Section 3
Model Development and Calibration

3.1 Hydraulic and Hydrologic Model

The Storm Water Management Model (SWMM) was selected to model the watersheds of the Spruce Run and Mulhockaway Creek study areas. SWMM is a comprehensive set of mathematical models originally developed for the simulation of urban runoff quantity and quality in storm and combined sewer systems. In recent years, SWMM has been adapted and applied to perform watershed modeling in suburban and rural settings. The SWMM RUNOFF module simulates the relationships between rainfall and stormwater runoff. The model determines how much of the rainfall soaks into the ground, is stored in shallow surface depressions, evaporates into the atmosphere, is transpired by vegetation, or runs off from pervious and impervious surfaces. The model also provides an empirical method for estimating the groundwater flow regime and the discharge of groundwater to a stream as baseflow and interflow. The groundwater portion of the model improves model calibration through the addition of baseflow so that the full streamflow regime can be simulated.

Results from the hydraulic and hydrologic model were used to estimate annual stormwater runoff pollutant loadings. Pollutant event mean concentrations or loading factors were used along with the simulated runoff volumes to generate annual pollutant loads.

3.2 Spruce Run Model Development

In addition to the land use data developed in Section 2, other physically based model parameters were generated from the GIS of the study area. These parameters include drainage area, width, length, slope, depression storage, and infiltration. These parameters are used to calculate the runoff volume and route the flows through the drainage area system to the reservoir.

Drainage Areas

To develop the SWMM RUNOFF hydrologic model for the watersheds of the Spruce Run and neighboring tributaries, the area was divided into 11 drainage areas (subwatersheds). The delineations were primarily based upon the New Jersey Department of Environmental Protection's (NJDEP) 14 Digit Hydrologic Unit Code (HUC14) basins[1]. The GIS dataset obtained from the NJDEP contained sub-delineations of the HUC14 basins with an additional 3-digit code. For the purposes of this study, the sub-delineations are referred to as HUC17, although these sub-delineations did not follow the hydrologic unit code platform. One of the HUC17 drainage areas was further divided at water quality gauging stations to facilitate the comparison of model results and observed data. The final drainage areas were

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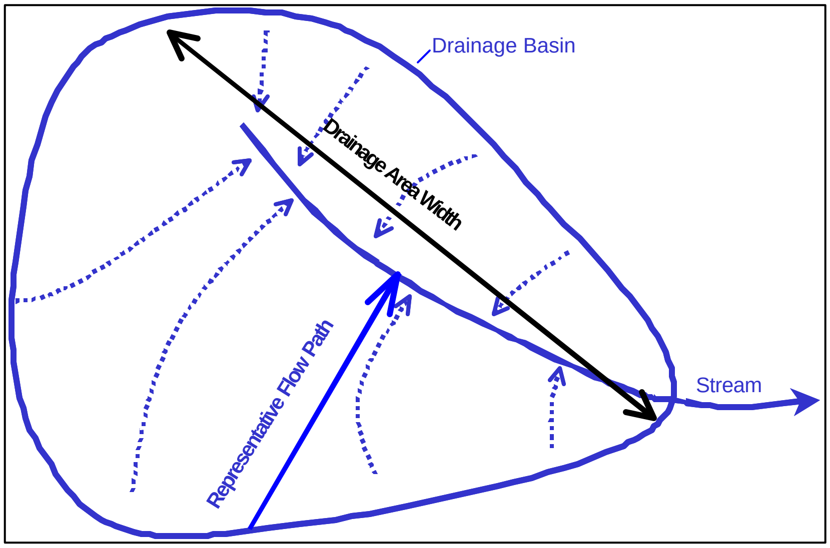
[1] State of New Jersey. Department of Environmental Protection. GIS Resource Data. Series 1 Volume 2. Central New Jersey. 1996

assigned an independent (non-HUC) 3-digit numerical identification number for use in modeling.

Drainage Area Widths, Lengths, and Slopes

The “drainage width”, “drainage length” and “drainage slope” of a drainage basin are calibration parameters used to adjust simulated peak flow values and timing to match observed values. The drainage length represents the physical length of overland flow for the main drainage channel in a drainage basin. The drainage length can be visualized as the representative flow path from the edge of the drainage basin to a channel or sewer as shown in Figure 3.1. The drainage width, as defined for RUNOFF, represents the physical width of overland flow, and is inversely proportional to the drainage length[2]. The drainage slope represents the average slope of overland flow, and is assumed to be the slope of the average drainage path used to determine the drainage length. In SWMM, only the drainage width and drainage slope are defined for each drainage basin, since the drainage length is directly related to the drainage width by the drainage area.

Figure 3.1



Since these parameters are used for calibration, estimates are usually adequate. For the initial determination of drainage area width and slope for the watersheds of the Spruce Run and neighboring tributaries, the length of the average overland flow path in each drainage area was estimated by scaling from available maps. The drainage area width was then calculated by dividing the basin area by the length of average overland flow. The drainage slope was assumed to be the slope of the chosen overland flow path. The drainage area widths and slopes were later updated using an automated GIS tool[3] developed specifically to assist in stormwater model development. The tool determines the flow length of multiple flow paths beginning at incremental starting points along the edge of each drainage area. Using the digital

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[2] Area=length x width so width = area/length

[3] Reference: CDM proprietary

elevation model (DEM), each flow path is drawn starting at the drainage area boundary and terminating when it reaches the pre-defined stream network. The average flow path length, width and slope are then determined for each drainage basin. Table 3.1 presents the drainage area lengths, widths and slopes for the subwatersheds of the Spruce Run study area.

Table 3.1

Subwatershed ID	Drainage Area (acres)	Drainage Length (ft)	Drainage Width (ft)	Drainage Slope (%)
101	746	3,229	10,063	0.6%
102	69	1,079	2,789	4.2%
103	127	1,392	3,964	3.6%
104	871	4,272	8,882	1.0%
105	664	2,457	11,781	4.2%
106	274	2,434	4,906	2.4%
107	639	2,166	12,850	5.0%
108	1,566	2,673	25,512	3.6%
109	627	2,960	9,221	2.9%
110	4,032	3,394	51,753	3.8%
111	3,561	3,781	41,033	1.9%

Depression Storage

Depression storage is a volume that must be filled by precipitation before surface runoff occurs from either pervious or impervious surfaces. This volume represents a loss or “initial abstraction” caused by phenomena such as surface wetting, interception, surface ponding, and evaporation. Depression storage is drained via evaporation from impervious areas, and via both evaporation and infiltration from pervious areas. Depression storage is difficult to calculate directly and is used as a calibration parameter to refine estimates of runoff volumes. Generalized estimates of depression storage are used rather than calculated values, since the values may be changed during calibration. For this study, depression storage values on pervious and impervious areas were estimated to be 0.15 inches and 0.02 inches, respectively. The depression storage values were not altered during calibration. Composite depression storage values for each of the subwatersheds can be found in Table 3.2.

Table 3.2

Subwatershed ID	Composite Depression Storage (in)
101	0.10
102	0.12
103	0.13
104	0.13
105	0.15
106	0.14
107	0.15
108	0.14
109	0.14
110	0.14
111	0.13

Infiltration

Infiltration is the process of water penetrating the ground surface and seeping into the soil. Only precipitation that occurs over pervious surfaces or that is routed onto a pervious surface has the opportunity to infiltrate. The rate at which water enters the soil is called the infiltration rate. Factors that influence the rate of infiltration include the condition of the ground surface, type and amount of vegetative cover, and properties of the soil (porosity, hydraulic conductivity and the current moisture content). Water that infiltrates into the ground becomes available for groundwater recharge, evapotranspiration, and groundwater discharge back to the surface as springs or into streams as baseflow. Infiltration also empties depression storage and affects the amount of rainfall that runs off from the pervious area. Runoff from pervious areas only occurs when the rainfall intensity is higher than the available soil infiltration rate, typically during high intensity or large volume/long duration storm events.

Infiltration is predicted using either the Horton or Green-Ampt Equations. The more commonly used Horton equation is empirical, while Green-Ampt uses physically measurable parameters. For this study, the Green-Ampt equation was used to estimate infiltration from pervious areas. In SWMM, Green-Ampt predicts the volume of water that will infiltrate before the surface becomes saturated. After surface saturation occurs, infiltration is driven by the saturated hydraulic conductivity of the soil, or HYDCON. HYDCON is one of the main calibration parameters used in SWMM to determine the runoff volumes from pervious surfaces. The two remaining parameters, the average capillary suction (SUCT) and the initial moisture deficit (SMDMAX) are rarely modified for calibration. Initial estimates for each of these parameters are adequate and can typically be assigned according to soil type. Initial estimates of each of the Green-Ampt infiltration parameters were assigned according to soil texture using data obtained from BOSS International that is based on literature values.[4]. Table 3.3 presents the values of Green-Ampt parameters by soil type used to develop values for subwatersheds.

Table 3.3

NRCS Soil Texture Classification	**SUCT** Avg. Capillary Suction (in)	**HYDCON** Saturated Hydraulic Conductivity (in/hr)	**SMDMAX** Initial Moisture Deficit for Soil (expressed as a fraction)
Sand	1.95	9.27	0.346
Loamy Sand	2.41	2.35	0.312
Sandy Loam	4.33	0.86	0.246
Loam	3.5	0.52	0.193
Silt Loam	6.57	0.27	0.171
Sandy Clay Loam	8.6	0.12	0.143
Clay Loam	8.22	0.08	0.146
Silty Clay Loam	10.75	0.08	0.105
Sandy Clay	9.41	0.05	0.091
Silty Clay	11.5	0.04	0.092
Clay	12.45	0.02	0.079

Notes:

1. These values are provisional, and are offered as reasonable parameter estimates for SWMM applications where more detailed soils information is not readily available. There is significant variance in these values; laboratory and field testing, sensitivity analysis, and calibration may be employed to improve upon these estimates.
2. Typically use NRCS Soil Survey to determine Soil Texture. In these surveys, Saturated Hydraulic Conductivity is reported as Permeability. Use the values reported in the soil survey for permeability for HYDCON, rather than HYDCON values
3. Synthesized from *Handbook of Hydrology* , D.R. Maidment, Editor in Chief, McGraw-Hill Inc., 1993, pp 5.1-5.39.
4. Calibrated values for the Spruce Run and Mulhockaway SWMM models are presented in Table 3.5

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[4] www.Bossint.com

Groundwater

Precipitation can reach a waterway through multiple pathways, such as direct overland runoff or through storm sewer outfalls. These two types of discharge are rapid and are responsible for peak flow rates experienced following storm events. A third way for precipitation to reach a waterway is through groundwater discharge. Groundwater discharge accounts for the time-delayed recession curve of the hydrograph and can contribute a large portion of the total discharge to a waterway following a storm event.

Infiltrated precipitation is subjected to a wide array of physical processes. In SWMM, the groundwater module simulates these processes as upper (non-saturated) and lower (saturated) zone evapotranspiration, percolation from the upper to lower zone, deep percolation from the lower zone, subsurface moisture content and groundwater inflow. Evapotranspiration and deep percolation represent net losses from the subsurface.

The groundwater module of SWMM is an approximate method of accounting for the groundwater discharge back to receiving waters and provides a more complete accounting of the quantity of water that reaches waterways following a storm event. Subsurface conditions specific to each drainage basin are defined using a global groundwater dataset. These parameters were based upon best professional experience from previous modeling efforts similar to this study and were adjusted during model calibration to reflect the conditions around Spruce Run.

3.3 Spruce Run Model Calibration

The objectives of a modeling study determine the level of effort and targets for calibration. Calibration targets are established to assess the effectiveness of the approach used and the model’s accuracy in predicting observed values. The Spruce Run Reservoir watershed model was designed to estimate annual pollutant loads, therefore, calibration of the models was geared toward reproducing annual flows. Model performance also was evaluated on a daily basis for discussion purposes and is intended only to provide additional insight into the ability of the model to simulate a more refined time series.

3.3.1 Annual Flow Calibration

The calibration target established for the SWMM model of the Spruce Run study area was to obtain simulated average annual runoff volumes within 10% of observed data. An effort also was made to achieve the same target calibration for average annual total flow, baseflow and evapotranspiration estimates. All of these calibration goals were achieved. Table 3.4 presents the results of the calibration.

Table 3.4

	Baseflow	Runoff	Total Flow	Evapotranspiration
	(in)	(in)	(in)	(in)
Simulated	16.2	8.3	24.5	21.0
Observed	15.4	8.7	24.1	23.4
% Error	-5.1%	4.4%	-1.7%	10.1%

3.3.1.1 Observed Stream Flow Data

Observed stream flow data from USGS discharge monitoring station 1396580, “Spruce Run at Glen Gardner, NJ”, were used to perform the model calibration. The drainage area of the monitoring station is approximately 11.3 square miles, slightly more than half of the study area. Since the gage was not located at the terminus of the model, calibration only could be performed on the portion of the watershed upstream of the monitoring location. To calibrate the areas downstream of the monitoring location, adjustments made during calibration were made uniformly to the entire study area. The discharge data were reviewed and filtered to ensure that only complete years of data were used to perform the calibration. The calibration data set included 16 years of observations, 1980 through 1987 and 1992 through 1999.

The data obtained from the discharge monitoring station provided daily readings of total flow. For calibration, these data were separated into baseflow and surface runoff using the “sliding-interval” technique described by White and Sloto[5]. Baseflow is mostly comprised of groundwater discharge to the stream, while runoff results from overland discharge. The “sliding-interval” technique assigns the baseflow for a particular day as the minimum daily flow experienced over a range of days beginning before and ending after the particular day. The time period interval is based upon the time of concentration and is determined by drainage area.

3.3.1.2 Surface Water Runoff Calibration

As stated above, the calibration target established for the SWMM model was to achieve simulated annual runoff volumes within 10% of observed annual runoff volumes. This target was achieved over the 16-year calibration. Adjustments that were made to the parameters that control or influence stormwater runoff are saturated hydraulic conductivity and impervious surface cover.

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[5] White K.E. and Sloto R.A., 1990, “Base-flow-frequency characteristics of selected Pennsylvania streams”. USGS Water Resources Investigations Report 90-4161.

Saturated Hydraulic Conductivity

The saturated hydraulic conductivity, or HYDCON, was determined to be a critical parameter in model calibration. The hydraulic conductivity is a measure of the rate at which water infiltrates through the pervious surface. For pervious surfaces, runoff only occurs when precipitation intensity is greater than the available soil infiltration rate. Besides impacts to surface water runoff, the hydraulic conductivity controls the amount of water available to the subsurface. The subsurface volume controls soil moisture content, groundwater availability, evapotranspiration and stream discharge.

The saturated hydraulic conductivity of each modeled drainage unit was determined using the weighted average of the saturated hydraulic conductivity of the soil types throughout the drainage unit area. The initial values of hydraulic conductivity for each soil type were based upon the values presented in Table 3.3. During calibration, these values were adjusted globally for all of the drainage units. Table 3.5 presents the final calibration values for HYDCON and other parameters used to simulate infiltration (discussed in Section 3.2) by subwatershed.

Table 3.5

Subwatershed	**SUCT** Avg. Capillary Suction (in)	**HYDCON** Saturated Hydraulic Conductivity (in/hr)	**SMDMAX** Intitial Moisture Deficit for Soil (expressed as a fraction)
101	2.17	0.16	0.254
102	2.18	0.12	0.267
103	2.60	0.05	0.246
104	2.35	0.15	0.283
105	1.16	0.34	0.398
106	2.54	0.06	0.247
107	2.15	0.16	0.297
108	1.98	0.18	0.314
109	2.44	0.09	0.265
110	2.57	0.09	0.257
111	2.59	0.09	0.257

Impervious Surface Cover

The majority of precipitation falling on impervious surfaces results in surface water runoff. Impervious surfaces include any area where precipitation cannot infiltrate the ground, such as a parking lot or rooftop. In SWMM, the percentage of impervious land cover is input for each drainage unit. Initial values of impervious cover were obtained from the NJDEP dataset. This dataset includes impervious surfaces directly connected to the stormwater drainage system and those that are routed to pervious surfaces. In SWMM, non-connected impervious surfaces are treated as pervious, since the stormwater runoff generated from these areas has an opportunity to infiltrate.

The percent impervious surface cover of each modeled drainage unit was determined using the NJDEP dataset. Initially, these values were reduced by 25% to account for areas that are not directly connected. During the model calibration, these values were further reduced, with the calibrated values at 60% of the original values to balance infiltration, runoff and evapotranspiration. Initial and calibrated percent impervious surface cover values by subwatershed are presented in Table 3.6.

Table 3.6

Subwatershed ID	% Impervious Surface Intial	Calibrated
101	69.9%	41.9%
102	39.6%	23.8%
103	19.4%	11.7%
104	24.8%	14.9%
105	5.6%	3.4%
106	16.6%	10.0%
107	6.2%	3.7%
108	16.3%	9.8%
109	16.5%	9.9%
110	13.2%	7.9%
111	24.2%	14.5%

3.3.1.3 Baseflow Calibration

The initial discharge to a waterway during or immediately following a precipitation event is largely attributed to runoff. Runoff discharge is characterized by a short time of concentration at a high intensity. After runoff has ceased, discharge will continue to a waterway as groundwater inflow. This baseflow discharge is characterized by a longer time of concentration with a lower/steadily decreasing intensity. Baseflow, while lower in intensity than runoff, accounts for a larger portion of the total flow volume through a stream. To account for baseflow discharge, the GROUNDWATER module of SWMM was utilized. While baseflow calibration was not included in the original target calibration criteria, an effort was made to obtain annual baseflow estimates within 10% of the observed annual baseflow. This target was achieved over the 16-year calibration dataset through a series of model runs and analysis. Adjustments that were made to the parameters that control or influence baseflow are discussed below.

Hydraulic Conductivity

In SWMM, infiltration provides the only source of water for the subsurface. The GROUNDWATER module uses infiltrated water to determine soil moisture, provide for evapotranspiration, determine the depth of the groundwater aquifer, and discharge water back to a waterway. Adjustments to the hydraulic conductivity were made primarily to achieve surface water calibration, but also to provide the necessary volume to the subsurface to simulate each of these processes reflective of observed conditions. The calibrated HYDCON values are presented in Table 3.5.

Additional Subsurface Parameters

As described above, the GROUNDWATER module of SWMM provides a rough method for simulating groundwater flow. Initial estimates for groundwater parameters were obtained from previous modeling studies of similar areas and adjusted during model calibration. Because GROUNDWATER is driven by a series of empirical coefficient and exponent driven equations that do not directly represent physical aspects of the aquifer, discussion of specific parameter adjustments would not be constructive. Therefore, a generalized discussion is provided.

In SWMM, the subsurface is made of two zones, an upper unsaturated zone and a lower saturated zone. Infiltrated water enters directly into the upper zone. Soil moisture present in the upper zone is subject to a number of driving forces, including evapotranspiration and percolation to the lower zone. Water that percolates to the lower zone is subject to groundwater recharge, evapotranspiration, deep percolation, and groundwater discharge. All of these processes must be balanced in SWMM to provide baseflow estimates consistent with observed data.

To perform the baseflow calibration, the parameters that determine the amount of the total evapotranspiration allotted to the subsurface and the amount of deep percolation were adjusted to achieve annual evapotranspiration and deep percolation estimates consistent with that of observed differences between precipitation and total flow. The available subsurface storage volume and resistance to subsurface flow also were adjusted to achieve discharge volumes and intensities consistent with observed baseflow data.

3.3.2 Total Flow on a Daily Basis

Although the model was not developed to simulate flow on a daily basis, an analysis of model performance on a daily basis provides significant insight into its behavior under varying flow conditions. Using the existing gage data over a 16-year period of record (1980-1988, 1992–1999), the total daily flow at the gage was compared to the simulated flow. The results are shown in Table 3.7.

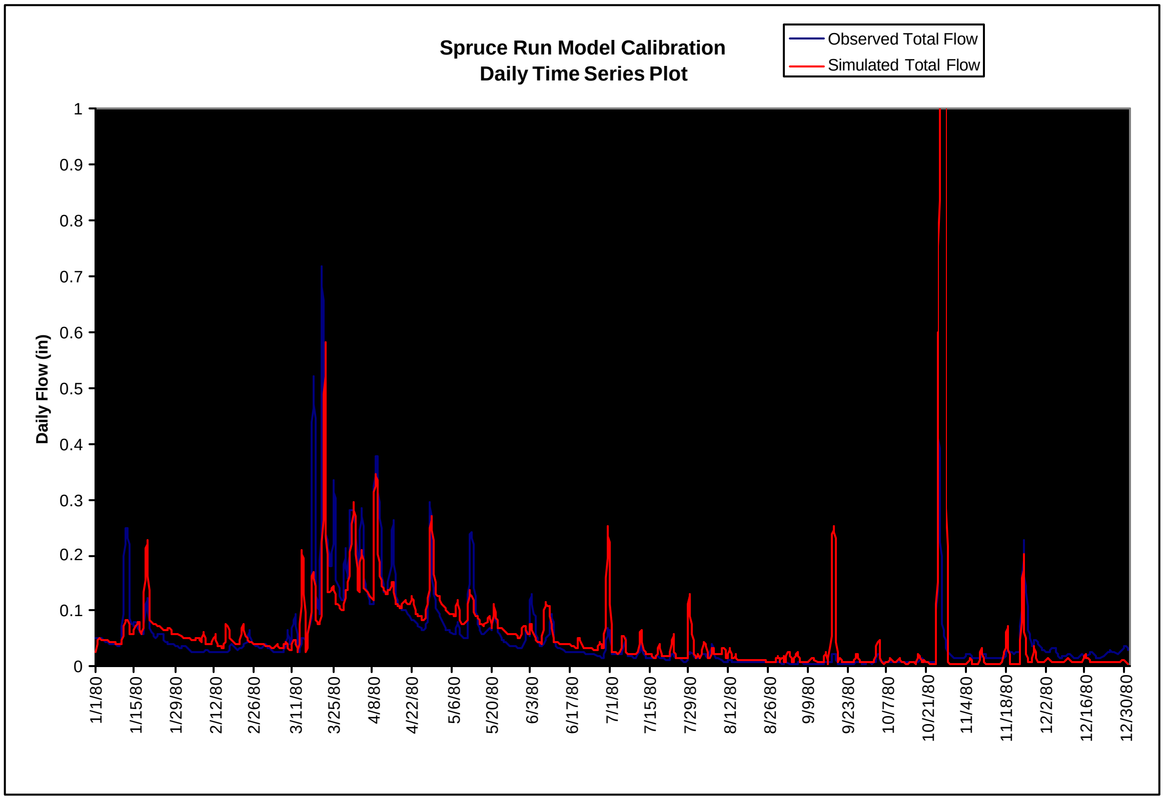
Table 3.7

	Daily Flows (cfs)		
	Observed	Simulated	Residual
Mean	21.8	23.1	-1.3
Standard Deviation	38.1	29.1	29.4

The model produced a mean flow over the period of record of 21.8 cfs, compared to the flow observed at the gate of 23.1 cfs. On a daily basis, the mean residual (observed daily flow minus simulated daily flow) is close to –1 cfs, a difference of 6 percent. The standard deviation of the simulated and observed flows vary by about 10%, showing that the model did a reasonable job of simulating the variability of flow over the period of record. The standard deviation of the residuals (defined as the daily value of the observed flow minus the simulated flow), however, is large (29.4 cfs). This indicates that the model is only moderately successful on a daily basis of predicting flows. This results mostly from inherent problems encountered developing a realistic distribution of rainfall over the watershed with limited rain gage data.

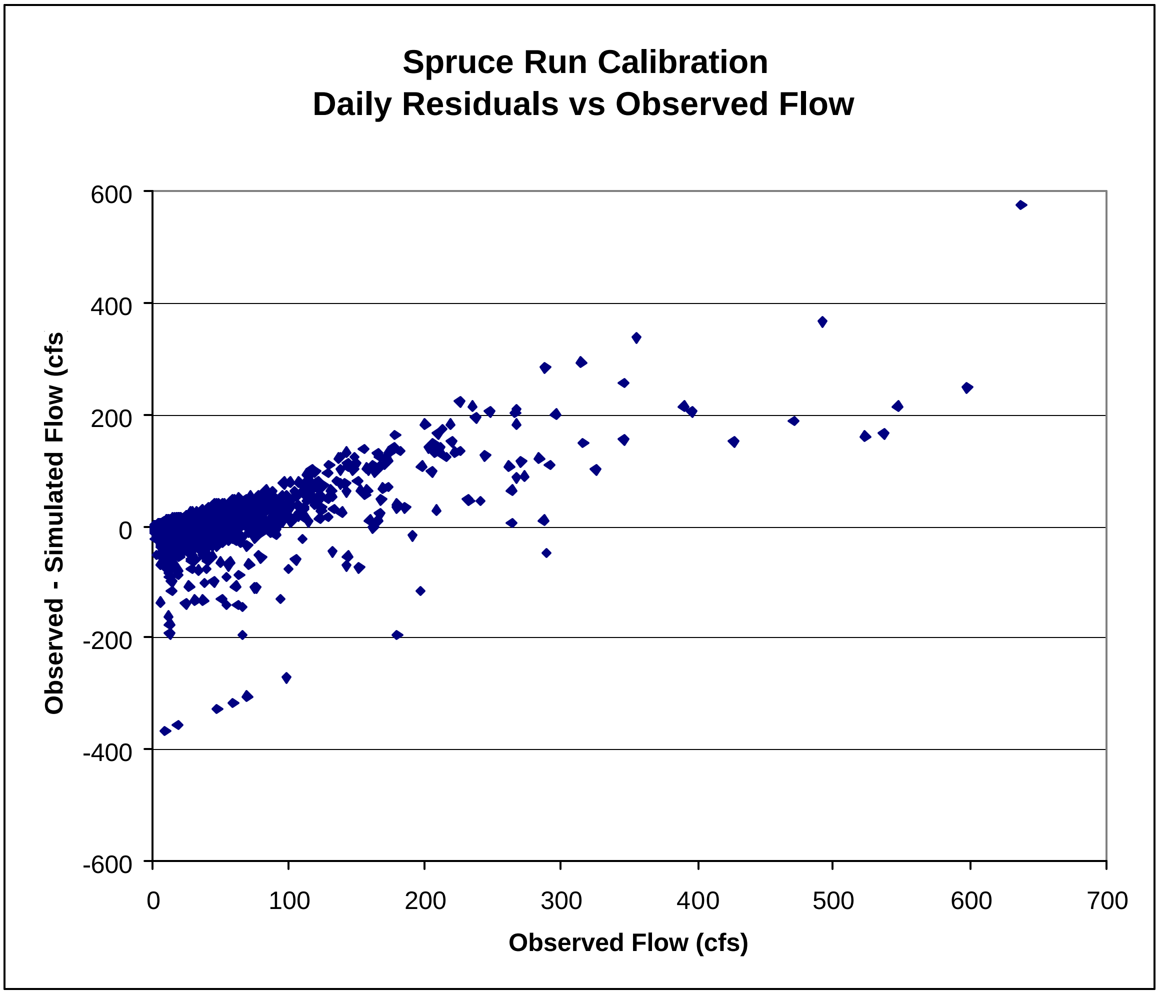
Visual inspection of time series plots provides another means of comparing modeled and observed total daily flow at the gage. Figure 3.2 presents the results for 1980, a representative year. The model is generally successful at simulating storm events with peak flows and recession curves that are similar in shape to the gage flow estimates on a daily basis. The plot suggests that the model is overestimating stream baseflow during the early part of this year, but underestimating stream baseflow during the latter part of this year.

Figure 3.2



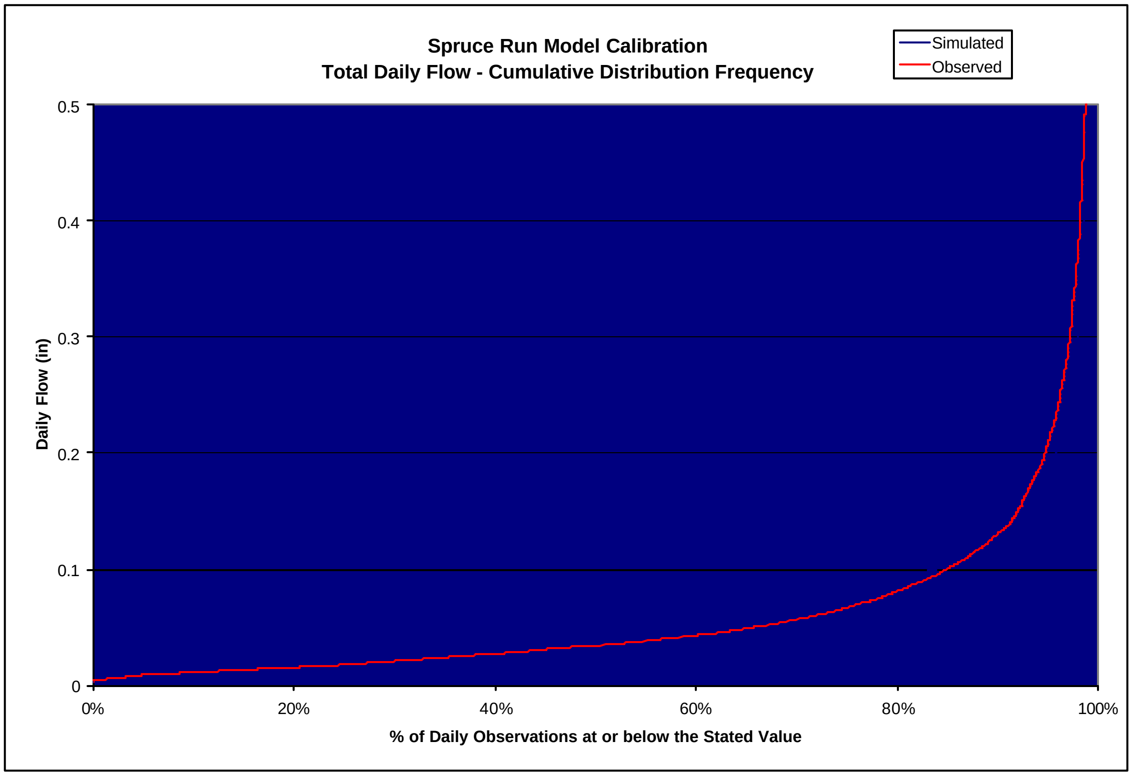
Another way to evaluate the accuracy of the model on a daily basis is to graph the residuals (observed minus simulated) against observed flow. This approach highlights trends in the way the model is simulating flows. Figure 3.3 presents the model residuals versus flow on a daily basis for the entire long term model simulation. The model tends to overestimate low flows (negative residuals), and underestimate higher flows (positive residuals).

Figure 3.3



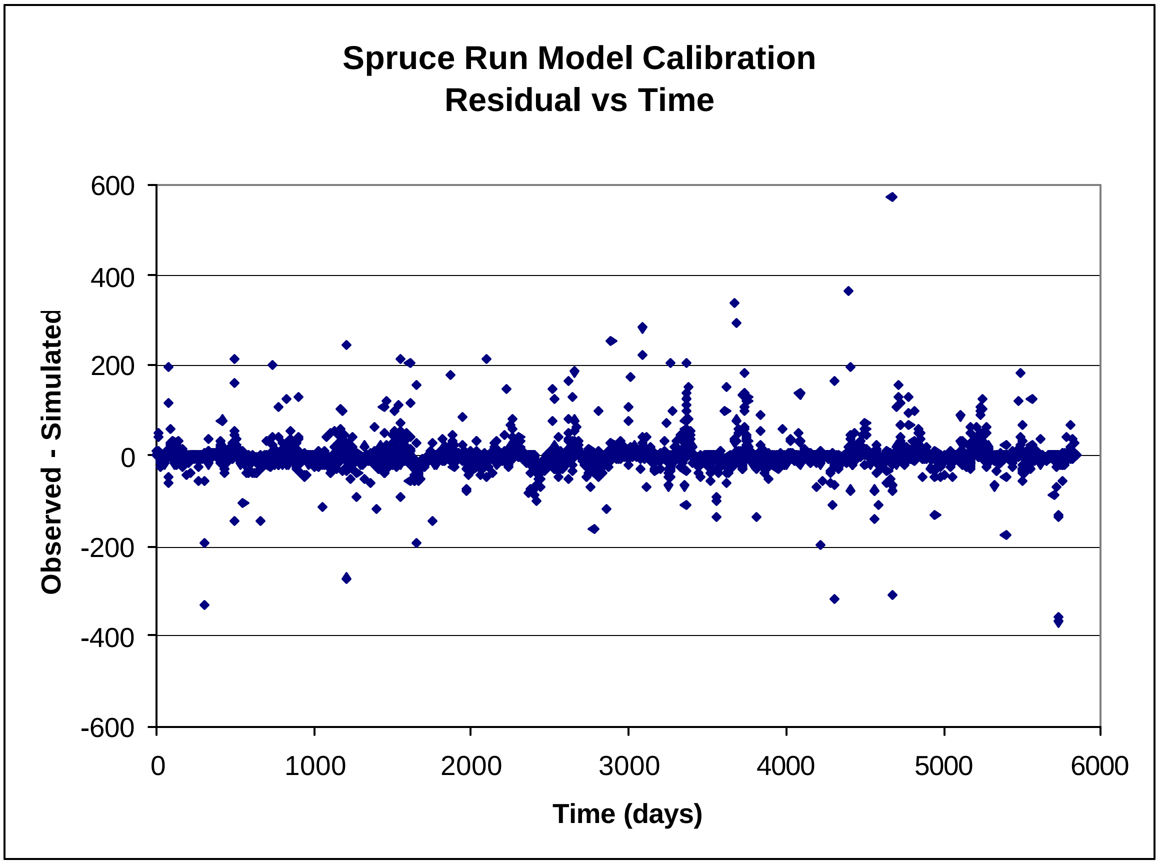
Model trends also can be demonstrated by plotting the cumulative frequency distribution of both observed and simulated flows, as shown in Figure 3.4. The plot shows the percentage of observations that occurred below the indicated flow expressed as inches per year. The model’s tendency to underestimate low flows, and overestimate medium to higher flows is evident when the cumulative frequency distributions are compared.

Figure 3.4



Trends over time can be evaluated by graphing residuals against time, as shown in Figure 3.5. The plot shows residual scatter throughout the 16-year simulation, indicating the model is simulating with the same accuracy across the entire period of record.

Figure 3.5



For calibration, the Likelihood Measure, developed by Nash and Sutcliffe[6], can be used to estimate the model's success in simulating observed flows. The Likelihood Measure accounts for the often significant variance of observed data through use of an error variance to calculate the accuracy of the model. The Error variance (var) is the sum of squared errors. The Likelihood Measure "E" is defined as:

$$E = 1 - var_e/var_o$$

Where:

E is the likelihood measure

Var_e is the error variance of the observed data minus the modeled data (e.g. observed discharge – modeled discharge on daily, monthly basis etc.)

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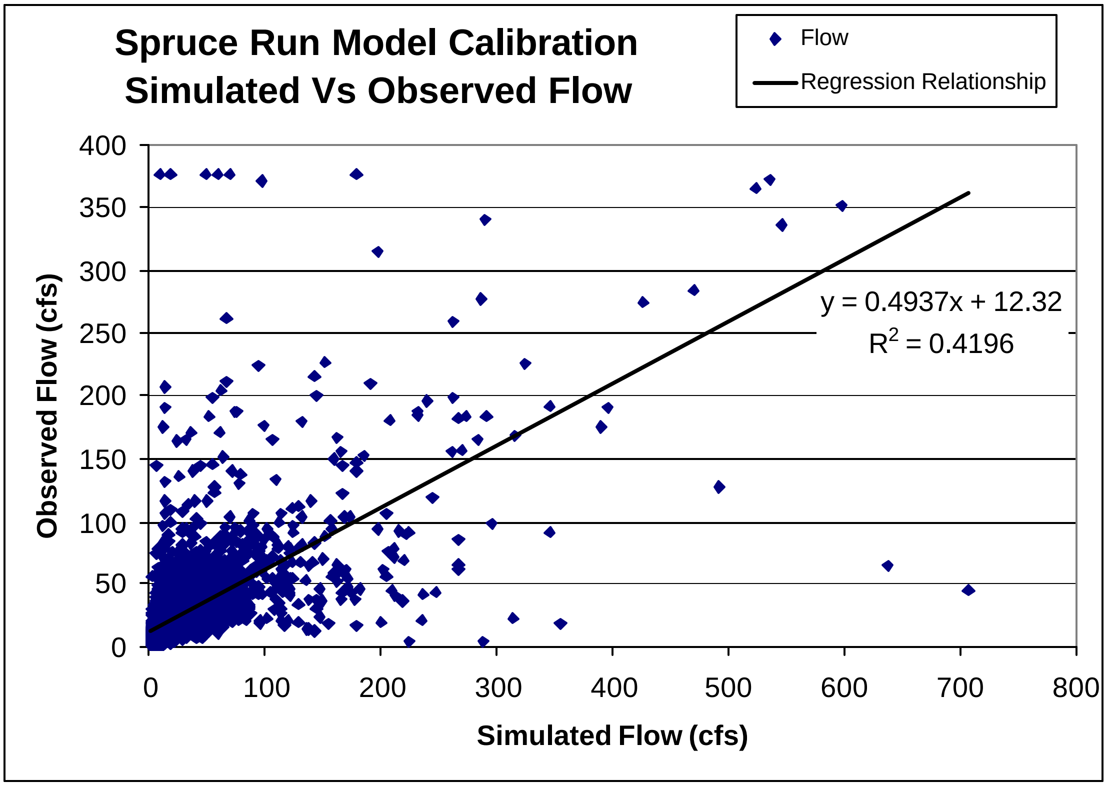
[6] Nash J.E. and Sutcliffe J.V., 1970, "River flow forecasting through conceptual models, a discussion of principles". Journal of Hydrology 10, pp 282-290.

Var_o is the variance of the observed data (e.g. discharge)

Values of the error variance between 0 and 1 indicate acceptable models, where values less than 0 indicate poor models. A score of 1.0 means the model is perfect in simulating flows, with no residual. A score of 0 means that the model is no better than using the mean as an estimator. Scores above zero can represent acceptable models.

For daily flows from the Spruce Run Creek SWMM model, the Nash Sutcliffe Likelihood Measure is 0.41, indicating that the model simulates daily flows with only a moderate degree of accuracy. This is further demonstrated by the plot of simulated daily flows against observed daily flows shown in Figure 3.6. By plotting a linear trend line, a number of characteristics of the simulation can be seen. Since the calculated linear equation does not pass through the origin, the value of the constant (12.32 cfs) indicates the model's tendency to underestimate extreme low flows. Because the slope of the line is less than 1, this indicates the model's tendency to overestimate extreme high flows. On a daily basis, the model is only moderately accurate, and should not be used as a daily flow predictor.

Figure 3.6



3.3.3 Annual Flow Comparison

The model is designed to estimate flow on an annual basis to calculate annual estimates of pollutant loads. Therefore, the measure of model calibration should be decided by its ability to accurately simulate average annual flows. Table 3.8 shows the annual flow expressed as mean total daily flows at the gage (observed) against those simulated by the model. The column labeled residual is the observed annual mean total daily flow minus the simulated annual mean total daily flow.

Table 3.8

	Mean Daily Flow (cfs)		
	Observed	Simulated	Residual
1980	17.2	19.5	-2.3
1981	14.7	17.0	-2.3
1982	17.8	19.3	-1.5
1983	26.7	32.8	-6.0
1984	31.1	33.6	-2.4
1985	17.7	19.3	-1.7
1986	24.1	29.8	-5.7
1987	22.6	23.7	-1.1
1992	19.6	15.5	4.1
1993	22.7	24.8	-2.1
1994	26.9	24.2	2.7
1995	17.1	20.8	-3.7
1996	37.4	35.0	2.4
1997	17.2	16.3	1.0
1998	18.7	17.8	0.9
1999	16.8	19.7	-2.9
Mean	21.8	23.1	-1.3
Stand. Dev.	6.2	6.4	2.9
Variance	38.5	41.4	8.2

The means for the observed and simulated flows are similar, with the simulated about 6 percent larger than the observed. The variance of the residual, however, is much smaller at 8.2 cfs. This yields a very high Nash Sutcliff Likelihood Measure of 0.79. (A "perfect" model with no residual would have a Likelihood Measure of 1.0.)

A plot of the simulated annual mean flow against the observed annual mean flow, shown is Figure 3.7, indicates little bias across the flow range. This is further demonstrated by the regression equation. The equation has a constant value of less than 2 cfs, and its slope, at 0.86 is much closer to the perfect value of 1. The regression line R^2 indicates that the model explains over 80 percent of the variation in annual flow. Figure 3.8, the plot of the residual versus observed flow, also indicates that there is no bias in the model at low or high flows. These results indicate that the model is highly successful in reproducing annual average flows, and is suitable for the modeling objectives of the study.

Figure 3.7

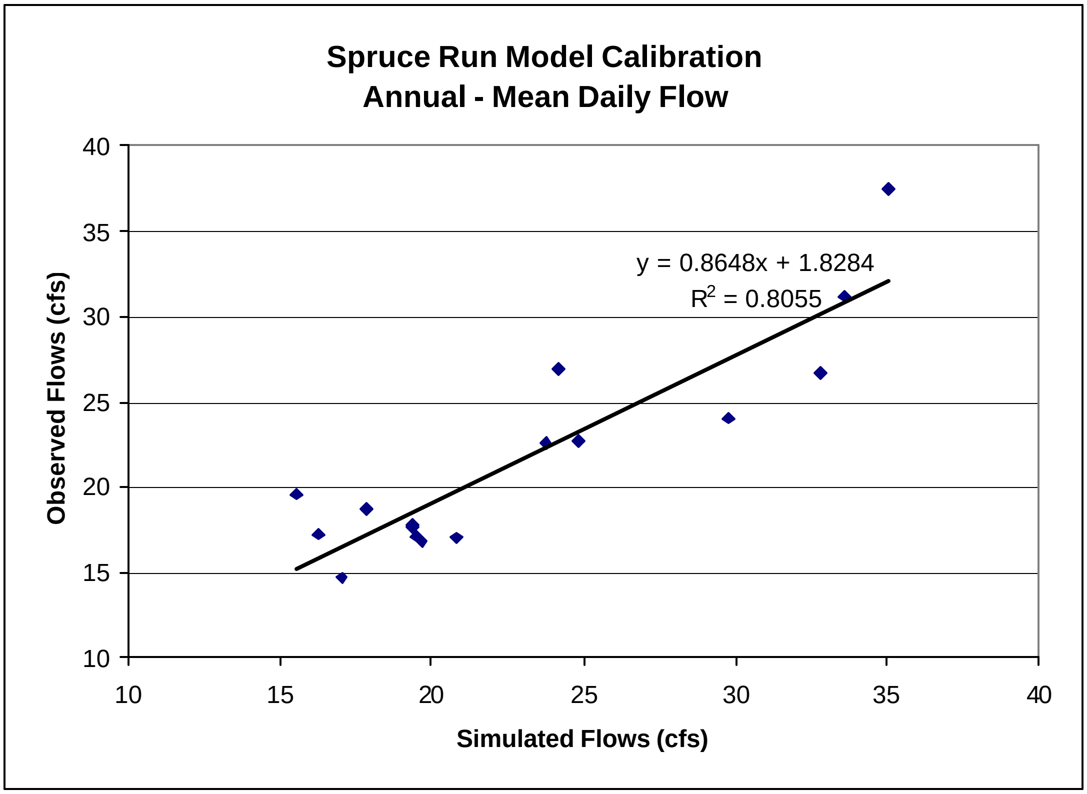
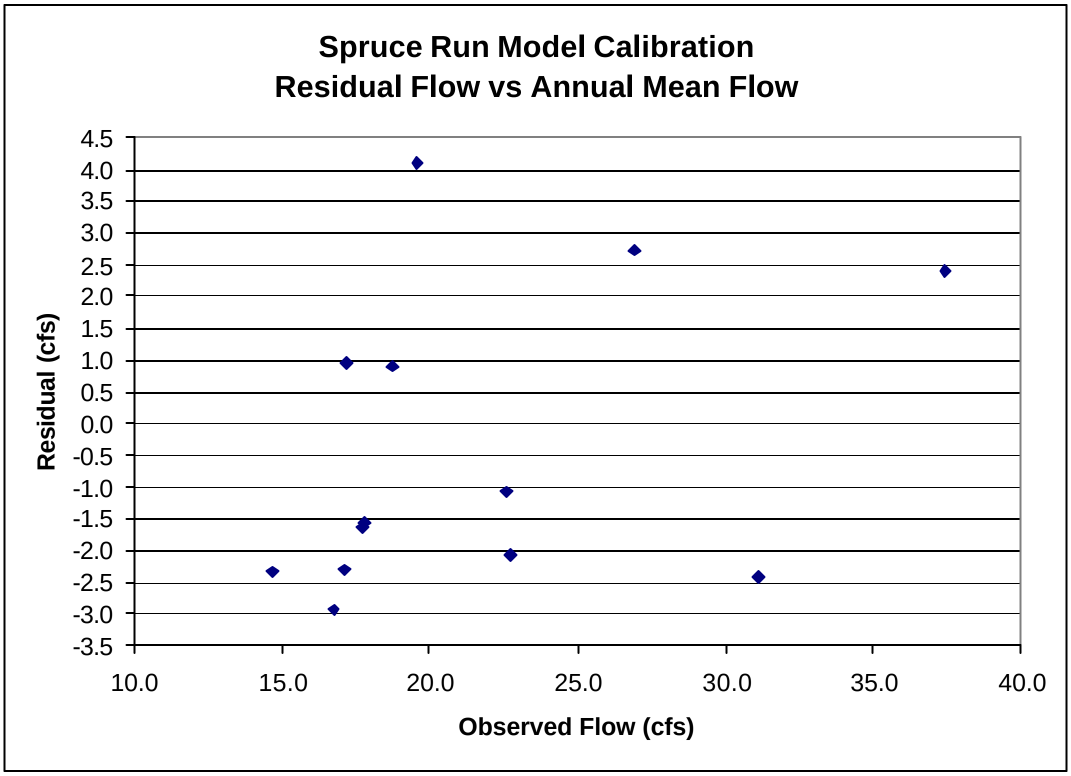


Figure 3.8



3.4 Mulhockaway Creek Model Development

The Mulhockaway Creek and neighboring tributaries model was developed and calibrated using the same procedure as for the Spruce Run Creek model. Discussion of the model parameters can be found in Section 3.2.

Drainage Areas

The Mulhockaway Creek and neighboring tributaries study area was divided into 16 drainage areas. The drainage areas were based upon the NJDEP HUC17 drainage areas as described in Section 3.2. Some of these drainage areas were divided to isolate minor tributaries that discharge directly to the reservoir.

Drainage Area Widths, Lengths, and Slopes

Table 3.9 presents the drainage area lengths, widths and slopes for the subwatersheds of the Mulhockaway Creek study area.

Table 3.9

Subwatershed ID	Drainage Area (acres)	Drainage Length (ft)	Drainage Width (ft)	Drainage Slope (%)
202	237	4,815	2,140	1.9%
203	629	3,346	8,190	1.6%
204	827	9,000	4,000	1.3%
205	1,772	2,894	26,671	2.3%
206	666	3,807	7,624	1.3%
207	1,134	3,587	13,774	1.9%
208	2,594	15,953	7,090	1.5%
209	192	4,336	1,927	0.6%
211	1,112	4,214	11,495	2.8%
212	829	4,460	8,107	2.2%
213	860	2,536	14,779	3.0%
214	430	2,861	6,553	1.2%
215	147	3,797	1,688	2.8%
216	146	3,777	1,678	2.6%
217	666	3,913	7,418	0.5%
218	1,002	3,175	13,747	0.1%

Depression Storage

Depression storage values for pervious and impervious surfaces were estimated to be 0.15 inches and 0.02 inches, respectively. The depression storage values were not altered during calibration. Composite depression storage values for each subwatershed can be found in Table 3.10.

Table 3.10

Subwatershed ID	Composite Depression Storage (in)
202	0.14
203	0.14
204	0.13
205	0.14
206	0.13
207	0.14
208	0.14
209	0.13
211	0.14
212	0.14
213	0.14
214	0.14
215	0.14
216	0.14
217	0.12
218	0.11

3.5 Mulhockaway Creek Model Calibration

The Mulhockaway Creek Model was calibrated using the same method described in Section 3.3 for the Spruce Run model.

3.5.1 Annual Flow Calibration

The calibration target established for the SWMM model of the watersheds of the Mulhockaway Creek and neighboring tributaries was to obtain simulated average annual runoff volumes within 10% of observed data. An effort also was made to achieve the same calibration targets for average annual total flow, baseflow and evapotranspiration estimates. All of these calibration targets were achieved. Table 3.11 presents the results of the calibration.

Table 3.11

	Baseflow	Runoff	Total Flow	Evapotranspiration
	(in)	(in)	(in)	(in)
Simulated	16.3	7.7	24.0	24.2
Observed	15.0	7.8	22.8	25.4
% Error	-8.7%	1.3%	-5.3%	4.7%

3.5.1.1 Observed Stream Flow Data

Observed stream flow data from USGS discharge monitoring station 1396660, “Mulhockaway Creek at Van Syckel, NJ”, was used to perform the model calibration. The drainage area of the monitoring station is approximately 11.8 square miles, about one third of the modeled area (including direct drainage tributaries). Since the gage was not located at the terminus of the model, calibration only could be performed on the portion of the watershed upstream of the monitoring location. To calibrate the areas downstream of the monitoring location, adjustments made during calibration were made uniformly to the entire study area. The discharge data were reviewed and filtered to ensure that only complete years of data were used to perform the calibration. The calibration data set included 22 years of observations, 1978 through 1999.

The “sliding-interval” baseflow separation technique described in Section 3.3 was used to distinguish daily baseflow from runoff in total daily flow measurements.

3.5.1.2 Surface Water Runoff Calibration

The calibration target established for the SWMM model was to achieve simulated annual runoff volumes within 10% of observed annual runoff volumes. This target was achieved over the 22-year calibration dataset through a series of model runs and analysis. Adjustments that were made to the parameters that control or influence stormwater runoff are discussed below.

Saturated Hydraulic Conductivity

The saturated hydraulic conductivity of each modeled drainage unit was determined using the weighted average of the saturated hydraulic conductivity of the soil types throughout the drainage unit area. The initial values of soil hydraulic conductivity were based the values presented in Table 3.3. During calibration, these values were adjusted globally for all of the drainage units. Table 3.12 presents the final calibration vales for HYDCON and other parameters used to simulate infiltration (discussed in Section 3.2) by subwatershed.

Table 3.12

Subwatershed	**SUCT** Avg. Capillary Suction (in)	**HYDCON** Saturated Hydraulic Conductivity (in/hr)	**SMDMAX** Intitial Moisture Deficit for Soil (expressed as a fraction)
202	3.15	0.07	0.223
203	3.34	0.04	0.227
204	3.15	0.04	0.233
205	2.28	0.12	0.283
206	3.35	0.06	0.227
207	1.86	0.19	0.321
208	2.57	0.09	0.257
209	4.21	0.06	0.209
211	2.53	0.13	0.274
212	2.59	0.05	0.243
213	2.50	0.11	0.270
214	3.86	0.10	0.219
215	2.85	0.18	0.280
216	2.97	0.07	0.249
217	3.50	0.02	0.141
218	2.69	0.03	0.124

Impervious Surface Cover

The percent impervious surface cover of each modeled drainage unit was determined using the NJDEP dataset. These values were then reduced by 25% to account for those areas that are not directly connected. During the model calibration, these values were further reduced to 50% of the original values to balance infiltration, runoff and evapotranspiration. Initial and calibrated percent impervious surface cover values are presented in Table 3.13.

Table 3.13

Subwatershed ID	% Impervious Surface Intial	% Impervious Surface Calibrated
202	17.7%	8.8%
203	22.2%	11.1%
204	26.2%	13.1%
205	7.9%	4.0%
206	30.9%	15.4%
207	12.4%	6.2%
208	15.1%	7.5%
209	33.4%	16.7%
211	15.5%	7.7%
212	9.5%	4.8%
213	11.7%	5.8%
214	18.0%	9.0%
215	11.0%	5.5%
216	10.3%	5.1%
217	48.5%	24.3%
218	54.2%	27.1%

3.5.1.3 Baseflow Calibration

To account for baseflow discharge, the GROUNDWATER module of SWMM was utilized. While baseflow calibration was not included in the original target calibration criteria, an effort was made to obtain annual baseflow estimates within 10% of the observed annual baseflow. This target was achieved over the 22-year calibration dataset through a series of model runs and analysis. Adjustments that were made to the parameters that control or influence baseflow are discussed below.

Hydraulic Conductivity

Adjustments to the hydraulic conductivity were made primarily to achieve surface water calibration, but also to provide the necessary volume to the subsurface to simulate each of these processes reflective of observed conditions. The calibrated HYDCON values are presented in Table 3.12.

Additional Subsurface Parameters

To perform the baseflow calibration, the parameters that determine the amount of the total evapotranspiration allotted to the subsurface and the amount of deep percolation were adjusted to achieve annual evapotranspiration and deep percolation estimates consistent with that of observed differences between precipitation and total flow. The available subsurface storage volume and resistance to subsurface flow were also adjusted to achieve discharge volumes and intensities consistent with observed baseflow data.

3.5.2 Total Flow on a Daily Basis

Although the model was not developed to simulate flow on a daily basis, an analysis of its performance on a daily basis provides significant insight into its behavior under varying flow conditions. Using the existing gage data over a 22-year period of record (1978-1999), the daily total flow at the gage was compared to the simulated flow. The results are shown in Table 3.14.

Table 3.14

Daily Flows (cfs)			
	Observed	Simulated	Error
Mean	19.9	20.7	-0.8
Standard Deviation	33.5	31.9	28.3

The model produced a mean flow over the period of record of 20.7 cfs, compared to the flow observed at the gate of 19.9 cfs. On a daily basis, the mean residual (observed daily flow minus simulated daily flow) is close –0.8 cfs, a difference of 4 percent. The standard deviation of the simulated and observed flows vary but are very close, showing that the model did a reasonable job of simulating the variability of flow over the period of record. The standard deviation of the residuals (defined as the daily value of the observed flow minus the simulated flow), however, is large (28.3 cfs). This indicates that the model is only moderately successful on a daily basis of predicting flows. This results mostly from inherent problems encountered developing a realistic distribution of rainfall over the watershed with limited rain gage data.

Visual inspection of plots provides another means of comparing modeled and observed total daily flow at the gage. Figure 3.9 presents the time series for 1982, a representative year. The model is successful at simulating storm events with peak flows and recession curves that are similar in shape to the gage flow estimates on a daily basis.

Figure 3.9

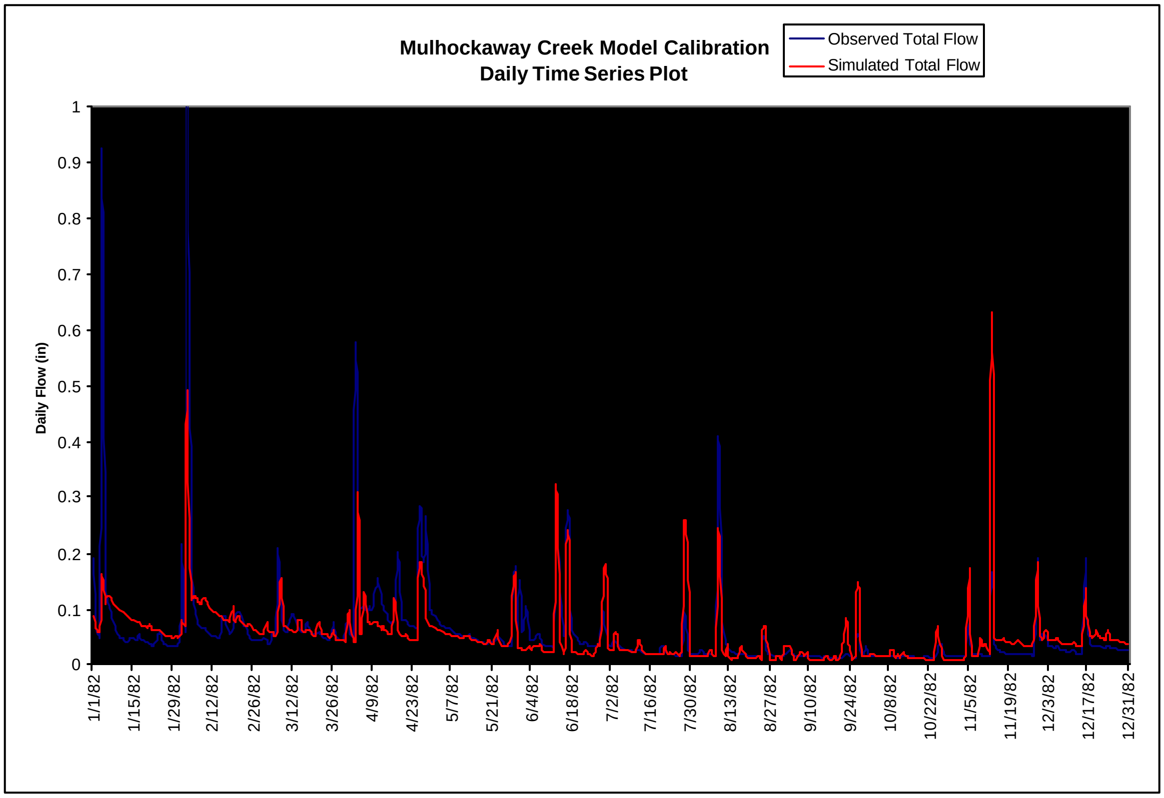
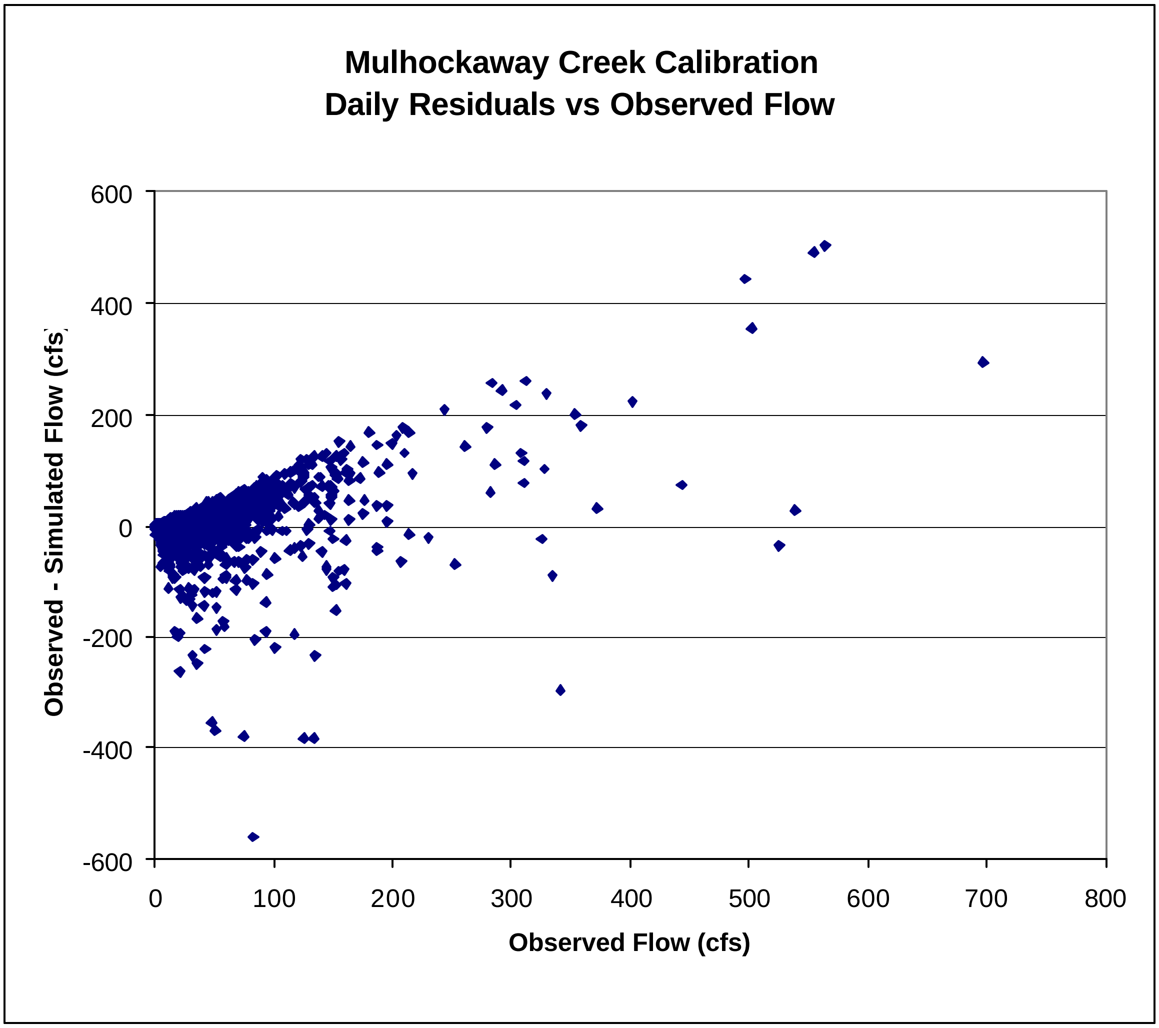


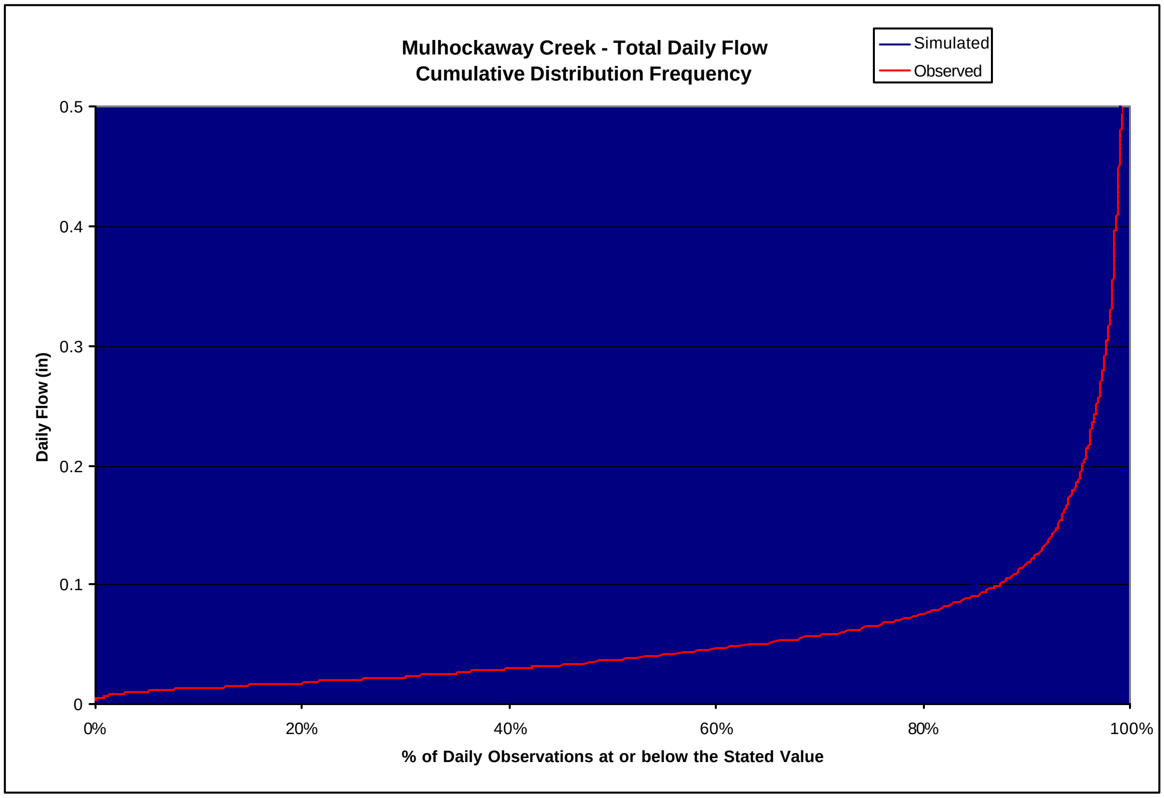
Figure 3.10 plots the model residuals versus flows on a daily basis. The model tends to overestimate low flows (negative residuals), and underestimate higher flows (positive residuals).

Figure 3.10



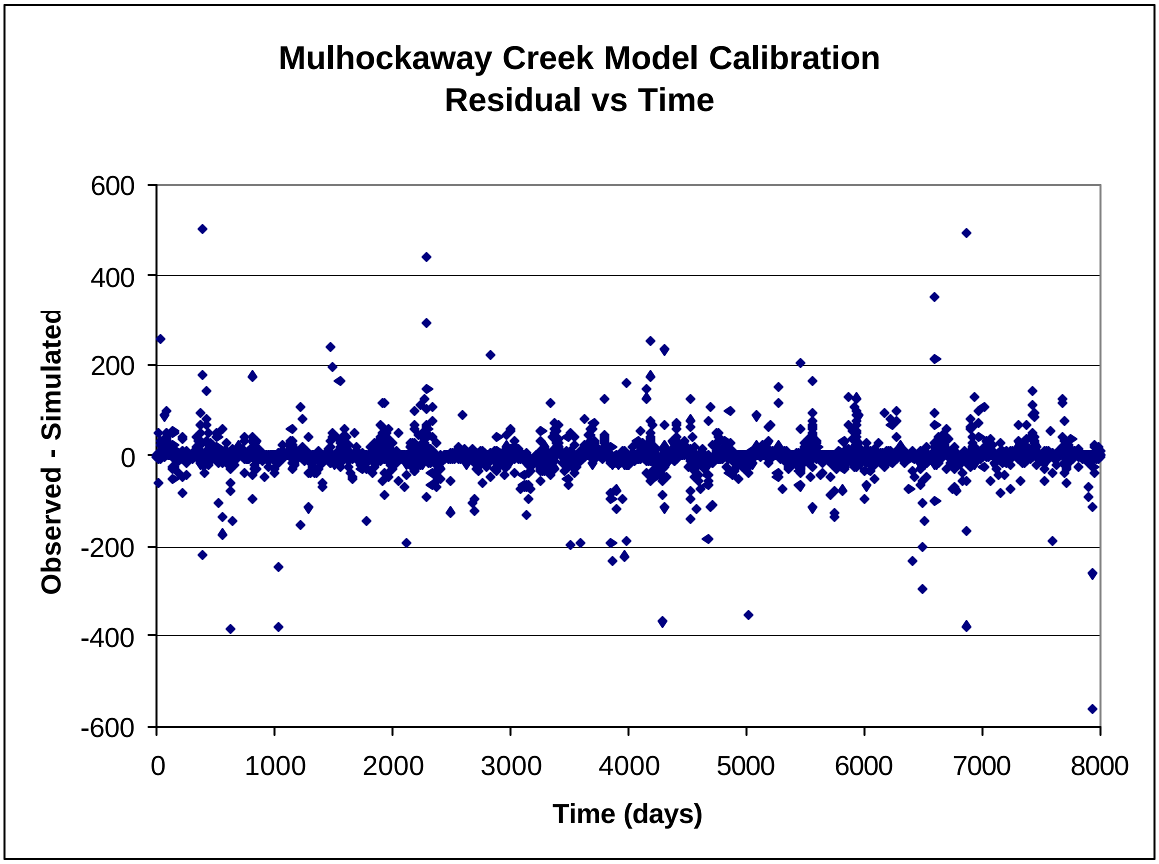
This can be demonstrated more clearly by plotting the cumulative frequency distribution of both observed and simulated flows, as shown in Figure 3.11. The plot shows the percentage of observations that occurred below the indicated flow expressed as inches per year. The model's tendency to underestimate low flows, and overestimate medium to higher flows is evident when cumulative frequency distributions are compared by the deviation of the simulated from the observed curves.

Figure 3.11



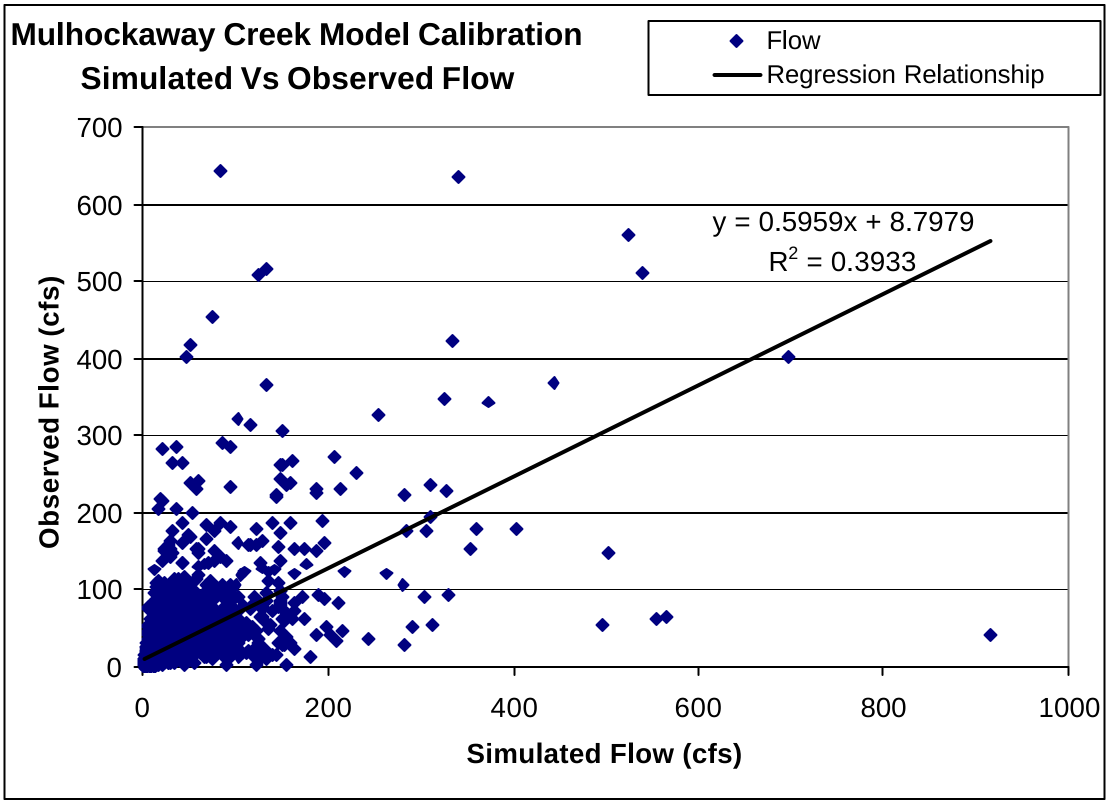
Trends over time can be evaluated by graphing residuals as a time series as shown in Figure 3.12. The plot shows residual scatter throughout the 22-year simulation, indicating the model is simulating with the same accuracy across the entire period of record.

Figure 3.12



For daily flows from the Mulhockaway Creek SWMM model, the Nash Sutcliffe Likelihood Measure is 0.29, indicating that the model only provides an approximation of daily flows. This is further demonstrated by the plot of simulated daily flows against observed daily flows shown in Figure 3.13. By plotting a linear trend line, a number of characteristics of the simulation can be seen. Since the calculated linear equation does not pass through the origin, the value of the constant (8.8 cfs) indicates the model's tendency to underestimate extreme low flows. Because the slope of the line is less than 1 (0.6), this indicates the model's tendency to overestimate extreme high flows. On a daily basis, the model is only moderately accurate, and should not be used as a daily flow predictor.

Figure 3.13



3.5.3 Annual Flow Comparison

The model is designed to estimate flow on an annual basis to calculate annual estimates of pollutant loads. Therefore, the measure of model calibration should be decided by its ability to accurately simulate average annual flows. Table 3.15 shows the annual flow expressed as mean total daily flows at the gage (observed) against those simulated by the model. The column labeled residual is the observed annual mean total daily flow minus the simulated annual mean total daily flow.

Table 3.15

	Mean Daily Flow (cfs)		
	Observed	Simulated	Residual
1978	20.3	17.0	3.2
1979	29.7	30.1	-0.4
1980	14.4	17.5	-3.1
1981	12.4	14.6	-2.1
1982	17.8	17.3	0.6
1983	26.8	29.9	-3.1
1984	30.7	30.7	-0.1
1985	14.8	17.2	-2.3
1986	18.9	27.0	-8.1
1987	20.0	21.3	-1.3
1988	16.5	20.0	-3.6
1989	25.7	28.6	-2.9
1990	21.8	25.7	-4.0
1991	13.6	14.7	-1.1
1992	14.1	12.9	1.2
1993	20.1	22.7	-2.6
1994	22.9	21.7	1.2
1995	15.2	18.8	-3.6
1996	33.0	32.0	0.9
1997	16.2	14.5	1.7
1998	17.1	16.0	1.1
1999	15.9	17.5	-1.5
Mean	19.9	21.3	-1.4
Stand. Dev.	5.9	6.1	2.5
Variance	35.1	37.5	6.4

The means for the observed and the simulated are similar, with the simulated about 7 percent larger than the observed. The variances of the observed and simulated data also are similar. The variance of the residual, however, is much smaller at 6.4 cfs. The model results yield a high Nash Sutcliff Likelihood Measure of 0.82. (A “perfect” model with no residual would have a Likelihood Measure of 1.0.)

A plot of the simulated annual mean flow against the observed annual mean flow, shown in Figure 3.14, indicates little bias across the flow range. The slope is 0.88, close to the perfect model value of 1, and the constant is small. The regression R^2 value suggests that the model explains over 80 percent of the variation in annual flow. Figure 3.15, the plot of the residual verses observed flow, also indicates no bias in model predictions at low or high flows. These results indicate that the model is highly successful in reproducing annual average flows, and is suitable for the modeling objectives of the study.

Figure 3.14

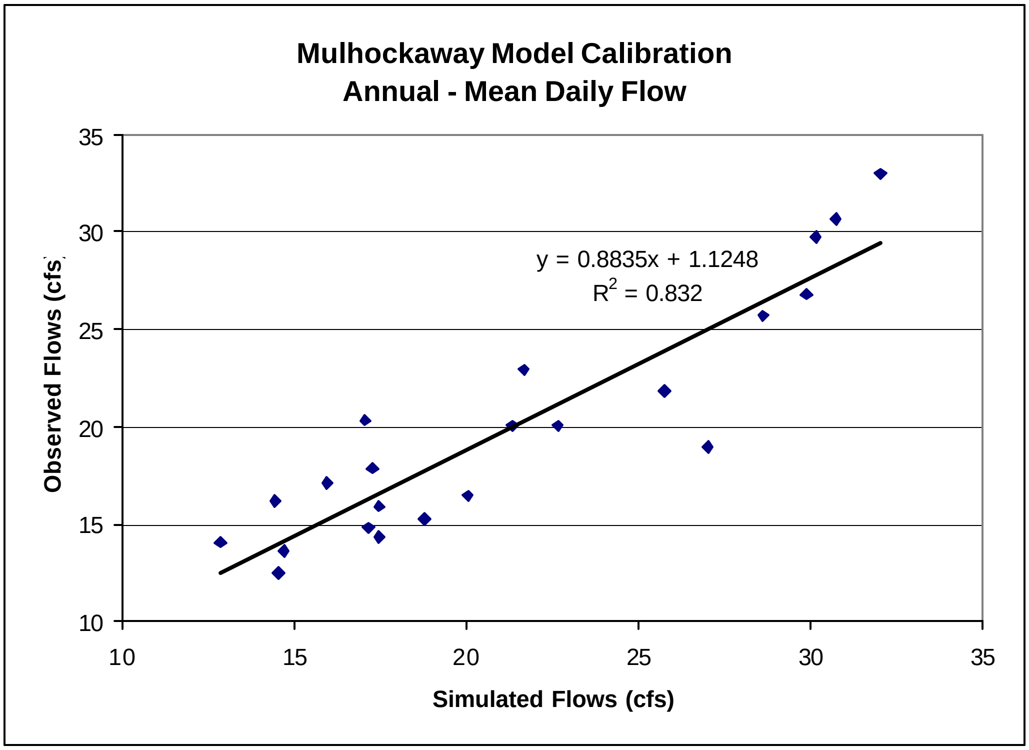
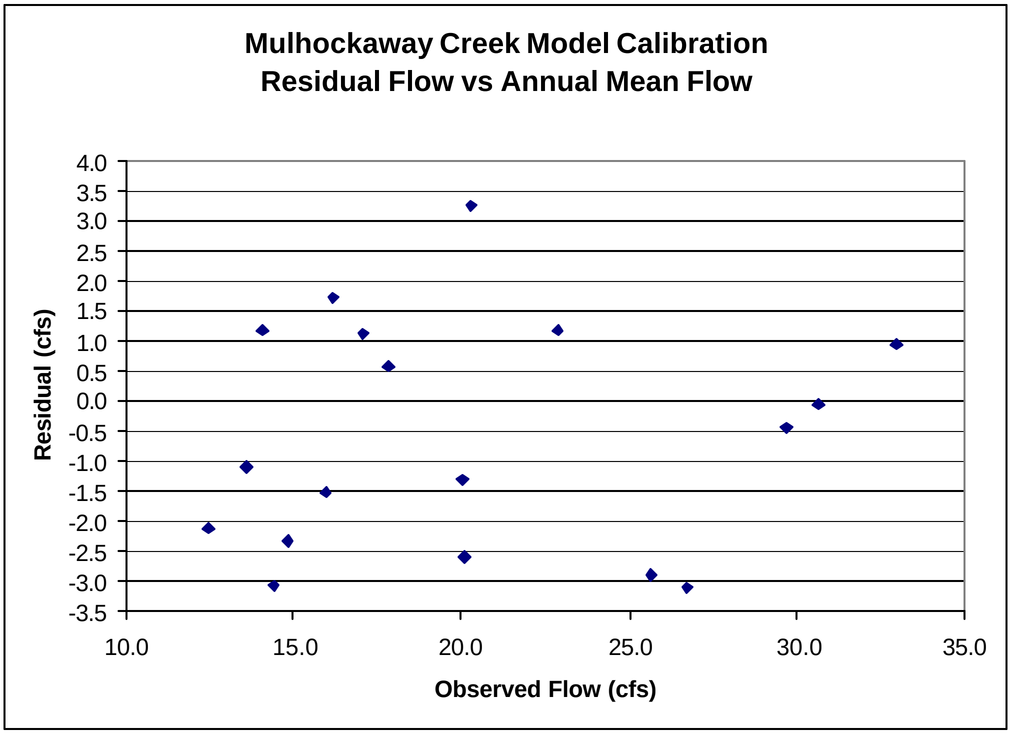


Figure 3.15


Mulhockaway Creek Model Calibration
Residual Flow vs Annual Mean Flow
Residual (cfs)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
10.0
15.0
20.0
25.0
30.0
35.0
Observed Flow (cfs)