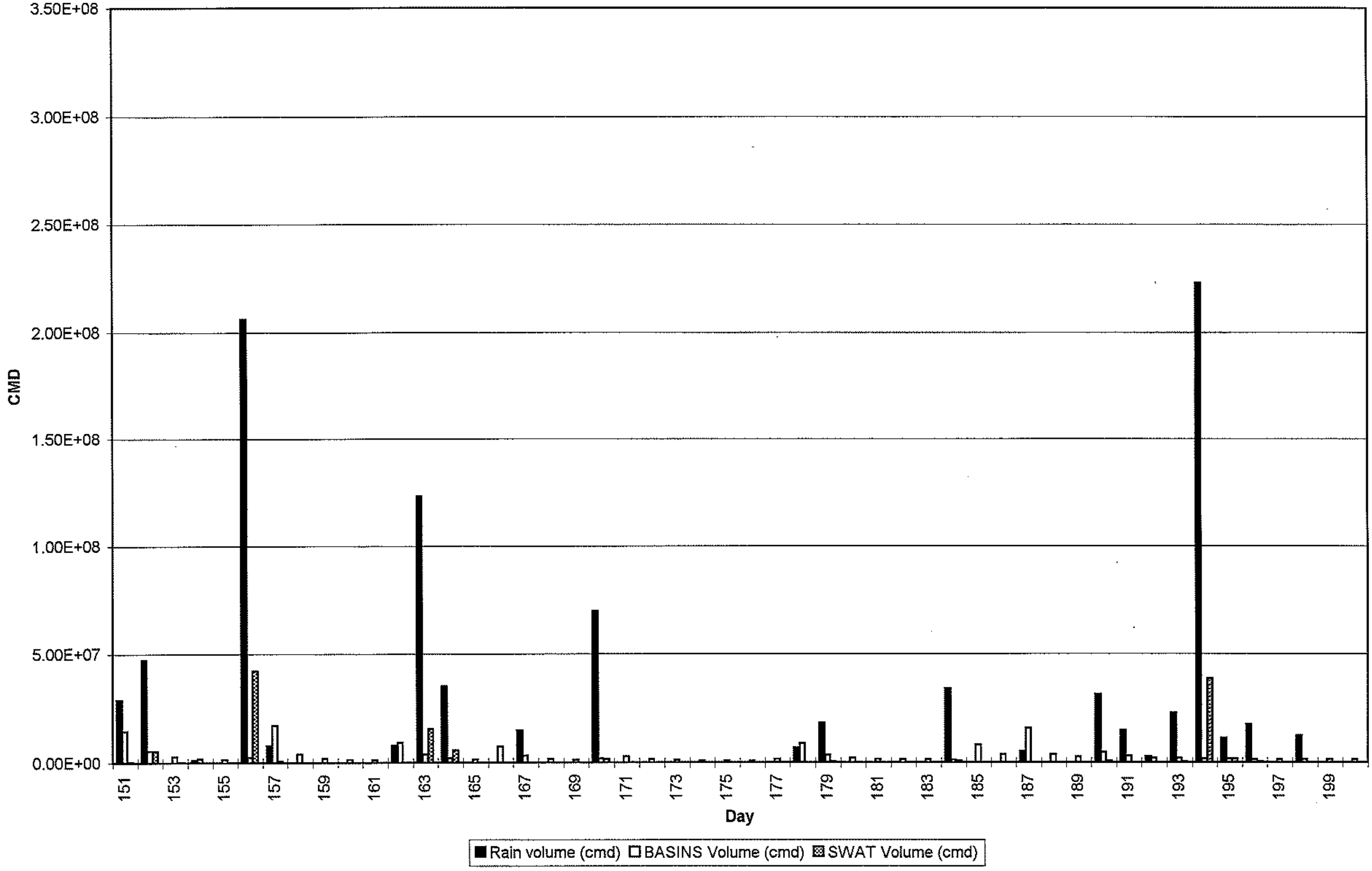
1975 Mass Balance Comparison

1975 Mass Balance Comparison

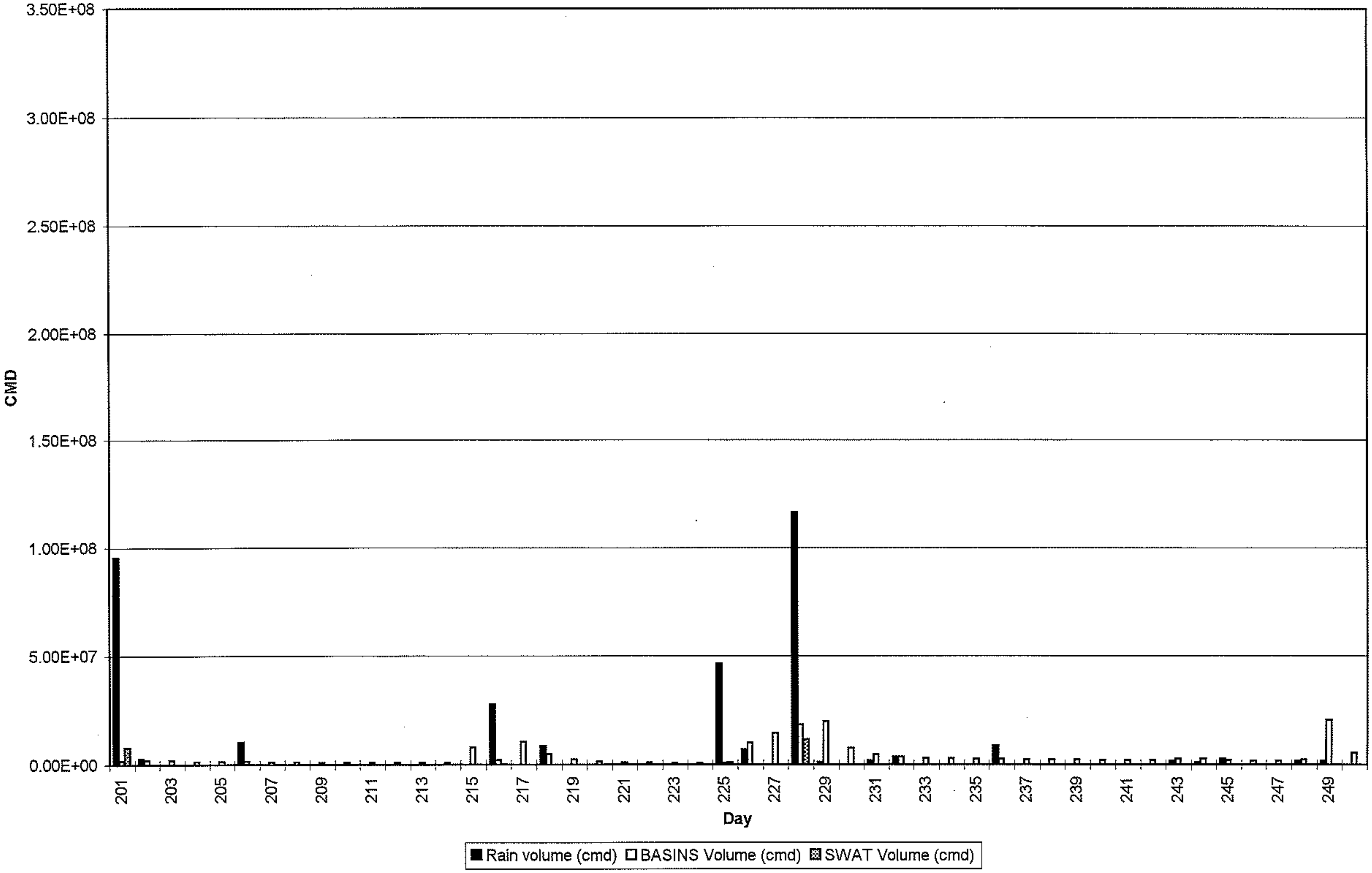



1975 Mass Balance Comparison
CMD
3.50E+08
3.00E+08
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
101
103
105
107
109
111
113
115
117
119
121
123
125
127
129
131
133
135
137
139
141
143
145
147
149
Day
■ Rain volume (cmd)
□ BASINS Volume (cmd)
▨ SWAT Volume (cmd)

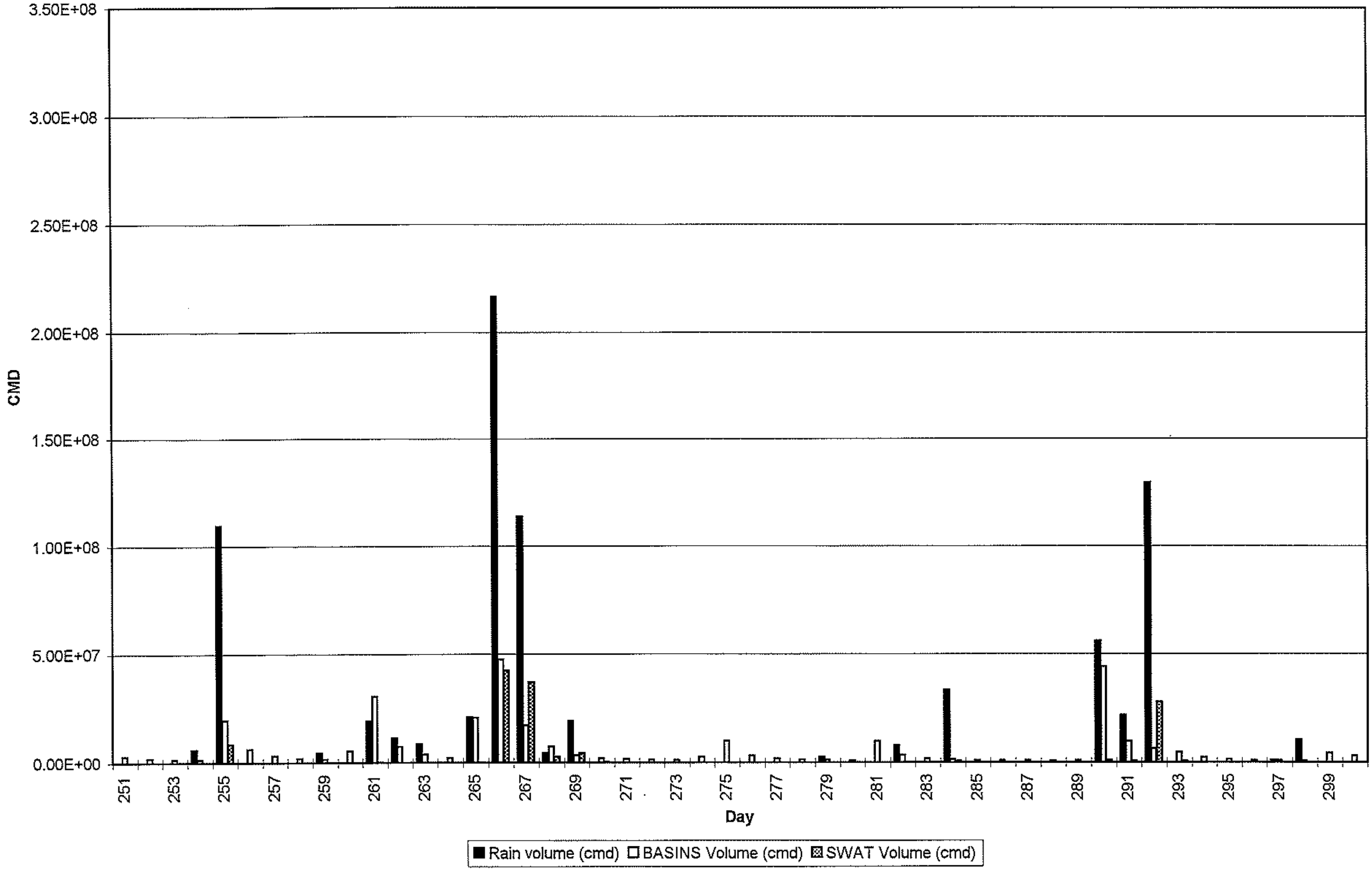
1975 Mass Balance Comparison



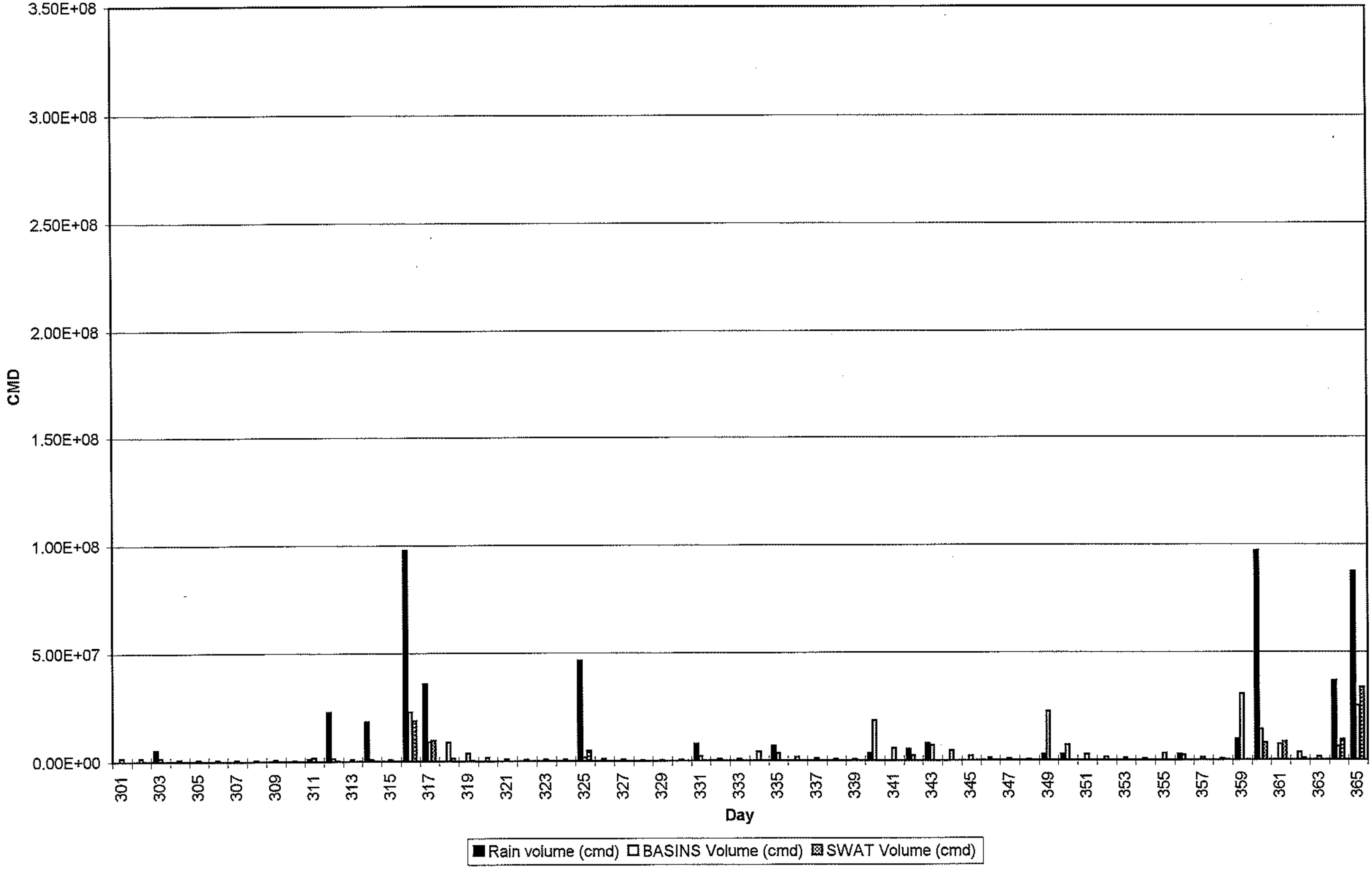
1975 Mass Balance Comparison



1975 Mass Balance Comparison



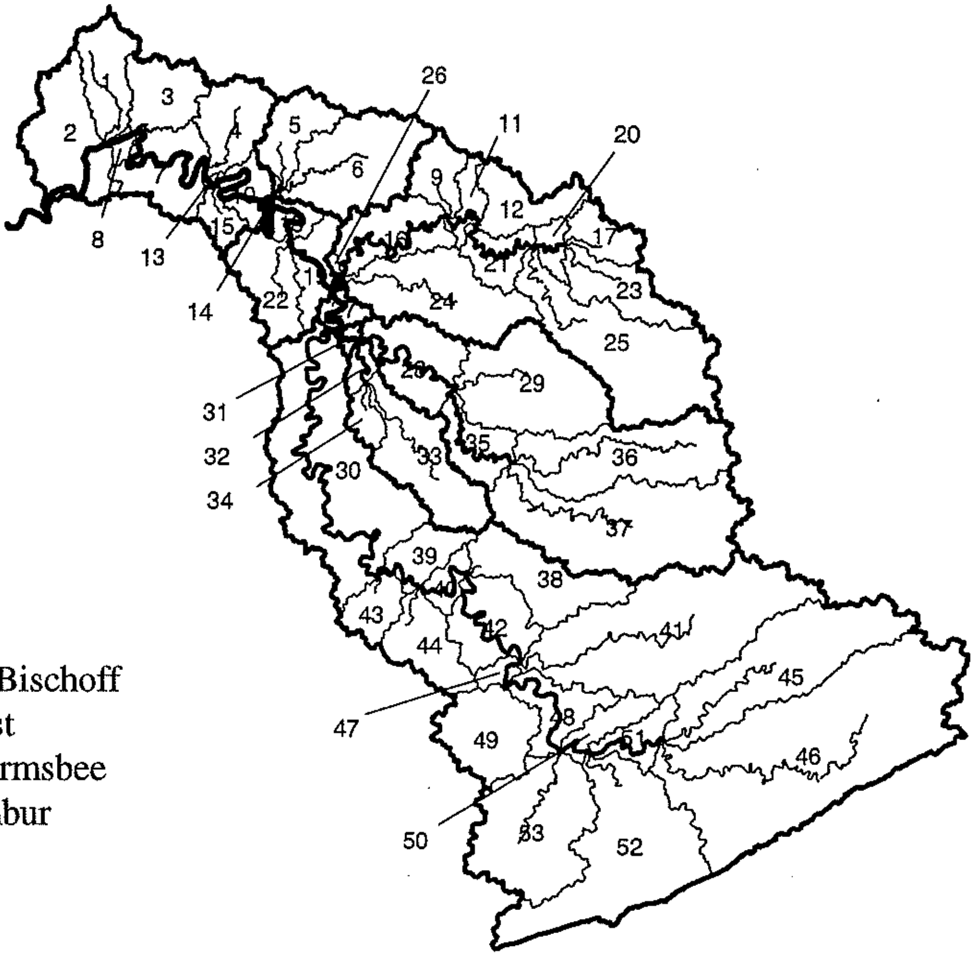
1975 Mass Balance Comparison



Appendix D: Information Sources

Organization	Contact Person	Address/Phone #/E-mail/Internet
KY Division of Water	Mike Mills	502-564-3410
USGS	Internet	h2o.usgs.gov/smr/ky
KY Climate Center	Glen Conner	502-745-4555 gg024004@wkuvx1.wku.edu
NWS (Office of Hydrology)	Frank Richards	301-713-1030 hic@smtpgate.ssmc.noaa.gov
KY Water Watch		kywwp@igc.org
USGS Water Quality Monitoring Program	Tom Maloney	tmaloney@usgs.gov
National Water Information Center		1-800-h2o-9000 h2oinfo@usgs.gov
KY USGS	Randolph See	502-635-8080 rbsee@usgs.gov
USGS Water Information Coordination Program	Lorna Dendrix	lkendrix@usgs.gov
National Water Quality Laboratory	Jon Raese	jwraese@usgs.gov
NOAA	Neal Lott	704-271-4995 nlott@ncdc.noaa.gov
NOAA	Tom Ross	tross@ncdc.noaa.gov
NCDC	US Monthly Precipitation Internet	www.ncdc.noaa.gov/coop-precip.html
NRCS	Doug Hines	606-234-3364
KY USGS (Data Section Chief)	Harry Rollins	502-635-8081
KY USGS	Lynn Jarrett	502-635-8011
STORET	Louie Hoelman	202-260-7050
KY Division of Water GIS	Ted Stumbur	502-564-3410
Hydrosphere	Kerstin Dickson	1-800-949-4937 kld@hydrosphere.com
BASINS	Jerry LaVeck	202-260-7771 laveck.jerry@epamail.epa.gov
SWAT	Nancy Sammons	817-770-6512 sammons@brcsun0.tamu.edu
University of Kentucky Agricultural Weather Center		www.ca.uky.edu/agcollege/agweather
EPA Office of Water		www.epa.gov/ow

COMPUTER MODELING OF THE NORTH FORK OF THE KENTUCKY RIVER USING SWAT AND BASINS



Anthony Bischoff
Scott Yost
Lindell Ormsbee
Ted Stumbur

Prepared for:
The Kentucky Division of Water

Prepared By:
The University of Kentucky Water Resources Research Institute
University of Kentucky
Lexington, Kentucky 40506

March 1997
KWRRI 9703