The Development of an HSPF Model of the Non-Tidal Anacostia River Watershed Phase II

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The Development of an HSPF Model of the
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Phase II

1. Introduction

The Anacostia River flows through Prince George's and Montgomery Counties in Maryland and the District of Columbia before entering the Potomac River at Hains Point. Figure 1.1 shows the location of the watershed. The total watershed area is 169.9 square miles, approximately 34% of which is in Montgomery County, 51% is in Prince George's County, and 15% is in the District of Columbia. The Northeast and Northwest Branches of the Anacostia are the largest tributaries to the river; Lower Beaverdam Creek is the largest tributary below their confluence. The Anacostia River is tidal from just above the confluence of the Northeast and Northwest Branches to its mouth, a distance of approximately 8.75 miles, most of which is in the District of Columbia. (Bandler and Dalpra, 1988).

The Anacostia watershed is heavily urbanized and the river suffers from many of the problems common to urban streams. The tidal Anacostia River has been placed on DC's 303(d) List for failing to meet water quality standards for dissolved oxygen, sediment, bacteria, nutrients, toxics, and metals. The DC Department of Health (DOH) has already developed Total Maximum Daily Loads (TMDLs) for biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform bacteria, and is in the process of developing TMDLs for toxics and metals (DOH, 2001, 2002, 2003). The Maryland Department of the Environment (MDE) placed the both the tidal and nontidal portions of the Anacostia River on its 303(d) List for nutrients, suspended sediment, BOD, fecal coliform bacteria, and PCBs. The nontidal portion is also listed for a variety of biological impairments and heptachlor epoxide (MDE, 2003).

This report describes the second phase of the development of a Hydrological Simulation Program–Fortran (HSPF) model of the non-tidal Anacostia River. The model represents the fate and transport of dissolved oxygen, nutrients, and sediment in the Northwest Branch, Northeast Branch, and Lower Beaverdam Creek. The Interstate Commission on the Potomac River Basin (ICPRB) developed this model on behalf of MDE primarily to help better estimate nutrient, sediment, and BOD loads in support of the ongoing development of DC's TMDLs in the tidal Anacostia River.

1.1 The Phase I Model of the Non-tidal Anacostia River

The Phase I Model of the non-tidal Anacostia River was completed in August of 2001. The Phase I Model had the following characteristics:

1. The model simulates the fate and transport of nutrients and sediment. Constituents modeled include ammonia, nitrate, organic nitrogen, chlorophyll, dissolved oxygen, temperature, organic phosphorus, inorganic phosphorus, BOD, and total suspended solids.

2. The model simulates the period 1988-1995. The simulation period was chosen to coincide with the simulation period used in modeling the tidal Anacostia River for its BOD TMDL.

3. The Phase I Model is calibrated against the data available during the simulation period from the Coordinated Anacostia Monitoring Program (CAMP). 1990 land use information from the Maryland Office of Planning was used in the simulation.

4. The Northwest Branch watershed was divided into 4 segments, and the Northeast Branch watershed was divided into 6 segments, roughly corresponding to the Maryland 12-digit watersheds. Figure 1.2 shows the segment boundaries.

5. In addition to cropland, forest, and pasture, three types of urban land uses were represented: low-density residential, medium- and high-density residential, and commercial/industrial/institutional. The urban land uses have both pervious and impervious segments.

6. Nutrient cycling using HSPF's AGCHEM module was implemented on pervious forest and agricultural land.

7. The PQUAL and IQUAL modules were used to simulate nutrient export from urban land. The concentration of nutrients in storm water were calibrated against event mean concentrations estimated from data collected by Montgomery and Prince George's Counties for their NPDES storm water permit applications.

The development of the Phase I Model is described in Manchester and Mandel (2001). For more information on the HSPF model, see Bicknell et al. (2000).

1.2 Goals of the Phase II Model

The primary goal of Phase II Model is to update the simulation to current conditions. To fulfill this goal, two tasks had to be performed: (1) update land use to 2000 conditions using land use information provided by Montgomery and Prince George's Counties; and (2) calibrate the model against data collected on the Northeast and Northwest Branches for the DC Water and Sewer Authority's (WASA) Long-term Control Plan (LTCP) for combined sewer overflows (CSOs) (Greeley and Hansen, 2002). This monitoring data was collected 1999-2000 to estimate upstream loads to the tidal Anacostia. It includes composite storm samples on both the Northeast and Northwest Branches. Previous storm samples that were collected in 1989-1991, which were used in the Phase I calibration, were primarily from the Northwest Branch. It was hoped that the Phase II Model could be calibrated against the storm samples to obtain better estimates of loads under the high flow conditions that supply most of the constituent loads to the tidal Anacostia.

The simulation period for Phase II was 1996-2000. There is no water quality monitoring data available for the Northeast and Northwest Branches outside of the data collected for the LTCP in 1999-2000. The simulation model of Lower Beaverdam Creek was calibrated against data collected by Prince George's County for their NPDES stormwater permit at Station 6.

2. Segmentation and Land Use

2.1 Segmentation

The same segmentation used in the Phase I Model was used in Phase II. The Phase I segmentation was chosen so that modeling segments terminated at monitoring stations active during CAMP. The only water quality monitoring data available during the simulation period were the data collected for LTCP at the USGS gages on the Northeast and Northwest Branches, (Gaging Stations 01649500 and 01651000, respectively), and data collected by Prince George's County on Lower Beaverdam Creek at Station 6 at the outlet of Segment 120 as part of their NPDES stormwater permit. There is an additional USGS gage on the Northwest Branch at Colesville (01650500), that was restarted in November 1997. Figure 2.1 shows the segmentation. Table 2.1 shows the names of the major tributaries represented in each modeling segment.

2.2 Land Use

The following eleven land uses were represented in the model:

1. Forest
2. Pasture
3. Cropland
4. Pervious Commercial
5. Impervious Commercial
6. Pervious Industrial
7. Impervious Industrial
8. Pervious Low Density Residential (LDR)
9. Impervious Low Density Residential (LDR)
10. Pervious Medium-to-High Density Residential (HDR)
11. Impervious Medium-to-High Density Residential (HDR)

Phase I had combined commercial and industrial land uses into one category. These were split in Phase II because county NPDES stormwater data was available for both industrial and commercial monitoring sites.

2.2.1. District of Columbia Land Use. A small portion of Segment 40 lies in the District of Columbia. Phase I land use, based on the Metropolitan Washington Council of Governments' (COG) DC Planned Land Use Cover (Warner et al., 1997), was used in the Phase II Model.

2.2.2. Prince George's County Land Use. Prince George's County provided a 2000 Land Use/Land Cover GIS layer created for the county by Towson State University from satellite data. PG County also provided estimates of the percent of each land use that was impervious. Table

2.2 shows how the PG County land uses were correlated with land uses represented in the model and the percent imperviousness associated with each land use. Agricultural land is concentrated on the property of the USDA's Beltsville Agricultural Research Center (BARC), located mostly in the Beaverdam and Indian Creek watersheds, Segments 80 and 90.

2.2.3. Montgomery County Land Use. Montgomery County provided a detailed set of GIS coverages to represent land use and land cover in their portion of the Anacostia watershed. Land use was a GIS coverage representing properties and their zoning classification. Table 2.3 shows how Montgomery County zoning categories were classified as modeling land uses. Land cover was determined through a set of photogrammatic layers which represented building footprints, parking lots, tree cover, and pasture; and a line coverage representing sidewalks. Table 2.4 shows the total impervious land by category in Montgomery County's portion of each subwatershed.

Model land uses were determined using the following process:

1. Sidewalk area was calculated from the sidewalk line coverage, assuming sidewalks had a width of four feet (L Darr, personal communication);

2. Sidewalk, building and parking lot impervious area was classified as low-density residential (LDR), medium-to-high density residential (HDR), commercial, or industrial using the property layer;

3. Forests and pasture, as determined by the photogrammatic layer, were subtracted from the zoning property layer;

4. Pervious urban land uses were determined by subtracting forest, pasture, and impervious areas from the zoned property layer; and

5. Area in roads was determined by subtracting properties from total watershed area. The result was checked against a road center-line coverage. The area of a watershed in roads was apportioned among the impervious land uses in proportion to the total area of each land use in the subwatershed. The area in roads was then added to the impervious area for each land use.

The only pastured area in the Anacostia watershed is Woodlawn Park, which is the location of the Montgomery County mounted police barracks, as well as a park open to the public. The park was reclassified as pervious commercial land. A windshield survey observed a large number of horses in the upper Northwest Branch watershed, northeast of Norwood Road. They appeared for the most part to be recreational horses on residential properties. These properties were classified in the model as LDR, and the impact of the horses on water quality was not explicitly accounted for in the model.

2.2.4. Land Use Summary. Table 2.5 shows the area in each subwatershed by model and use category. As explained below, a 20% reduction in impervious area was later made in the model to take into account the effective impervious area.

Figures 2.2 and 2.3 compare Phase I and Phase II land uses for the Northwest and Northeast Branch, respectively. Industrial land has been classified together with commercial land. Some of differences between the Phase I and Phase II land uses may represent real land use changes over the 1990's. There has been, for example, increased development and a decrease in agriculture in the upper Northwest Branch.

Some changes, however, are probably more of an artifact of the change in methodology. The differences in classifying HDR and LDR is nominal. Forests account for 6% more of both the Northeast and Northwest watersheds in Phase II. That difference is probably due to a difference in methodology rather than reforestation. Overall, there is a 13% increase in urban pervious land in the Northeast Branch, and 15% in urban pervious land in the Northwest Branch between the Phase I and Phase II simulations. Impervious land increases by a much smaller amount, 2% and 5%, respectively, for the Northeast and Northwest Branches. Some land use conversion from agricultural to urban land uses occurred over the decade, but it is not possible to say how much conversion took place.

3. Hydrology Calibration

The simulation of hydrology was calibrated against daily flows observed at the USGS gages on the Northeast and Northwest Branches, at stations 01649500 and 01651000, respectively. The USGS gage on the Northwest Branch at Colesville (0160500) was not used in calibration, because the period of record at that station was dominated by the low flows that occurred after the spring, 1998. Overall, the simulation period was characterized by extreme flows. 1996 was a wet year in which a January snowmelt caused flooding. 1997 was the wettest December on record for both the Northeast and Northwest Branches. 1998 and 1999 were dry years overall; 1999 was the driest July on record for the Northeast Branch. The drought of 1999 ended with Hurricane Floyd in September. Overall, however, the calibrated model was able to match the variability in observed flows.

3.1 Meteorological Data

Meteorological data was derived primarily from Reagan National Airport (448906). Hourly air temperature, wind speed, and dewpoint temperature were taken from this station. Hourly precipitation was also taken Reagan National Airport, as is explained below. Solar radiation, cloud cover, and potential evaporation were not available from this station and had to be derived from other sources.

3.1.1. Precipitation. The Phase I model used daily precipitation from ten NOAA cooperative weather stations in and around the Anacostia watershed. The precipitation records from the ten stations were combined by weighing the area in each segment of a Theissen polygon containing the station. The most heavily-weighted station, College Park (181955), ceased to operate during the simulation period. Three stations were used only to fill in missing data; a fourth, Glenndale (183675) contributed less than 10% to any subwatershed. The precipitation records of the remaining stations, with the exception of Rockville (187705), were highly correlated with Reagan Airport. Table 3.1 shows the correlation matrix for daily precipitation among the stations.

To determine whether the differences in the precipitation record between stations was significant for the calibration, the Northwest Branch was calibrated using both (1) precipitation data from Rockville and Reagan Airport and (2) data only from Reagan Airport. The latter calibration proved mores successful, so hourly precipitation data from Reagan Airport was applied to all modeling segments.

3.1.2. Solar Radiation and Potential Evaporation. The Phase I Model used potential evaporation calculated for the Potomac region in Chesapeake Bay Program's Phase 4.3 Watershed Model (Wang et al., 1997). The utility program METCMP was used to calculate potential evaporation using the Penman Pan Evaporation method. Meteorological data collected at Dulles Airport in Sterling, VA, was used in the calculation. The first step in using the Penman method is to calculate net solar radiation from extraterrestrial solar radiation, which is a function of latitude, calendar day, and cloud cover.

Cloud cover is not reported at Reagan National Airport and ceased to be reported at Dulles Airport during the simulation period. Direct measurements of global radiation, which takes in to account cloud cover, are made at NOAA's Integrated Surface Irradiance Study (ISIS) station at Sterling, VA. A PET time series for the period 1996-2000 was then calculated in WDMUTIL, the successor program to METCMP, using the Penman Pan Evaporation method. Wind speed, dewpoint temperature, and air temperature from Reagan National Airport were used in the calculation.

The output synthetic pan evaporation time series was compared to observed pan evaporation recorded at Beltsville on weekdays between April and October. Total observed pan evaporation for each month was compared to total synthetic evaporation for each month, using synthetic data only on the days where observations were made at Beltsville. The synthetic pan evaporation time series was then multiplied by a monthly coefficient so that average monthly synthetic pan evaporation agreed with observed monthly totals. Table 3.2 shows the monthly coefficients. An average coefficient value of 0.67 was used for winter months during which no observations were made in Beltsville. Figure 3.1 shows average monthly synthetic pan evaporation used as input to the HSPF model.

3.2 Results of the Hydrology Calibration

The hydrology simulation was calibrated against observed flows at the USGS gages on the Northeast Branch (01649500) and Northwest Branch (01651000). The parameter optimization software PEST (Doherty, 2001) was used to help calibrate the model.

3.2.1.Parameterization. Preliminary calibration attempts indicated that the hydrology parameters for the Northeast and Northwest Branches should be different. This difference was traced to the soils found in the watersheds. The Montgomery County-Prince George's County border approximates the division between the Piedmont and the Coastal Plain Physiographic Provinces. Soils in the Piedmont portion of the Anacostia watershed belong to the Glenelg-Gaila-Occoquan Association or the Wheaton-Glenelg Association which are typically well-drained (NRCS, 1995). Soils in the Atlantic Coastal Plain, however, belong to either the Beltsville-Leonardstown-Chillum Association or the Christiana-Sunnyside-Beltsville Association. Soils in both these associations can have compact subsoils that inhibit drainage (SCS, 1967). A consistent set of parameters was therefore used for modeling Segments 10-60 in the Piedmont and Segments 70-140 in the Coastal Plain. Table 3.3 shows the key hydrology parameters used in the final calibration.

3.2.2. Effective Impervious Area. Not all impervious area is connected directly to storm sewers or drains directly to surface water. Runoff from some impervious areas are redirected onto pervious surfaces where infiltration can take place. Roof runoff, for example, can be diverted to run onto lawns. Runoff from other impervious surfaces pass through storm water controls like detention ponds. Effective impervious area is the impervious area that behaves as if it were directly connected to surface water.

Originally, it was hoped that the percentage of effective impervious area could be determined by calibration. The model was calibrated with 70%. 80%, 90%, and 100% of the estimated impervious area simulated as impervious surface. The remainder was simulated as if it were pervious. At each level of effective impervious area, approximately the same level of agreement between simulated and observed flows, as measured by the coefficient of determination, was attained. Somewhat arbitrarily, the effective impervious area was set at 80% of the original impervious area determined by the GIS analysis of land use in the Anacostia watershed.

3.2.3. F-Tables. F-tables were taken from the Phase I calibration without any changes. See Manchester and Mandel (2001) for details.

3.2.4. Calibration Measures. Three types of measures were used in evaluating the hydrology calibration:

1. The coefficient of determination (R^2) between daily, monthly, and seasonal observed and simulated values;
2. Comparison of observed and simulated flow volumes; and
3. Cumulative distribution plots of observed and simulated daily flows.

The coefficient of determination (R^2) measures the fraction of variability seen in the observed data that can be explained by the simulation. The coefficient of determination was calculated on a daily, monthly, and seasonal basis. Table 3.4 shows the results. The coefficients of determination between observed and simulated daily flows on both the Northeast and Northwest Branches were 0.80 and 0.81, respectively. R^2 was 0.88 between simulated and observed monthly flows for the Northwest Branch and 0.90 for the Northeast Branch. Figures 3.2 through 3.4 show the relation between simulated and observed daily, monthly, and seasonal flows for the Northeast Branch. Figures 3.5 through 3.7 show the same comparisons for the Northwest Branch.

Table 3.5 shows the simulated total flow and seasonal flow on the Northeast and Northwest Branches as a percentage of the corresponding observed flows. Total simulated flow is within 2% of observed flow for both branches. Simulated seasonal flow volumes are within 10% of the observed volumes; except for summer flow on the Northwest Branch, they are within 4% of observed volumes. Table 3.5 also compares the simulated flow volume of the highest 10% of the flows and the flow volume of the lowest 50% of flows with their observed counterparts. High flow volumes are generally in agreement. Simulated low flow volumes are somewhat higher than the observed flows, which is perhaps not surprising considering that the simulation period encompassed some unusually low flows.

Paired cumulative distribution plots of observed and simulated daily flows show how well simulated flows imitate the distribution of observed flows. Figures 3.8 and 3.9 show the paired cumulative distribution plots for the Northeast and Northwest Branches, respectively. There is generally good agreement between the distribution of observed and simulated flows at both the low and high ends.

Figures 3.10 and 3.11 show time series plot of observed and simulated flows on the Northeast and Northwest Branches, respectively, during the period in which water quality data was collected for WASA's LTCP.

3.2.5. Verification at Gaging Station 01650500 on the Northwest Branch.
As explained above, the hydrology simulation of the Northwest Branch was not calibrated against daily flows at the USGS gaging station 01650500 at the outlet of Segment 10. The gage was restarted only in November 1997, and therefore most of the daily flows available from that gage during the simulation period were extremely low. Simulated daily average flows were compared to the daily average flow at the gage, however, as a verification of the Northwest Branch hydrology calibration. The results are shown in Table 3.6. The overall correlation between observed and simulated flows, as measured by the coefficient of determination, is approximately the same as the calibration. High flows are undersimulated compared to the calibration. There is good agreement between simulated and observed volumes except for summer flows and low flows (flows less than the median flow). The volume difference is somewhat exaggerated, since base flows are very low during the simulation period. Five percent of the observed daily flow was less than 1 cfs during the time period of the simulation. Nevertheless, it is fair to say that the model does less well simulating low flow conditions.

3.2.6. Hydrology Simulation for Lower Beaverdam Creek. The hydrology parameters calibrated for coastal plain segments were used to represent segments in Lower Beaverdam Creek.

There is no USGS gage on Lower Beaverdam Creek. Prince George's County made instantaneous flow measurements while collecting storm flow data at Station 6. Figure 3.12 compares the minimum and maximum simulated flow with the observed instantaneous flow. For the most part, observed flows are within the range enveloped by the minimum and maximum simulated flows, which demonstrates that the hydrology simulation of Lower Beaverdam Creek is compatible with the observed data.

4. Simulation of Pervious and Impervious Land

In the Phase II Model, as in the Phase I Model, the fate and transport of nutrients on urban land uses was simulated using the PQUAL module. PQUAL simulates the fate and transport of a constituent using a simple buildup-washoff model. Constituents are added to surface storage at a user-determined rate. Constituents can decay in storage, but the primary mechanism for their removal is runoff. The user supplies the rate at which constituents are removed from storage by runoff. Constituent loads in interflow and groundwater discharge determined by setting the concentration of the constituents in these flow components. For more details on the PQUAL modules, see Bicknell et al. (2000).

On agricultural land, nutrients were simulated using the AGCHEM module, which maintains a mass balance while simulating the fate and transport of nitrogen and phosphorus. AGCHEM simulates plant uptake, sorption dynamics, and mineralization, among other processes. On forest land, nitrogen is simulated using AGCHEM, but phosphorus is simulated using PQUAL.

4.1 Simulation of Urban Land Uses

Constituent loads in runoff from urban land uses were calibrated so that the flow-weighted average of constituent concentrations agreed with the average concentrations observed by Montgomery and Prince George's County in the stormwater monitoring performed for their MS4 permits. To calculate the target concentrations, first a site average was calculated for each of the stormwater monitoring sites. Then the average was taken of sites by land use. Table 4.1 shows the average concentration observed at each site and the target concentration obtained for each land use.

An analysis of sediment concentrations during storm events showed that sediment concentrations could be represented as a linear function of the rate of flow. Figures 4.1 and 4.2 show the flow-weighted sediment concentrations as a function of average storm flow for the Northeast and Northwest Branches, respectively. For this reason, sediment transport on urban land uses was modeled as an unlimited reservoir with removal rates as a linear function of flow. Removal rates were calibrated against the target concentrations determined from the monitoring data collected by Prince George's and Montgomery Counties for their NPDES stormwater permits. Table 4.1

shows the observed TSS concentrations. It should be noted that the target TSS concentrations are approximately twice as high as the average TSS concentrations observed in MS4 samples collected throughout the rest Maryland (Bahr, 1997).

Interflow and groundwater concentrations for all constituents were determined by calibration against in-stream observations.

4.2 Simulation of Forests

As in the Phase I Model, the simulation of nitrogen dynamics in forests was based upon the CBP Phase 4.3 Watershed Model. Nitrogen export from forests is determined by atmospheric deposition. The CBP developed a time series of atmospheric deposition loads applied to forests for their simulation period, 1985-1997 (Wang et al., 1997). A time series of atmospheric deposition loads for the simulation period 1996-2000 was developed by substituting for the years 1998, 1999, and 2000 the years with highest correlation of monthly precipitation from 1990-1997. Table 4.2 shows the correlation matrix between years 1990-1997 and the years 1998, 1999, and 2000.

4.3 Simulation of Agricultural Land

All of the agricultural land simulated in the watershed is located on the ARS's Beltsville Agricultural Research Center (BARC). ARS personnel provided information on livestock and crop management (D. Shirley, personal communication; K. Hummel, personal communication). Three land uses were simulated: pasture, conservation till cropland, and hay. These land uses were parameterized according to their counterparts in CBP Phase 4.3 Watershed Model Segment 540 in which the Anacostia Watershed is located. The timing and rate of application of nutrient loads were determined according to the information supplied by ARS personnel.

4.3.1. Pasture. A wide variety of animals is pastured on BARC land. Waste from confined dairy cattle is treated. Some of the treated manure is applied to crops; the remainder is ultimately disposed of through the treatment plant associated with NPDES permit MD0020851. The waste from other confined animals is collected and composted. The compost is also applied to crops and hay. Table 4.3 gives the livestock numbers, time spent in pasture, average weight, and percent of manure removed from pasture for compost or treatment. Table 4.4. shows the total nitrogen and phosphorus loads produced by animal type, per animal unit (thousand pound weight). Using this information, the average monthly loading rate on pasture was calculated. Nitrogen is applied to pasture at 0.328 lbs/ac/d (0.349 lbs/ac/d in the summer months when heifers are in pasture); Phosphorus was applied at a rate of 0.117 lbs/ac/d (0.120 lbs/ac/d in summer). Nitrogen and phosphorus were partitioned among species according at the ratios used in the Phase 4.3 Watershed Model.

4.3.2. Cropland. Table 4.5 shows the approximate number of acres of each crop grown at BARC. Soybeans and some grains are double-cropped. The Phase 4.3 Watershed Model represents a "composite crop" of corn, soybeans, and small grains. Nutrient loading rates were modified to represent the average rate applied to 500 acres of corn, 250 acres of soybeans, and

250 acres of small grains. Table 4.6 shows the rate and timing of nutrient applications applied to the crops.

4.3.3. Hay. Table 4.5 also shows the number of acres of alfalfa, sudan grass, and orchard grass currently grown at BARC. Only alfalfa was simulated in the model. Table 4.6 shows the rate and timing of nutrient applications to alfalfa.

4.4. Simulation of Urban BMPs

Montgomery County provided a GIS layer with the location and classification of installed urban best management practices. Using this layer, the number of acres of each modeled land use type under each type of BMP was estimated. Table 4.7 shows the results. Table 4.8 shows the estimated BMP reduction efficiency for the major types of BMPs. The reduction in load for each land use type was calculated using the information in Table 4.7 and 4.8. Since most of the urban load comes from impervious land, BMPs were applied to impervious land only. Table 4.9 shows the net reduction in load by constituent, segment, and land use type used in the model.

4.5. Simulation of Point Source Loads. Warner et al.(1996) identify 22 facilities holding active NPDES permits in the non-tidal Anacostia watershed. Almost all of these have flows less than 0.01 MGD, and many discharge only intermittently. Two significant point sources were represented: USDA-BARC WEST (MD0020851), which discharges into Little Paint Branch (Segment 70), and USDA-BARC EAST (MD0020842), which discharges into Beaverdam Creek (Segment 80).The average flow from the BARC EAST facility is 0.202 MGD; It discharges 4.19, 18.34, and 4.67 lbs/day of BOD, TN, and TP. The average flow from the BARC WEST facility is 0.126 MGD; It discharges 1.88, 6.55, and 1.63 lbs/day of BOD, TN, and TP.

5. Calibration of Instream Processes

One of the primary objectives of the development of the Phase II Model was to calibrate the model against the monitoring data collected at the USGS gages on the Northeast and Northwest Branches for WASA's LTCP. This proved difficult to do.

5.1 LTCP Monitoring Data

Table 5.1 and 5.2 show base flow concentrations observed at the Northeast and Northwest Branches for key constituents. The monitoring period ran from August, 1999 through March, 2000. Twenty-one base flow observations of constituents were made on the Northeast Branch; Twenty on the Northwest Branch. Table 5.3 shows the storm composite concentrations observed during the monitoring period. Table 5.4 shows the corresponding loads. Fourteen storm composites were taken on the Northeast Branch and thirteen on the Norwest Branch. Two snowmelt events were also monitored.

The weather was unusually dry during the summer of 2000 until September, when several storms occurred, the largest being Hurricane Floyd on September 15-17. In October, the dry weather pattern resumed. The storm data set is characterized by a dozen small storms and one storm more than an order of magnitude larger than the rest. While the value of the storm data set should not be underestimated, it may not be representative of storm events under a wider variety of conditions.

5.2 Calibration Strategy

Many attempts were made to correlate storm sediment loads with simulated hydrological variables such as runoff rates and shear stress, but no significant relation was found. There was one significant problem with the hydrology calibration that the sediment and nutrient calibration inherited. While the largest loads are associated with Hurricane Floyd, the largest concentrations are associated with a smaller storm starting on September 9, a week before Hurricane Floyd. This storm is poorly simulated in the hydrology calibration. Part, but not all of the problem, lies in the fact that the precipitation recorded at Reagan National Airport is lower than any of the neighboring gages in and around the basin--one of a handful of examples where using the precipitation time series from National Airport alone led to a poorer calibration. The precipitation records at the other gages, however, explain neither the flows associated with the event nor the observed concentrations. This problem is particularly acute on the Northeast Branch.

The failure to find a significant correlation between simulated hydrological variables and stormflow loads and concentrations led to a simple calibration strategy. Instream parameters determining storm flow loads--erosion rates, sediment concentrations of phosphorus and organic nitrogen--were determined by matching the simulated average storm load to the observed storm load, or, what amounts to the same thing, matching the simulated load over the observed storms with the observed storm load. Some adjustments were made to prevent Hurricane Floyd, or the failure to simulate the September 9 storm, from dominating the calibration.

More specifically, simulated sediment loads were calibrated, first, by examining the simulated shear stress over the observed storm dates and choosing the appropriate thresholds for deposition and erosion. The erosion rate was then uniformly adjusted until the total simulated sediment load over the observed storm dates matched the total observed load. Simulated phosphorus loads were calibrated against the total observed storm load by adjusting the phosphorus concentration in observed sediment. Simulated organic nitrogen loads were calibrated by associating an organic nitrogen concentration with the simulated eroded phosphorus. As will be explained below, no significant adjustments were made in the BOD loads or in nitrate or ammonia loads.

Simulated concentrations in groundwater discharge from pervious urban land segments were adjusted until the simulated average baseflow concentration on the observation dates matched the average observed baseflow concentrations. Seasonal adjustments were made to nitrate concentrations.

Other details of the calibration are discussed below.

5.3 Nutrient and Sediment Calibration of the Northeast Branch

Simulated flow failed to adequately represent the September 9 storm. Simulated flow for that event is only 10% of observed flow. Stormflow loads were calibrated so that the total simulated load for the monitoring period lay between the total observed load including and excluding the September 9 storm.

5.3.1. Water Temperature. Figure 5.1 shows observed and simulated temperature for the Northeast Branch during the period when data was collected. The simulation tends to underestimate water temperature during October. Overall, the agreement between observed and simulated values is very good; the coefficient of determination is 0.94.

5.3.2. Dissolved Oxygen. Figure 5.2 shows observed and simulated dissolved oxygen concentrations for the Northeast Branch during the period when data was collected. The overall agreement between observed and simulated values is good; the coefficient of determination is 0.80. The model may tend to overpredict DO in the winter months.

5.3.3. Sediment. Figure 5.3 shows a time series of observed and simulated sediment concentrations. As will be done throughout the rest of the report, the observed flow-weighted average concentration for each storm is used to represent each day of the storm, so the storm concentrations are not strictly comparable to the daily average concentration represented in the simulation. Figure 5.4 shows a scatter plot of observed and simulated sediment loads for the Northeast Branch. The model does a good job of estimating the sediment load associated with Hurricane Floyd, but does not capture much of the variability associated with the sediment loads of other storms. Table 5.5 shows the coefficient of determination for observed and simulated sediments for three sets of data; (1) all data, (2) all data excluding the September 9 storm, and (3) all data excluding both the September 9 storm and Hurricane Floyd. As is generally the case, the agreement between observed and simulated loads for Hurricane Floyd is responsible for the misleadingly large R^2 value. Although two or three storms are oversimulated, the sediment loads for a large number of storms are close to agreement with observed values.

5.3.4. BOD. Figure 5.5 shows a time series of observed and simulated BOD concentrations. Figure 5.6 shows a scatter plot of observed and simulated BOD loads for the Northeast Branch. Observed baseflow concentrations were consistently below the detection limit of 2 mg/l. Only six storm events were monitored. The model overpredicts stormflow BOD loads by 200%. Only modest parameter adjustments were made to reduce simulated storm flows. There is no realistic decay rate or settlement rate at could reconcile the edge-of-stream loads, based on the target BOD stormwater concentrations and observed loads. Either the target stormwater concentrations are too high or the six observed storms are not representative of BOD loads in the Northeast Branch. Since observed stormwater BOD concentrations in Montgomery and Prince George's County are not incompatible with those observed throughout Maryland or elsewhere in the U.S. (Bahr, 1997), it is likely that the observed storm loads are not representative of average conditions on the Northeast Branch.

5.3.5. Total Phosphorus. Figure 5.7 shows a time series of observed and simulated total phosphorus concentrations. Figure 5.8 shows a scatter plot of observed and simulated TP loads for the Northeast Branch. There is good agreement between observed and simulated phosphorus concentrations both under baseflow and stormflow conditions. The model underpredicts the total phosphorus load associated with Hurricane Floyd and tends to overpredict loads for other storms. The late summer storms in particular are oversimulated; otherwise there is reasonable agreement between observed and simulated storm loads. As shown by Table 5.5, the model does capture some of the variability associated with observed storm flows.

5.3.6 Nitrate. Figure 5.9 shows a time series of observed and simulated nitrate concentrations. Figure 5.10 shows a scatter plot of observed and simulated nitrate loads for the Northeast Branch. As was the case with total phosphorus, the model oversimulates late summer storms and undersimulates the nitrate load associated with Hurricane Floyd. The simulations capture the general trend in seasonal baseflow nitrate concentrations.

5.3.7 Ammonia. Figure 5.11 shows a time series of observed and simulated ammonia concentrations. Figure 5.12 shows a scatter plot of observed and simulated ammonia loads for the Northeast Branch. The model captures the general trend of ammonia baseflow concentrations. Much of the ammonia stormflow load is derived from the breakdown of organic material associated with BOD. The model captures little of the variability associated with ammonia stormflow loads, as shown in Table 5.5.

5.3.8. Organic Nitrogen. Figure 5.13 shows a time series of observed and simulated organic nitrogen concentrations. Figure 5.14 shows a scatter plot of observed and simulated organic nitrogen loads for the Northeast Branch. Organic nitrogen observed during baseflow is almost always below 0.5 mg/l.; the model simulates this tendency observed in the data. The model captures the stormflow load observed in Hurricane Floyd, but overpredicts the other late summer storms, with the exception of the September 9 storm.

5.3.9. Chlorophyll a. Figure 5.15 shows a time series of observed and simulated chlorophyll a concentrations for the Northeast Branch during the period in which data was collected. Much of that time period was late fall or winter, when chlorophyll a concentrations were below the detection limit of 1 ug/l.

5.4 Nutrient and Sediment Calibration of the Northwest Branch

Although simulated flow for the September 9 storm on the Northwest Branch is also undersimulated, the September 9 storm does not make as large a contribution to the total load during the monitoring period on the Northwest Branch as it does on the Northeast Branch.

5.4.1. Water Temperature. Figure 5.16 shows observed and simulated temperature for the Northwest Branch during the monitoring period. The agreement between observed and simulated values is very good; the coefficient of determination is 0.94.

5.4.2. Dissolved Oxygen. Figure 5.17 shows observed and simulated dissolved oxygen concentrations for the Northwest Branch during the monitoring period. Overall, the agreement between observed and simulated values is good. The coefficient of determination is 0.62. The model underpredicts DO in late summer, when supersaturated concentrations were observed. Excess algal growth is the likely cause of supersaturated DO concentrations during a dry summer period. Observed chlorophyll a concentrations in the water column are less than 5 ug/l. If primary production by algae is the cause of supersaturation, then periphyton, not phytoplankton, must be responsible. Unfortunately, in HSPF, it was not possible to increase the growth rate of benthic algae without increasing the growth rate of phytoplankton, so the observed supersaturated DO concentrations could not be reproduced by simulating benthic algae.

5.4.3. Sediment. Figure 5.18 shows a time series of observed and simulated sediment concentrations. Figure 5.19 shows a scatter plot of observed and simulated sediment loads for the Northwest Branch. The model captures the sediment load associated with Hurricane Floyd, but tends to underpredict the loads from other storms.

Table 5.6 shows the coefficient of determination for observed and simulated sediments for three sets of data; (1) all data, (2) all data excluding the September 9 storm, and (3) all data excluding both the September 9 storm and Hurricane Floyd. As is generally the case, the agreement between observed and simulated loads for Hurricane Floyd is responsible for the misleadingly large R^2 value.

5.4.4. BOD. Figure 5.20 shows a time series of observed and simulated BOD concentrations. Figure 5.21 shows a scatter plot of observed and simulated BOD loads for the Northwest Branch. Observed baseflow concentrations were consistently below the detection limit of 2 mg/l. Only five storm events were monitored. Just as on the Northeast Branch, but to a lesser extent, the model overpredicts stormflow BOD loads. Just as on the Northeast Branch, there is no realistic decay rate or settlement rate at could reconcile the edge-of-stream loads, based on the target BOD stormwater concentrations, and observed loads.

5.4.5. Total Phosphorus. Figure 5.22 shows a time series of observed and simulated total phosphorus concentrations. Figure 5.23 shows a scatter plot of observed and simulated TP loads for the Northwest Branch. There is good agreement between observed and simulated phosphorus concentrations both under baseflow and stormflow conditions. The model simulates the total phosphorus load associated with Hurricane Floyd reasonably well. As shown by Table 5.6, the model does capture some of the variability associated with observed storm flows.

5.4.6 Nitrate. Figure 5.24 shows a time series of observed and simulated nitrate concentrations. Figure 5.25 shows a scatter plot of observed and simulated nitrate loads for the Northwest Branch. The model simulates many storm loads reasonably well, including the nitrate load associated with Hurricane Floyd. The simulations captures the general trend in seasonal baseflow nitrate concentrations.

5.4.7 Ammonia. Figure 5.26 shows a time series of observed and simulated ammonia concentrations. Figure 5.27 shows a scatter plot of observed and simulated ammonia loads for the

Northeast Branch. The model captures the general trend of ammonia baseflow concentrations, but oversimulates stormflow ammonia loads by almost 100%. Much of the ammonia stormflow load is derived from the breakdown of organic material associated with BOD.

5.4.8. Organic Nitrogen. Figure 5.28 shows a time series of observed and simulated organic nitrogen concentrations. Figure 5.29 shows a scatter plot of observed and simulated organic nitrogen loads for the Northwest Branch. Just as on the Northeast Branch, organic nitrogen observed during baseflow is almost always below 0.5 mg/l.; the model simulates this tendency observed in the data. The model captures the stormflow load observed in Hurricane Floyd and most of the observed storms.

5.4.9. Chlorophyll a. Figure 5.30 shows a time series of observed and simulated chlorophyll a concentrations for the Northwest Branch during the period in which data was collected. Much of that time period was late fall or winter, when chlorophyll a concentrations were below the detection limit of 1 ug/l.

5.5 Lower Beaverdam Creek

Measurements of constituent concentrations during stormflow were made by Prince George's County at Station 6, which is approximately at the outlet of Segment 120. Observations were made during 45 storms 1996-1999. Two to three measurement were made each storm. Generally, the measurements were made over a period of three to six hours. A handful of observations were made under baseflow conditions.

The Phase II Model of Lower Beaverdam Creek was calibrated against estimates of storm loads derived from the observed data. The storm was divided into intervals, defined by pairs of consecutive observations. If a storm had two observations, it had one interval; if it had three observations, it had two intervals, etc. The average concentration of a constituent over the interval was calculated as the average concentration of the observations bounding the interval. The average flow was calculated as the product of the duration of the interval (the time between observations) and the average flow during the interval, that is, the average of the instantaneous flows of the bounding observations. The constituent load was defined as the product of the flow and average concentration. The total load for a storm is the sum of the loads of the intervals making up the storm. Table 5.7 shows the observed loads as calculated for each storm.

The model was calibrated against TSS and TKN instead of sediment and organic nitrogen, because there were no measurements made of ammonia or volatile suspended solids. TSS, TP, and TKN were calibrated so the total simulated load for each of these constituents matched the total load in the observed storms over the simulation period. The results are discussed below. No time series plots of simulated and observed concentrations are shown because the storm concentrations are valid for time periods of only three to six hours.

5.5.1. Total Suspended Solids. Figure 5.31 shows a scatter plot of observed and simulated TSS loads. The simulation captures the load observed during Hurricane Floyd and some of the variability associated with other storms. As shown in Table 5.8, the coefficient of determination between observed and simulated values is 0.66 for all storms and 0.20 for all storms excluding Hurricane Floyd.

5.5.2. Total Phosphorus. Figure 5.32 shows a scatter plot of observed and simulated TP loads. The simulation underpredicts the load observed during Hurricane Floyd but captures much of the variability associated with other storms. As shown in Table 5.8, the coefficient of determination between observed and simulated values is 0.58 for all storms and 0.47 for all storms excluding Floyd.

5.5.3. Total Kjeldahl Nitrogen. Figure 5.33 shows a scatter plot of observed and simulated TKN loads. Just as in the case of TP, the simulation underpredicts the load observed during Hurricane Floyd, but captures some of the variability associated with other storms. As shown in Table 5.8, the coefficient of determination between observed and simulated values is higher (0.29) when Hurricane Floyd is excluded than when it is included (0.16).

5.5.4. BOD. Figure 5.34 shows a shows a scatter plot of observed and simulated BOD loads. The model oversimulates BOD loads by almost 100%, and the coefficient of determination between observed and simulated values is low. Contrary to what was said in Section 5.3.4, the fact that BOD is oversimulated on Lower Beaverdam Creek as well as the Northeast and Northwest Branches may an indication that edge-of-stream BOD loads are too high.

5.5.5. Nitrate. Figure 5.35 shows a shows a scatter plot of observed and simulated nitrate loads. Nitrate loads are oversimulated by about 30%, and the coefficient of determination between observed and simulated values are low.

5.5.6. Overall Calibration of Lower Beaverdam Creek. Overall, the simulation of sediment and nutrients in Lower Beaverdam Creek fits the observed data less well than the simulations of the Northeast and Northwest Branch. Part of the difficulty is the shorter duration of the observations during storms. The short duration of observations is more unforgiving of errors of timing. It is not always clear that the observations even captured the peak flow of the storm event.

6. An Analysis of Sediment and Nutrient Loads From the Phase II Model

The purpose of developing an HSPF model of the non-tidal Anacostia River is to help determine sediment, nutrient, and BOD loads entering the tidal river from upstream sources. A BOD TMDL for the tidal Anacostia has been submitted by the District of Columbia and approved by EPA. In that TMDL, upstream sources in Maryland were assumed to contribute average annual loads of 2,102,821 lbs. of BOD, 842,837 lbs. of TN, and 126,652 lbs. of TP (DC DOH, 2001). The TMDL calls for a 50% reduction in the BOD loads a 30% reduction in nutrient loads from upstream sources. DOH has submitted a TMDL for sediment. It assumes that the Northeast and Northwest Branches combined contribute on average 8,763 tons of total suspended solids during the critical season (April through October) while Lower Beaverdam Creek contributes 210 tons on average during the same period. The TMDL calls for a reduction of 86% of TSS from Maryland's upstream sources. The TMDL is expected to approved by the EPA, pending review D. C.'s new standards for water clarity (EPA, 2002). MDE is expected to submit TMDLs for both the tidal and non-tidal sections of the Anacostia River after more monitoring data is collected.

Maryland is also a signatory to the Chesapeake Bay Program, and is committed to reducing nutrient and sediment loads to Chesapeake Bay. As part of that effort, CBP has developed an HSPF model of the entire Chesapeake Bay Basin to estimate nutrient and sediment loads from both point and nonpoint sources. The CBP's Watershed Model provides another estimate of nutrient and sediment loads for the Anacostia watershed.

In this section, the average annual sediment and nutrient loads from the Phase II Model will be summarized and compared with other estimates.

6.1. Total Average Annual Loads and Average Annual Loads By Source

Table 6.1, 6.2, and 6.3 show the total average annual sediment and nutrient loads for the Northeast Branch, the North Branch, and Lower Beaverdam Creek, respectively, over the five-year simulation period, 1996-2000. These tables also show the annual load by land use and the instream contribution to total load.

Urban land uses tend to be the dominate sources of load, but instream contributions are also significant. The instream load represents the difference between total load, as simulated at the outlet of watersheds, and the edge-of-stream load delivered in stormwater and groundwater discharge. For sediment, total phosphorus, and organic nitrogen, it represents primarily the contribution of in-stream erosion to total loads. For ammonia, nitrate, and BOD, it represents the in-stream transformation of constituents. Instream erosion accounts for 35% of the sediment load in the Northwest Branch and just over 50% of the load in the Northeast Branch. Instream erosion also accounts for a little less than half the total phosphorus load in the Northeast Branch and 21% of the load in the Northwest Branch. About a quarter of the simulated organic nitrogen load on the Northeast Branch and about 10% of the load on the Northwest Branch comes from instream sources. There is also a large instream contribution to simulated ammonia loads from the decay of organic material.

Over half of the total phosphorus and almost two-thirds of the sediment in Lower Beaverdam Creek comes from instream erosion. Unlike the Northeast and Northwest Branches, instream erosion does not contribute to organic nitrogen loads. Some organic nitrogen under low flow conditions is lost instream through deposition.

Average annual sediment loads on the Northwest Branch are low relative to the Northeast Branch and Lower Beaverdam Creek. Under the Phase II calibration, sediment loads from Lower Beaverdam Creek are over quarter larger than those from the Northwest Branch, even though the

Lower Beaverdam Creek watershed is one-third the size of the Northwest Branch. This result should be viewed with some suspicion. Part of the reason for this result lies in the observed data. Figure 6.1 shows the cumulative distribution of observed total suspended solid concentrations for Lower Beaverdam Creek, 1996-2000, and the Northwest Branch 1999-2000. Concentrations on Lower Beaverdam Creek are at least double the concentrations on the Northwest Branch. Part of the reason lies in the calibration strategy implemented in the Phase II Model. In contrast to Lower Beaverdam Creek and the Northeast Branch, simulated sediment loads for storms other than Hurricane Floyd are on average undersimulated, on the Northwest Branch, as can be seen from Figure 5.19. This may imply that the Northwest Branch as a whole undersimulates sediment storm concentrations relative to the Northeast Branch or Lower Beaverdam Creek.

6.2. Comparison with the TAM/WASP Model and Phase I Model of the Nontidal Anacostia River

Table 6.4 compares the average annual nutrient and sediment loads as they were calculated for the TAM/WASP Model and in the Phase I Model of the Nontidal Anacostia River.

6.2.1 Comparison with the TAM/WASP Model. The TAM/WASP Model was developed for use in the District of Columbia's TMDLs for the tidal Anacostia River. The upstream loads used in the TAM/WASP Model were based on daily average observed flows and storm and baseflow concentrations estimated from observed data from CAMP. Stormflow composite concentrations were available only for the Northwest Branch. The following procedure was used:

1. Median baseflow concentrations for the Northeast and Northwest Branches were estimated from observed data;

2. Median stormflow concentrations for the Northwest Branch were estimated from storm composites collected 1989-1991;

3. Ratio of Northeast Branch loads to Northwest Branch loads were calculated based on land use and average stormwater concentrations observed in the counties'stormwater permit monitoring programs;

4. Those ratio were used to estimate median stormwater concentrations for the Northeast Branch;

5. HYSEP, a USGS computer program for separating baseflow from stormflow, was used to separate daily flows on the Northeast and Northwest Branches in baseflow and stormflow components; and, finally

6. Daily loads were calculated as the product of the baseflow and stormflow components and the respective median constituent concentrations.

No stormflow BOD composites were available for either branch. Stormflow BOD concentrations were estimated to be 8 mg/l. For more details on the calculation of loads for the TAM/WASP Model, see Mandel and Schultz (2000).

Loads for Lower Beaverdam Creek were taken from a preliminary version of an HSPF model of the watershed built by Tetra-Tech for Prince George's County (Tetra-Tech, 2000). The final version of the model calculated average annual total nitrogen loads of 58,930 lbs, total phosphorus loads of 7,122 lbs, and BOD5 loads of 382,197 lbs. Sediment was not calibrated in the model.

Phase I of the HSPF Model of the non-tidal Anacostia River tended to have considerably larger estimates of average annual loads of all constituents. Average annual sediment loads were twice as high as the TAM/WASP Model and organic nitrogen loads were higher by an order of magnitude. Average annual loads from the Phase II Model are closer to the estimates used in the TAM/WASP Model. Average annual sediment loads are about 10% lower in the Phase II Model. Total phosphorus loads are about 5% lower. Organic nitrogen loads are over 80% larger in the Phase II Model than in the TAM/WASP Model estimates. The TAM/WASP estimates for organic nitrogen loads probably underestimate average annual loads, because, as will be shown below, the flow-weighted storm organic nitrogen concentrations are skewed towards higher values that are not captured by the use of the median as a measure of central tendency.

All models agree on average annual BOD loads, because those estimates are based essentially on edge-of-stream loads determined by the observed NDPES stormwater concentration data.

6.2.2. Comparison with the Phase I Model. The Phase I Model estimates higher average annual loads for sediment, total phosphorus, and organic nitrogen than the Phase II Model. The estimates of the average annual loads for BOD, nitrate, and ammonia are comparable in the two models. It is not hard to determine why the constituents fall into these two groups: For the first group, instream processes make a significant contribution to total loads; for the second group, total loads are less impacted by instream processes. Total loads for the second group reflect edge-of-stream loads, which in turn are determined by calibrating simulated stormwater concentrations to the target stormwater concentrations from NPDES monitoring data. Because this same methodology was used in Phase I and Phase II, the simulated average annual loads of ammonia, nitrate, and BOD are comparable in the Phase I and Phase II Models.

To explain in more detail, there are many differences between the Phase I and Phase II Models that could contribute to differences in their estimate of average annual loads. Among the differences are:

1. **Changes in land use:** As explained in Section 2, updated land use information provided by Prince George's and Montgomery Counties was used in the Phase II Model. The Phase I Model used land use information provided by the Maryland Office of Planning representing conditions in 1990. Between 1990 and 2000, a significant amount of

development occurred in the Anacostia watershed. Part of the difference in land use between Phase I and Phase II represents these changes; part represents the difference sources of information and how land use was classified by those sources.

2. **Differences in the simulation period:** The simulation period for Phase I was 1988-1995; the simulation period for Phase II was 1995-200. These represent real differences in hydrological conditions. The wettest year, 1996, occurs in Phase II. Record low monthly low flows were set in 1999. Despite the impression that the Phase II simulation period was dryer, because of the low flows that occurred in the summer 1998 and 1999, the average flow for the Phase II simulation period was 118 cfs on the Northeast Branch and 69 cfs on the Northwest Branch, compared to 81 cfs and 48 cfs, respectively, during Phase I.

3. **Differences in the hydrology calibration:** By many measures, the Phase II hydrology calibration better represents observed flows during its simulation period than the Phase I calibration. The Phase II calibration could not be extended to cover the Phase I simulation period, however, because it was difficult to develop a uniform time series of potential evaporation over 1988-2000. The Phase I simulation used potential evaporation developed for Phase 4.3 of the CBP's Watershed Model. That time series was based on, among other things, an estimate of daily net radiation derived from observations of cloud cover at Dulles Airport. Observations of cloud cover at Dulles Airport became unavailable after 1997, and comparable data could not be found. As was explained in Section 3, potential evaporation for Phase II was derived from observations of global solar radiation. The difference in the potential evaporation time series contributed to the differences in the parametization of the Phase II Model and made it difficult to simply transfer the Phase II paramterization to the Phase I simulation period.

4. **Differences in the calibration strategy:** The Phase I Model was calibrated against stormflow concentrations; the Phase II Model was calibrated against stormflow loads.

5. **Differences in the observed data used in the calibration.** The Phase I Model was calibrated primarily against stormflow monitoring data collected by the Occoquan Watershed Monitoring Laboratory 1989-1991. Data was collected on the Northwest Branch only. The observed stormflow concentrations are significantly different from those observed in 1999-2000. Figures 6.2, 6.3, and 6.4 show comparative cumulative distribution plots for observed stormflow concentrations of TSS, TP, and TKN. Generally, the concentrations observed during the Phase I simulation period are higher than those observed during the Phase II simulation period. The distribution of TKN concentration during the Phase I simulation period is markedly skewed towards higher concentrations.

As was described in Section 2, changes in land use are relatively minor compared to the difference in load estimates. Edge-of-stream loads are comparable between the Phase I and Phase II Models, also indicating that the differences in land use play a minor role in the difference in simulated loads. Both simulation periods capture a variety of hydrological conditions. The differences in the hydrology calibrations, the calibration strategy, and the observed data used in the calibration are primarily responsible for the difference in simulated annual average loads.

The performance of the Phase I and Phase II simulations were evaluated by running the Phase I simulation with Phase II erosion rates, erosion and deposition thresholds, and organic nitrogen and phosphorus sediment concentrations. Total simulated constituent loads for observed storms were compared to observed loads. The results are shown in Table 6.5. The models both overpredict TSS and underpredict total phosphorus. The original Phase I model overpredicts TKN by a factor of five, while the Phase I Model with Phase II parameters underpredicts it by a factor of almost three.

The large overprediction of TSS and TKN by the original model can be attributed to the use of stormflow concentrations as a calibration target. It is difficult to compare simulated daily average concentration with the average concentration observed over a storm that starts on one day and ends on another. Errors in the hydrology calibration, which could be adjusted for if loads were the target of the calibration, may also magnify the error.

The fact that use of Phase II parameters leads to underpredicting TP and TKN loads is most likely a direct result of the fact that the observed concentrations of the calibration data used in Phase II are lower than those used in Phase I Model. The contribution of erosion to total loads is determined by calibrating the edge-of-stream load to observed loads. Since edge-of-stream loads for the Phase I and Phase II Model are comparable, the differences in observed loads are responsible for the differences in the contribution of instream process to total loads. The higher the observed load, the more erosion will be necessary for the total load to match the observed load. Since the Phase II parameters were set against smaller loads on average than were observed in the Phase I simulation period, they fail to generate enough eroded constituents to match observed loads when used in the Phase I simulation.

Whether the Phase II Model underestimates TN and TP loads depends on whether the Phase II calibration period data is more representative of conditions in the Anacostia watershed than the earlier data. While further analysis may contribute to answering this question, collection of additional monitoring data is the best way to establish what are currently representative loads in the Anacostia watershed. MDE and Prince George's County have joined with the USGS to design a monitoring program that will measure baseflow and stormflow concentrations of key constituents at the USGS gages on the Northeast and Northwest Branches over the next three years. The new data collected should help resolve any lingering questions about the magnitude of storm loads entering the tidal Anacostia River from upstream sources.

6.3. Comparison with CBP Watershed Model

Table 6.6 compares simulated average annual sediment, phosphorus, and nitrogen loads from the

Phase II Model with loads from Segment 540 of the CBP Phase 4.3 Watershed Model 's 2000 Progress Scenario, which represents the nutrient reduction achieved by 2000 and is the modeling scenario most closely resembling the conditions which the Phase II Model represents. Segment 540 represents the entire Anacostia watershed; the loads reported are for Maryland's portion of the watershed, which includes some drainage to the tidal Anacostia River not represented in the Phase II Model.

The estimates of average annual sediment and total phosphorus loads from the two models are within 5% of each other. The Phase I Model's estimate of the average annual total nitrogen load is 20% less than the Watershed Model's estimate. The proportion of nitrogen species is very different in the two models; the Watershed Model predicts a higher proportion of nitrogen as nitrate, and a lower proportion of nitrogen as organic N, than the Phase II Model. The Watershed Model does not simulate BOD.

In comparing the Watershed Model with the Phase II Model, it is important to note the following differences between them:

1. The Watershed Model's Segment 540 was not calibrated against observed data;

2. The simulation of Segment 540 does not represent stream reaches and the associated instream processes;

3. The Watershed Model is run with 1985-1994 meteorology and hydrology; and

4. The representation of land use in the Watershed Model is more impervious (30% to 20%) and less forested (16% to 31%) than the Phase II Model.

With the support of MDE, Phase 5 of the Watershed Model is currently being developed. The main channels of the Northwest and Northeast Branches of the Anacostia will be represented in the Phase 5 Model, and the model will be calibrated against available water quality data collected at the USGS gaging stations on the Northeast and Northwest Branches. A greater variety of urban land uses and agricultural land uses will also be represented.

6.4. Summary of Comparison of Load Estimates

Generally, there is a wide range of agreement in the estimate of average annual loads among the TAM/WASP Model, the CBP Watershed Model, and the Phase II Model. The Phase I Model tends to predict higher estimates of average annual loads for all constituents than the other models. A comparison of simulated and observed loads for the Phase I Model shows that the Phase I Model overpredicts sediment, organic nitrogen, and, as a consequence of the latter, total nitrogen.

6.4.1. BOD. All of the estimates of average annual BOD load are within approximately 10% of each other and are roughly in agreement with the assumptions of DOH's BOD TMDL. The Phase

II Model, when compared to observed storm loads, overpredicts BOD loads by 50-200%. Only five to six stormflow composite samples were available, however, for the Northeast and Northwest Branches and all were taken in late fall or winter.

6.4.2. Sediment. With the exception of the Phase I Model, all estimates of average annual sediment loads are within 10% of each other and are roughly in agreement with the assumptions of DOH's sediment TMDL.

6.4.3. Total Phosphorus. Again, with the exception of the Phase I Model, all estimates of average annual total phosphorus loads are within 10% of each other and are roughly in agreement with the assumptions of DOH's TP TMDL. However, if the earlier CAMP data is more representative of Anacostia storm loads than the data collected for LTCP, a comparison of Phase I simulated TP loads with observed loads indicates that even the Phase I Model is underpredicting average annual TP loads.

6.4.4. Nitrogen. Estimates of total nitrogen and the composition of nitrogen species vary widely. The Phase I Model oversimulates organic nitrogen loads. If the CAMP stormwater data is more representative of Anacostia stormwater organic nitrogen concentrations, then the Phase II Model undersimulates organic nitrogen loads.

6.4.5. Value of Additional Monitoring Data. A calibrated water quality simulation model is a tool for making inferences from observed data. Its predictions are a function of the observed data used to calibrate it. The additional monitoring data which MDE is planning to collect will help resolve two outstanding inconsistencies in the observations collected so far:

- As Figures 6.2, 6.3, and 6.4 show, the stormwater concentrations observed in 1989-1991 tend to result in higher predicted concentrations of total suspended solids, total phosphorus, and organic nitrogen than the data collected in 1999-2000 for WASA's LTCP. It is not clear which data set is representative of conditions in the Anacostia watershed.

- Observed instream stormflow BOD concentrations are not consistent with BOD concentrations observed in stormwater runoff.

These two inconsistencies need to be resolved before a definitive determination of sediment and nutrient loads can be made for the Anacostia River.

7. Summary and Recommendations

7.1 Summary

Phase II of the HSPF Model of the non-tidal Anacostia River has been developed. The model simulates the Northwest Branch, Northeast Branch, and Lower Beaverdam Creek watersheds. The key elements of the Phase II Model include

- the use of current land use information provided by Montgomery and Prince George's Counties;

- calibration of the simulation of the fate and transport of nutrient and sediment against base flow and stormflow monitoring data collected by COG for WASA's CSO LTCP; and

- the use of observed storm loads, not observed storm concentrations, to calibrate the model.

Like the Phase I Model, the simulation of stormwater runoff was calibrated so that flow-weighted average constituent concentrations in stormwater agreed with the average observed stormwater concentrations as monitored by Prince George's and Montgomery Counties for their NPDES stormwater permits.

7.1.1 Calibration Results. The model was successfully calibrated so that the total simulated sediment, total phosphorus, and organic nitrogen loads were consistent with the total observed loads for monitored storms. In other words, the model reproduces the average observed storm load of sediment, total phosphorus, and organic nitrogen in the Northeast Branch, Northwest Branch, and Lower Beaverdam Creek. The model accounts for 20-35% of the variability in storm loads for these constituents, outside of the loads associated with Hurricane Floyd and a preceding storm.

The model overpredicts BOD loads by a factor of two on the Northwest Branch and a factor of three on the Northeast Branch. The simulated BOD loads in stormwater are not compatible with the stormwater loads observed instream. Since simulated stormwater concentrations were calibrated against the average observed stormwater concentrations, this implies that those average stormwater concentrations are incompatible, at least, with the observed stormwater loads. It must be kept in mind, however, that stormflow concentrations of BOD were monitored for only a half-dozen storms, all in winter.

Total simulated nitrate and ammonia loads are in agreement with total observed loads except for the Northwest Branch, where the simulated load is twice as high as the observed load. The decay of organic material associated with BOD is responsible for the most of the storm load of ammonia.

7.1.2 Comparison of Phase II Loads with Other Estimates. The average annual sediment and total phosphorus loads from the Phase II Model are consistent with the estimates of the loads for the non-tidal Anacostia watershed used in the TAM/WASP models and the 2000 Progress scenario of the CBP's Phase 4.3 Watershed Model. Average annual total nitrogen loads are larger in the Phase II Model than for the TAM/WASP model, but smaller than the estimate from the CBP model.

For sediment, total phosphorus, and organic nitrogen–constituents for which instream erosion significantly contributes to total load–average annual loads as calculated by the Phase I Model were significantly higher than those calculated by the Phase II Model. For nitrate, ammonia, and BOD, average annual loads from the two models were comparable. While there are many differences between the Phase I Model and the Phase II Model, including different land uses, different simulation periods, and differences in the hydrology calibration, the difference in load estimates stems primarily from (1) the observed stormflow data used to calibrate the models, and (2) the fact that the Phase I Model was calibrated against stormflow concentrations, while the Phase II Model was calibrated against stormflow loads. In both models, edge-of-stream loads were calculated using the same methodology and are comparable in the two models. The contribution of instream processes are determined by the difference between the total instream load and the edge-of-stream load. Part of the reason for the larger loads in the Phase I model is due to the fact that concentrations of constituents observed in 1989-1991 are higher than those observed in 1999-2000. Part of the reason, also, is that calibrating against observed concentrations, rather than loads, tended to overpredict storm loads.

MDE, Prince George's County, the USGS are planning to monitor baseflow and stormflow concentrations on the Northeast and Northwest Branches over the next two years. The data collected should help determine the representative stormflow concentrations on the Northeast and Northwest Branches of the Anacostia River, and therefore, their representative loads.

7.2 Recommendations

The new monitoring program for the Anacostia River is designed to provide a more definitive determination of the characterization of baseflow and stormflow loads from the non-tidal Anacostia River watershed. Correspondingly, a model of the non-tidal Anacostia River watershed, calibrated against the data collected, would provide a more definitive representation of the sediment and nutrient loads entering the tidal Anacostia River. Until the results of the new monitoring program are available, steps can be taken in three areas to improve our understanding of the fate and transport of sediment and nutrients in the non-tidal Anacostia River.

7.2.1 Integration of Phase I and Phase II Models. Further steps should be taken to analyze the differences between the Phase I and Phase II Models. Are there any explanations for the differences between the observed stormwater concentrations used to calibrate the models that can be incorporated into the modeling framework? It may be possible, for example, to construct a unified framework for assessing land use over both the Phase I and Phase II simulation periods.

It was not possible to construct a single model covering the Phase I and Phase II simulation periods because the two models do not share a common hydrology calibration. The primary difficulty in developing a hydrology model covering both simulation periods is a lack of continuity in the available data used to estimate potential evaporation. The Phase 5 CBP Watershed Model may develop potential evaporation time series that can span both simulation periods, and make possible a common hydrology calibration.

7.2.2. Consistency Between the Non-tidal Anacostia Model and the Phase 5 CBP Watershed Model. In addition to providing meteorological inputs that span both phases of the non-tidal Anacostia Watershed Model, CBP Phase 5 Model will greatly expand the number of urban and agricultural land uses simulated. The innovations in representing land uses in the Phase 5 Model should be examined to see if they could be used to help improve the representation of sources in the Anacostia watershed. In particular, any innovations in the simulation of agricultural land that help to more accurately represent the practices used at the Beltsville Agricultural Research Center should be incorporated into the Anacostia model.

7.2.3. Simulation of Other Land Uses. There are several land uses present in the Anacostia watershed that are not planned to be represented in the Phase 5 Model but which may make a significant contribution to sediment nutrient loads. These include wetlands, sand and gravel mining operations, and land under development. The land zoned as "rural' in Montgomery County needs to better represented in the model, and, in particular, the impact of the horse population in the watershed needs to be incorporated into the model.

7.2.4. Collection of Additional Monitoring Data. The Anacostia River watershed is probably one of the most heavily studied in the United States. It may appear either greedy or embarrassing to suggest that more information is needed before determining the sediment and nutrient loads to the tidal Anacostia River. Nevertheless, the monitoring data collected up to this point has significant gaps and inconsistencies. The sediment, total phosphorus, and organic nitrogen loads observed in 1989-1991 are considerably larger than those observed in 1999-2000. The stormwater BOD loads observed in 1999-2000 are considerably less than the estimate of the contribution of urban stormwater to BOD loads. These inconsistencies need to be addressed by additional monitoring if agreement is to be reached on quantifying the sediment and nutrient loads from the Northwest Branch and the Northeast Branch, and Lower Beaverdam Creek.

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Table 2.1. Subwatersheds in the Anacostia River Basin

Segment	Subwatershed	Segment	Subwatershed
10	Upper Northwest Branch	80	Indian Creek
20	Middle Northwest Branch	90	Beaverdam Creek
30	Sligo Creek	100	Northeast Branch
40	Lower Northwest Branch	120	Lower Beaverdam Creek (Upper)
50	Upper Paint Branch	130	Cabin Branch
60	Middle Paint Branch	140	Lower Beaverdam Creek (Mainstem)
70	Little Paint Branch		

Table 2.2 Model Classification of Prince George's County Land Uses

Land Use Code	Description	Impervious Percentage	Model Land Use Class
11	Low-density residential	12%	LDR
12	Medium-density residential	38%	HDR
13	High-density residential	65%	HDR
14	Commercial	85%	Commercial
15	Industrial	72%	Industrial
16	Institutional	20%	Commercial
171	Highway corridors	72%	Commercial
172	Railroad corridors	5%	Industrial
18	Open urban land	0%	Commercial
21	Cropland	0%	Cropland
22	Pasture	0%	Pasture
23	Orchards/vineyards/horticulture	0%	Cropland
242	Agricultural buildings	0%	Cropland
30	Urban herbaceous	0%	Commercial
41	Deciduous forest	0%	Forest
42	Evergreen forest	0%	Forest
43	Mixed forest	0%	Forest
44	Brush	0%	Forest
73	Bare ground	0%	LDR
74	Extractive	0%	LDR

Table 2.3. Model Classification of Montgomery County Zoning

Zoning Category	Zoning Codes	Model Land Use
Nonzoned		LDR
Commercial	C-*, O-*, CBT-*, TS-R, TS-M, H-M, MXPD,	Commercial
Residential	RT-*, R-H, R-10, R-20, R-30, P-R-C, RMH	HDR
Industrial	I-*	Industrial
Residential	R-40, R-60, R-90, R-150, R-200	LDR
Other	Town Sector, Planned Neighborhood	Commercial
Rural	RDT, RZ, RC, RE-*	LDR

Table 2.4. Impervious Area (acres) in Anacostia Watershed, Montgomery County

Segment	Buildings	Parking Lots	Roads	Sidewalks
10	593	406	1,081	34
20	443	221	997	42
30	540	276	994	47
40	191	124	370	17
50	202	72	450	2
60	353	455	604	18
70	206	291	404	23

Table 2.5. Model Land Uses By Subwatershed (acres)

	Pervious Land (Acres)						Impervious Land (Acres)		
Segment	Forest	Pasture	LDR	Commercial/industrial	Medium-H density R	Crop	LDR	Commercial/industrial	Medium-H density R
10	3,927	15	7,379	14	383	0	1,706	103	305
20	1,524	0	2,556	38	69	0	1,472	48	221
30	509	0	2,115	36	107	0	1,390	341	204
40	1,151	0	1,122	927	1,423	0	532	816	1,241
50	1,395	4	2,614	9	25	0	727	14	11
60	1,339	0	1,901	353	118	0	937	463	171
70	2,962	17	1,631	682	891	621	626	539	711
80	5,442	115	119	1,646	194	1,014	12	168	210
90	2,781	10	356	847	396	632	16	763	311
100	3,851	0	197	2,428	2,717	26	11	1,363	2,051
120	1,266	0	91	1,126	911	0	9	1,025	852
130	1,106	0	128	527	536	14	7	311	553
140	334	0	7	202	217	0	0	227	135

Table 3.1. Correlation In Daily Precipitation Among Stations in Anacostia Region

Station name	Coop ID	448906	180700	185111	186350	187705
Reagan AP	**448906**	1.000				
Beltsville	**180700**	0.933	1.000			
Laurel	**185111**	0.906	0.942	1.000		
Arboretum	**186350**	0.951	0.925	0.910	1.000	
Rockville	**187705**	0.911	0.933	0.918	0.891	1.000

Table 3.2. Monthly Pan Evaporation Adjustment Coefficients

Month	J	F	M	A	M	J	J	A	S	O	N	D
Coef.	0.67	0.67	0.67	0.72	0.67	0.66	0.69	0.63	0.69	0.67	0.67	0.67

Table 3.3. Key Hydrology Parameters

Variable	Description	Piedmont	Coastal Plain
LZNS	lower zone nominal storage (in)	5.64	2.30
UZNS	upper zone nominal storage (in)	2.55	0.05, 0.115
INFILT	base infiltration rate (in/hr)	0.064	0.061
INTFLW	interflow runoff ratio	1.0, 1.5(F)	1.50, 1.75(F)
IRC	interflow recession coefficient	0.20	0.21
AGWRS	base flow recession coefficient	0.984	0.991
KVARY	groundwater augmentation factor	0.001	0.438
LZEPT (dormant)	growing season evaportranspiration coefficient	0.03	0.03
LZEPT (growing season)	growing season evaportranspiration coefficient	0.260, 0.286	0.236, 0.286, 0.309
RETSC	impervious retention storage (in)	0.03, 0.05	0.05

Piedmont: Segments 10 - 60
Coastal Plain: Segments 70-140
F: forest

Table 3.4. Coefficient of Determination Between Simulated and Observed Flows

	Northeast Branch	Northwest Branch
Daily	0.80	0.81
Monthly	0.90	0.89
Seasonally	0.90	0.93

Table 3.5. Simulated Flow Volumes As A Percentage of Observed Volumes

	Northeast Branch	Northwest Branch
Winter	93%	101%
Spring	97%	100%
Summer	103%	108%
Fall	104%	104%
Total	98%	102%
Less Than Median Flow	112%	118%
Greater Than 90th Percentile Flow	99%	99%

Table 3.6. Hydrology Statistics for Northwest Branch at USGS Station 01650500

Coefficient of Determination Between Simulated and Observed Flows	
Daily	0.78
Monthly	0.89
Seasonally	0.97
Simulated Flow Volumes As A Percentage of Observed Volumes	
Winter	87%
Spring	92%
Summer	130%
Fall	109%
Total	99%
Less Than Median Flow	142%
Greater Than 90th Percentile Flow	82%

Table 4.1 Average Constituent Concentrations in NDPES Stormwater Monitoring Data from Montgomery and Prince George's Counties (mg/l)

Jurisdiction	Site ID	Land Use	Samples	BOD5	TKN	TSS	TP	NO3
Montgomery	BC	Commercial	3	11.33	2.35	8	0.17	0.46
Montgomery	CO	Industrial	32	14.43	0.97	78	0.14	0.48
Montgomery	QA	Residential	3	8.00	1.33	151	0.27	0.32
Montgomery	SL	Residential	3	16.00	1.35	410	0.27	1.23
Montgomery	V	Residential	3	20.50	1.35	79	0.34	0.66
Montgomery	WP	Residential	3	21.00	3.67	102	0.16	0.63
Prince George's	1	Commercial	26	17.83	2.41	259	0.25	0.67
Prince George's	2	Residential	78	16.24	2.07	204	0.56	0.74
Prince George's	3	Industrial	31	13.17	1.60	117	0.23	0.58
Prince George's	4	Residential	3	22.67	1.33	39	0.46	0.67
Prince George's	5	Industrial	3	20.67	0.63	69	0.35	0.63
Average for all Sites								
Commercial				16.7	2.81	123	0.19	0.59
Industrial				16.1	1.14	169	0.25	0.73
Residential				16.9	1.52	118	0.41	0.60

Table 4.2 Correlation Coefficient Monthly Precipitation

	1990	1991	1992	1993	1994	1995	1996	1997
1998	-0.27	-0.03	-0.09	0.08	0.45	-0.40	-0.17	-0.05
1999	-0.36	0.30	-0.05	0.21	0.26	-0.15	0.53	-0.20
2000	0.03	0.17	0.44	-0.13	0.21	-0.55	0.22	-0.47

Table 4.3. Livestock Population at Beltsville Agricultural Research Center

Animal Type	Numbers	Average Weight (lbs)	Months in Pasture	Percent Waste Removed From Pasture
Holstein heifers	35	500	4	0%
Holstein dry cows	15	1000	12	60%
Hogs	70	400	12	0%
Hogs	200	375	12	0%
Angus cows	60	1000	12	20%
Calves less than 1 year	60	500	12	5%
Heifers 1 to 2 year	18	1000	12	20%
Bulls less than 1 year	12	500	12	20%
Bulls more than 1 year	18	1000	12	20%
Sheep-dorset ewes	70	60	12	20%
Beef-Angus cows	100	1000	12	15%
Angus calves less than 1 year	100	500	10	5%
Replacement heifers 1 to 2 year	30	1000	10	35%
Mature bulls	5	1000	12	5%

Table 4.4. Livestock Nitrogen and Phosphorus Production Rates (lbs/1000 lb weight)
Palace et al. (1998)

Animal Type	Total Nitrogen	Total Phosphorus
Holstein heifers	164.25	25.55
Holstein dry cows	164.25	25.55
Hogs	153.3	58.4
Hogs	153.3	58.4
Angus cows	113.15	40.15
Calves less than 1 year	113.15	40.15
Heifers 1 to 2 year	113.15	40.15
Bulls less than 1 year	113.15	40.15
Bulls more than 1 year	113.15	40.15
Sheep-dorset ewes	164.25	25.55
Beef-Angus cows	113.15	40.15
Angus calves less than 1 year	113.15	40.15
Replacement heifers 1 to 2 year	113.15	40.15
Mature bulls	113.15	40.15

Table 4.5. Crop Acres at Beltsville Agricultural Research Center

Crop	Acres	Crop	Acres
Corn	500	Alfalfa	150
Small Grains (Barley, Rye)	225	Orchard Grass	120
Soybeans	225	Sudan Grass	25

Table 4.6 Crop Fertilization Schedule At BARC

Crop	Schedule
Corn	1. Starter Fertilizer: 27 lbs. N; 3.5 lbs P 2. Sidedress at 2 ft. tall: 30% UAN depending on N credits
Small Grain	1. Planting: 3500-4000 gallons liquid dairy manure (14-10-18 per 1000 gal). 2. Late Feb- early March: 20 -30 lbs. N 3. Late March - early April: 40-60 lbs. N
Soybeans	1. Use compost (20-15-20 per ton) when P needed; usually not needed in rotation.
Alfalfa	1. Topdress with 4 tons compost in late fall or early spring if P needed.

Table 4.7 Acres of Land Use Under BMPs

Segment	LU		DP	EDSD	IB	IT	OGS	SM	WP
10	COM	per	2.0						
		imp	0.5				1.1	6.1	26.7
	HDR	per	142.6			11.3	8.9	5.9	49.2
		imp	39.7			6.3	2.7		4.72
	LDR	per	535.3	20.0	21.5	1.1	68.1	10.4	192.1
		imp	105.2	0.8	10.3	0.7	18.3	36.4	25.2
20	COM	per				1.0	0.1		0.7
		imp	0.4			4.9	0.4		2.9
	HDR	per	0.1			1.0	0.3		4.3
		imp	0.1			0.1	0.0		0.6
	LDR	per	1.7			0.2	103.2	0.1	20.9
		imp	4.1			0.1	18.6	0.9	33.6
30	COM	per	1.2				32.4		26.9
		imp	1.4				4.0		78.3
	HDR	per	1.7			0.7	0.5		36.1
		imp	0.4			0.3	0.1		28.1
	LDR	per	0.6			5.1	58.4		715.2
		imp	0.4			2.2	5.7	6.5	148.2
40	COM	per							
		imp							
	HDR	per						0.3	
		imp						0.0	
	LDR	per				0.2	1.9	1.5	
		imp				0.5	1.0		
50	COM	per	12.0						
		imp	0.9						
	HDR	per	16.2			4.4	3.6		9.1
		imp	2.5			0.1		0.1	1.1
	LDR	per	584.8			73.2	67.8	83.1	110.5
		imp	92.9			16.0	8.6	6.5	15.0
60	COM	per				2.5	0.2		11.8
		imp	0.1			2.5	1.2		6.9
	HDR	per	3.1						12.9
		imp	6.4						9.9
	LDR	per	31.7			101.7	49.9	78.6	250.0
		imp	10.1			22.1	13.6	7.2	51.0
70	COM	per	7.5	0.2	15.2	0.0	55.6		3.4
		imp	24.5	2.6	11.4	2.4	40.3		1.3
	HDR	per	95.0		9.6		11.3		3.2
		imp	59.6		0.4		9.3		1.1
	LDR	per	164.3	72.2	167.5	0.8	378.0		68.2
		imp	55.3	19.3	4.7	0.9	65.8		17.1

Table 4.8 BMP Pollution Removal Efficiencies

BMP TYPE	TN*	TP*	TSS*	BOD**
Detention Structure(Dry Pond) - DP	25%	19%	47%	25%
Extended Detention Structure (Dry) - EDSD	31%	20%	61%	25%
Infiltration Basin - IB	60%	67%	75%	54%
Infiltration Trench(Three Types) - IT	49%	50%	88%	54%
Oil/Grit Separator - OGS	41%	55%	84%	
Shallow Marsh - SM	26%	41%	83%	18%
Retention Structure(Wet Pond) - WP	32%	50%	79%	43%

* CBP Urban Workgroup, personal comm.; 2002

**Winer, 2002

Table 4.9 Percent BMP Load Reduced By Segment

segment	10	20	30	50	60	70
Commercial						
TN	8.9%	7.2%	25.0%	2.4%	3.2%	7.3
TP	13.3%	8.6%	37.1%	1.5%	2.0%	11.3%
TSS	22.3%	14.5%	58.4%	4.7%	6.2%	17.9%
BOD	10.9%	8.1%	23.3%	1.9%	2.6%	9.8%
High Density Residential						
TN	10.2%	1.0%	9.9%	9.0%	3.7%	4.0%
TP	10.1%	1.3%	15.1%	5.8%	2.4%	6.2%
TSS	20.5%	2.2%	24.0%	17.7%	7.3%	9.8%
BOD	10.1%	1.2%	13.0%	7.2%	3.0%	5.3%
Low Density Residential						
TN	2.2%	3.0%	8.5%	5.0%	4.3%	10.2%
TP	2.4%	4.2%	13.0%	3.2%	2.8%	6.6%
TSS	4.6%	6.5%	20.6%	9.7%	8.5%	20.1%
BOD	2.1%	1.4%	10.4%	4.0%	3.5%	8.2%

Table 5.1 Observed Baseflow Concentrations--Northeast Branch

Date	Temp (^{o}C)	Chla (ug/l)	DO (mg/l)	TP (mg/l)	NH3 (mg/l)	NO3 (mg/l)	ON (mg/l)	BOD (mg/l)	SED (mg/l)
8/5/99	27.0	5.60	9.6	0.04	0.02	0.06	0.47	1.0	6.40
8/12/99	28.0	1.00	8.9	0.04	0.02	0.02	0.36	1.0	1.20
8/19/99	25.0	1.00	8.4	0.03	0.03	0.06	0.33	1.0	0.00
9/299	19.5	4.60	10.9	0.03	0.01	0.37	0.29	1.0	0.00
9/9/99	26.5	1.00	8.7	0.08	0.03	0.80	0.70	1.0	1.00
9/23/99	16.0	1.00	9.9	0.06	0.05	0.85	0.44	1.0	6.40
10/7/99	15.5	1.00	11.4	0.05	0.03	0.86	0.33	1.0	2.30
10/14/99	15.0	1.00	10.6	0.05	0.01	0.89	0.33		5.10
10/2199	14.0	2.70	10.2	0.05	0.02	0.69	0.38	1.0	4.70
11/3/99	12.5	4.20	10.2	0.06	0.02	0.55	0.55	3.6	4.40
11/16/99	10.0	1.00	12.4	0.03	0.01	0.53	0.24	1.0	
12/1/99	4.0	1.00	12.8	0.05	0.04	0.89	0.30	1.0	0.80
12/16/99	8.5	1.00	12.2	0.06	0.05	0.95	0.44	1.0	8.80
12/28/99	2.5	2.10	12.8	0.33	0.07	1.22	0.26	1.0	0.80
1/13/00	7.0	1.00	12.3	0.06	0.05	0.99	0.44	1.0	3.10
1/27/00	0.0	1.00	12.8	0.06	0.17	1.08	0.77	1.0	7.50
2/9/00	2.0	1.00		0.04	0.27	1.05	0.62	1.0	6.40
2/23/00	7.0	1.00		0.04	0.06	1.14	0.26	1.0	3.20
3/8/00	14.0	1.00	11.7	0.03	0.01	0.99	0.26	1.0	0.00
3/27/00	12.0	2.50	11.1	0.06	0.04	0.79	0.45	1.0	10.40

Table 5.2 Observed Baseflow Concentrations--Northwest Branch

Date	Temp (ºC)	Chla (ug/l)	DO (mg/l)	TP (mg/l)	NH3 (mg/l)	NO3 (mg/l)	ON (mg/l)	BOD (mg/l)	SED (mg/l)
8/5/99	27.5	3.30	11.0	0.03	0.03	0.51	0.25	1.0	2.00
8/12/99	28.0	1.00	10.4	0.02	0.03	0.37	0.24	1.0	0.00
8/19/99	24.5	3.60	8.2	0.04	0.03	0.46	0.38	1.0	1.00
9/299	20.0	5.60	10.8	0.03	0.02	0.48	0.30	1.0	0.00
9/9/99	25.5	1.00	8.4	0.06	0.02	0.56	0.66	1.0	0.80
9/23/99	15.5	1.00	9.9	0.04	0.03	0.73	0.41	1.0	2.80
10/7/99	14.5	1.00	10.4	0.04	0.03	0.66	0.40	1.0	2.00
10/14/99	15.0	1.00	9.8	0.04	0.03	0.69	0.33	1.0	1.50
10/2199	13.5	1.00	9.8	0.05	0.07	0.66	0.41	1.0	2.30
11/3/99	13.0	8.20	10.1	0.05	0.01	0.43	0.53	5.2	0.00
11/16/99	8.6	1.00	12.3	0.02	0.01	0.35	0.20	1.0	0.00
12/1/99	3.0	1.00	12.6	0.03	0.01	0.36	0.27	1.0	0.00
12/16/99	8.5	1.00	12.2	0.05	0.03	0.73	0.41	1.0	8.80
12/28/99	2.5	1.00	13.1	0.04	0.07	1.44	0.29	1.0	
1/13/00	6.0	1.00	12.4	0.03	0.02	1.00	0.31	1.0	0.00
1/27/00	0.0	1.00	13.0	0.03	0.2	1.44	0.84	1.0	4.00
2/9/00	1.0	1.00		0.04	0.3	1.38	0.74	1.0	0.40
2/23/00	7.0	1.00		0.02	0.05	1.13	0.16	1.0	
3/8/00	13.0	2.00	11.4	0.02	0.01	1.11	0.24	1.0	0.80
3/27/00	11.5	3.00	11.4	0.05	0.08	0.69	0.57	1.0	1.60

Table 5.3 Observed Storm Composite Concentrations

Starting Date & time	Ending Date & time	TP (mg/l)	NH3 (mg/l)	NO3 (mg/l)	TKN (mg/l)	ON (mg/l)	BOD (mg/l)	TSS (mg/l)	VSS (mg/l)	SED (mg/l)
Northeast Branch										
8/25/99 12:40	8/26/99 13:27	0.32	0.12	0.57	1.33	1.21		426	46	380
8/26/99 19:30	8/27/99 12:48	0.30	0.11	0.89	1.33	1.22		198	24	174
9/4/99 15:10	9/6/99 8:31	0.23	0.03	0.34	1.14	1.11		183	23	161
9/6/99 18:10	9/7/99 12:00	0.22	0.03	0.64	1.08	1.05		211	24	187
9/9/99 19:50	9/10/99 9:31	2.15	0.18	0.61	8.33	8.15		1930	243	1687
9/15/99 11:30	9/17/99 21:47	0.49	0.09	0.63	1.56	1.46		528	29	499
9/29/99 21:30	10/1/99 0:01	0.34	0.02	0.22	1.41	1.39		263	41	222
11/26/99 15:50	11/27/99 18:27	0.38	0.02	0.58	1.80	1.78	13	230	3	227
12/6/99 4:25	12/7/99 0:42	0.11	0.06	0.67	0.67	0.61	5	39	7	31
12/10/99 11:45	12/11/99 4:20	0.12	0.02	0.68	0.71	0.69	4	71	10	61
12/13/99 15:20	12/15/99 11:15	0.27	0.07	0.81	1.24	1.17	2	262	30	232
2/10/00 15:11	2/11/00 9:58	0.14	0.22	1.04	1.15	0.93	2.5	45	7.2	38
2/27/00 22:25	2/28/00 20:06	0.37	0.11	0.67	1.90	1.80	6	338	39	299
3/27/00 16:05	3/28/00 11:45	0.24	0.07	0.58	1.19	1.12	6	250	36	214
Northwest Branch										
8/25/99 14:15	8/26/99 5:15	0.37	0.06	0.51	1.66	1.6		238	38	200
9/4/99 15:50	9/6/99 9:41	0.31	0.02	0.36	1.55	1.53		208	31	177
9/6/99 18:05	9/7/99 11:15	0.32	0.01	0.34	1.51	1.51		272	38	234
9/9/99 19:30	9/10/99 10:00	1.07	0.02	0.21	5.93	5.91		517	113	404
9/15/99 11:55	9/17/99 10:00	0.51	0.04	0.43	1.82	1.78		451	54	397
9/21/99 5:25	9/22/99 9:30	0.26	0.01	0.35	1.27	1.27		168	28	140
9/29/99 22:05	10/1/99 0:01	0.41	0.02	0.37	1.96	1.94		289	51	238
11/26/99 15:40	11/27/99 22:00	0.42	0.01	0.46	2.11	2.10	17.5	224	4	220
12/6/99 5:40	12/7/99 1:13	0.12	0.01	0.60	0.86	0.85	9.5	27	8	19
12/10/99 11:50	12/11/99 11:030	0.11	0.01	0.60	0.78	0.77	6.3	39	9	30
12/13/99 12:50	12/15/99 10:47	0.25	0.04	0.61	1.25	1.21	2.2	179	28	150
2/27/00 22:15	2/28/00 23:30	0.45	0.04	0.67	2.32	2.28	7.4	326	49	277
3/27/00 16:40	3/28/00 11:40	0.16	0.01	0.71	0.93	0.92	6.8	109	25	84

Table 5.4 Observed Storm Loads

Starting Date & time	Ending Date & time	TP (lbs)	NH3 (lbs)	NO3 (lbs)	ON (lbs)	BOD (lbs)	SED (tons)
Northeast Branch							
8/25/99 12:40	8/26/99 13:27	8,572	321	1,527	3,241		5,090
8/26/99 19:30	8/27/99 12:48	355	130	1,054	1,445		103
9/4/99 15:10	9/6/99 8:31	856	100	1,269	4,098		297
9/6/99 18:10	9/7/99 12:00	406	55	1,182	1,939		172
9/9/99 19:50	9/10/99 9:31	9,474	793	2,688	35,913		3,717
9/15/99 11:30	9/17/99 21:47	12,465	2,333	15,822	36,973		6,298
9/29/99 21:30	10/1/99 0:01	977	58	641	4,025		322
11/26/99 15:50	11/27/99 18:27	1,187	62	1,810	5,539	392,563	354
12/6/99 4:25	12/7/99 0:42	88	52	555	501	4,303	13
12/10/99 11:45	12/11/99 4:20	107	18	606	615	3,653	27
12/13/99 15:20	12/15/99 11:15	1,867	477	5,555	8,007	10,604	791
2/10/00 15:11	2/11/00 9:58	88	138	652	583	1,568	12
2/27/00 22:25	2/28/00 20:06	925	268	1,676	4,465	14,823	371
3/27/00 16:05	3/28/00 11:45	728	212	1,759	3,396	17,282	324
Northwest Branch							
8/25/99 14:15	8/26/99 5:15	471	7	650	2,039		127
9/4/99 15:50	9/6/99 9:41	827	62	971	4,076		236
9/6/99 18:05	9/7/99 11:15	486	8	516	2,285		178
9/9/99 19:30	9/10/99 10:00	2,010	38	394	11,100		379
9/15/99 11:55	9/17/99 10:00	5,474	392	4,546	19,059		2,126
9/21/99 5:25	9/22/99 9:30	365	7	491	1,776		98
9/29/99 22:05	10/1/99 0:01	645	37	591	3,068		189
11/26/99 15:40	11/27/99 22:00	932	22	1,019	4,691	39,053	246
12/6/99 5:40	12/7/99 1:13	53	4	265	375	4,195	4
12/10/99 11:50	12/11/99 11:030	82	7	448	575	4,702	11
12/13/99 12:50	12/15/99 10:47	776	117	1,904	3,811	6,785	236
2/27/00 22:15	2/28/00 23:30	731	65	1,096	3,714	12,060	226
3/27/00 16:40	3/28/00 11:40	130	8	576	746	5,516	34

Table 5.5 Coefficient of Determination Between Observed and Simulated Northeast Branch Storm Loads

Constituent	All Storms	All Storms Except September 9	All Storms Except September 9 and Hurricane Floyd
Sediment	0.64	0.95	0.12
BOD	0.84	0.84	0.84
Total Phosphorus	0.43	0.91	0.38
Ammonia	0.55	0.11	0.07
Nitrate	0.52	0.60	0.23
Organic Nitrogen	0.29	0.89	0.37

Table 5.6 Coefficient of Determination Between Observed and Simulated Northwest Branch Storm Loads

Constituent	All Storms	All Storms Except September 9	All Storms Except September 9 and Hurricane Floyd
Sediment	0.96	0.98	0.29
BOD	0.96	0.96	0.96
Total Phosphorus	0.63	0.80	0.24
Ammonia	0.39	0.40	0.16
Nitrate	0.62	0.61	0.11
Organic Nitrogen	0.50	0.80	0.18

Table 5.7 Observed Storm Loads--Lower Beaverdam Creek

Starting Date & time	Ending Date & time	BOD (lbs)	TSS (tons)	TP (lbs)	NO3 (lbs)	TKN (lbs)
01/02/96 06:37	01/02/96 12:37	921	5	31	142	103
03/15/96 06:57	03/15/96 10:57	234	1	1	21	33
07/26/96 01:24	07/26/96 05:23	1,173	55	55	81	142
08/12/96 19:20	08/13/96 02:19	1,255	74	31	134	558
09/04/96 16:27	09/04/96 19:26	518	26	42	44	163
09/06/96 11:09	09/06/96 13:07	861	25	10	51	173
11/08/96 15:17	11/08/96 18:18	6,441	111	67	205	820
01/2297 20:39	01/22/97 21:39	180	3	3	7	10
03/01/97 10:58	03/01/97 12:55	314	27	8	75	251
03/14/97 11:53	03/14/97 12:52	77	0	1	8	3
04/27/97 20:00	04/28/97 01:43	39	1	0	2	4
06/01/97 22:54	06/02/97 00:52	442	9	6	17	45
06/13/97 12:30	06/13/97 14:30	2,074	45	7	81	221
07/23/97 16:51	07/23/97 18:20	131	3	2	5	32
08/12/97 16:00	08/12/97 18:00	73	1	1	5	8
08/17/97 17:07	08/17/97 21:05	7,065	374	323	214	507
08/20/97 11:21	08/20/97 16:21	1,697	218	261	271	683
10/15/97 05:00	10/15/97 08:00	506	4	7	34	92
11/07/97 07:53	11/07/97 13:53	3,096	61	40	124	261
01/15/98 17:44	01/15/98 23:44	3,090	22	86	79	234
01/28/98 14:10	01/28/98 19:10	2,061	67	275	286	504
02/04/98 08:00	02/05/98 10:45	5,746	117	496	603	1,334
02/17/98 12:35	02/17/98 23:04	1,107	18	70	86	168
03/08/98 17:01	03/08/98 18:23	454	8	26	40	130
05/01/98 17:01	05/05/98 20:00	1,401	20	63	39	206
05/07/98 17:28	05/08/98 03:57	571	12	33	39	86
06/02/98 20:50	06/03/98 10:49	656	6	17	43	81
07/08/98 09:35	07/08/98 11:05	259	3	6	16	31
08/10/98 13:02	08/10/98 16:02	1,730	63	151	76	479

Starting Date & time	Ending Date & time	BOD (lbs)	TSS (tons)	TP (lbs)	NO3 (lbs)	TKN (lbs)
08/17/98 18:39	08/17/98 21:39	244	3	9	15	31
09/22/98 02:53	09/22/98 10:05	917	32	60	45	146
02/28/99 09:04	02/28/99 19:34	2,987	20	72	276	367
03/01/99 10:52	03/01/99 10:52	0	0	0	0	0
03/03/99 21:23	03/04/99 08:00	558	6	16	144	119
04/04/99 20:23	04/05/99 02:23	1,755	22	69	155	215
05/22/99 23:45	05/23/99 04:13	1,876	12	47	53	261
06/14/99 17:29	06/14/99 20:28	3,548	115	283	115	863
07/12/99 19:42	07/12/99 23:11	644	3	17	37	67
08/14/99 16:49	08/14/99 21:17	2,269	53	73	71	347
08/20/99 04:31	08/20/99 13:39	1,004	2	15	85	55
08/24/99 04:15	08/24/99 08:43	1,898	62	119	128	293
08/25/99 17:10	08/25/99 20:09	0	84	198	0	251
08/27/99 20:55	08/28/99 02:55	575	26	80	131	152
09/08/99 22:05	09/08/99 23:36	287	12	28	51	74
09/09/99 02:36	09/10/99 03:32	1,673	38	110	228	285
09/16/99 06:05	09/16/99 20:19	14,727	604	2,179	1,795	2,993

Table 5.8. Coefficient of Determination Between Observed and Simulated Lower Beaverdam Creek Storm Loads

Constituent	All Storms	All Storms Except Hurricane Floyd
Total Suspended Solids	0.66	0.20
BOD	0.03	0.10
Total Phosphorus	0.58	0.47
Total Kjeldahl Nitrogen	0.16	0.30
Nitrate	0.01	0.06

Table 6.1 Average Annual Loads Northeast Branch

Land Use	SED (tons/y)	BOD (lbs/yr)	TP (lbs/yr)	NH4 (lbs/yr)	NO3 (lbs/yr)	ORN (lbs/yr)
Commercial	1,311	230,339	2,982	994	28,474	42,174
Corn	490	5,341	603	1,623	2,564	1,446
Forest	1,628	51,818	1,887	4,623	38,571	45,977
Hay	26	1,478	202	165	1,348	57
Industrial	617	98,657	1,576	151	7,805	7,789
LDR	1,124	249,491	7,035	1,344	40,324	33,498
HDR	1,681	324,739	9,536	871	29,978	41,479
Pasture	37	970	354	316	340	96
Edge-of-Stream	6,912	980,834	24,176	10,087	149,404	172,515
PS	17	2,217	2,300	186	8,757	958
In-stream	8,793	-247,664	29,380	6,075	12,119	53,520
Total	15,817	733,243	53,627	16,168	161,891	226,066

Table 6.2 Average Annual Loads Northwest Branch

Land Use	SED (tons/y)	BOD (lbs/yr)	TP (lbs/yr)	NH4 (lbs/yr)	NO3 (lbs/yr)	ORN (lbs/yr)
Commercial	427	115,581	1,361	209	6,649	19,875
Forest	314	19,484	396	178	4,791	5,780
Industrial	37	6,923	108	8	413	522
LDR	1,781	526,948	14,271	2,420	48,248	65,276
HDR	647	187,752	5,154	405	11,626	21,936
Edge-of-Stream	3,206	856,689	21,290	3,220	71,727	113,389
In-stream	1,754	-132,606	5,790	2,802	1,562	13,901
Total	4,960	724,083	27,080	6,022	73,289	127,290

Table 6.3 Average Annual Loads Lower Beaverdam Creek

Land Use	SED (tons/yr)	BOD (lbs/yr)	TP (lbs/yr)	NH4 (lbs/yr)	NO3 (lbs/yr)	ORN (lbs/yr)
Commercial	468	94,971	1,169	216	7,681	16,739
Forest	264	7,849	286	519	6,811	6,146
Industrial	539	87,352	1,377	69	6,570	
LDR	49	4,085	118	76	769	65,276
HDR	825	184,979	5,129	287	21,599	21,936
Edge-of-Stream	2,145	379,236	8,079	1,167	51,823	113,389
In-stream	4,189	-22,802	8,515	788	-14,444	13,901
Total	6,334	358,434	16,594	1,955	37,378	127,290

Table 6.4. Comparison of Average Annual Loads Between TAM/WASP Model Loads, Phase I HSPF Model of the Non-Tidal Anacostia, and Phase I Model

	Sediment (ton/yr)	BOD (lbs/yr)	TP (lbs/yr)	NH4 (lbs/yr)	NO3 (lbs/yr)	ORN (lbs/yr)	TN (lbs/yr)
TAM/WASP Model (Mandel and Schultz, 2000*; Schultz, 2001*)							
Northeast Branch Northwest Branch	30,470*	1,686,142	100,331	17,061	225,101	213,316	455,478
Lower Beaverdam Creek	752*	127,587	2,557	1,757	15,818	1,993	19,568
Total	31,222*	1,813,729	102,888	18,818	240,919	215,309	475,046
Phase I Model (Manchester and Mandel, 2001)							
Northeast Branch	23,637	1,062,932	76,274	14,317	122,522	392,491	529,330
Northwest Branch	26,109	569,585	44,255	6,814	111,238	771,904	889,956
Lower Beaverdam Creek	21,422	442,907	13,585	2,331	14,159	243,845	260,335
Total	71,168	2,075,424	134,114	23,462	247,919	1,408,240	1,679,621
Phase II Model							
Northeast Branch	15,817	733,243	53,627	16,168	161,891	226,066	404,125
Northwest Branch	4,960	724,083	27,080	6,022	73,289	127,290	206,601
Lower Beaverdam Creek	6,334	358,434	16,594	1,955	33,965	37,378	73,298
Total	27,111	1,815,760	97,301	24,145	269,145	390,734	684,024

Table 6.5. Total Simulated Load as Percent of Observed Load During Phase I Simulation Period

Constituent	Original Phase I Model	Phase I Model with Phase II Parameters
TSS	337%	142%
TP	70%	47%
TKN	625%	37%

Table 6.6. Comparison of Average Annual Loads Between Phase II HSPF Model of the Non-Tidal Anacostia and CBP Phase 4.3 Watershed Model, 2000 Progress Scenario

Constituent	Phase II Model	CBP Phase 4.3
Sediment (tons/yr)	27,111	27,621
Total Phosphorus (lbs/yr)	97,301	92,843
Ammonia (lbs/yr)	24,145	64,185
Nitrate (lbs/yr)	269,145	538,548
Organic Nitrogen (lbs/yr)	390,734	244,867
Total Nitrogen (lbs/yr)	684,024	847,601

Figure 1.1. Location of the Anacostia River Watershed

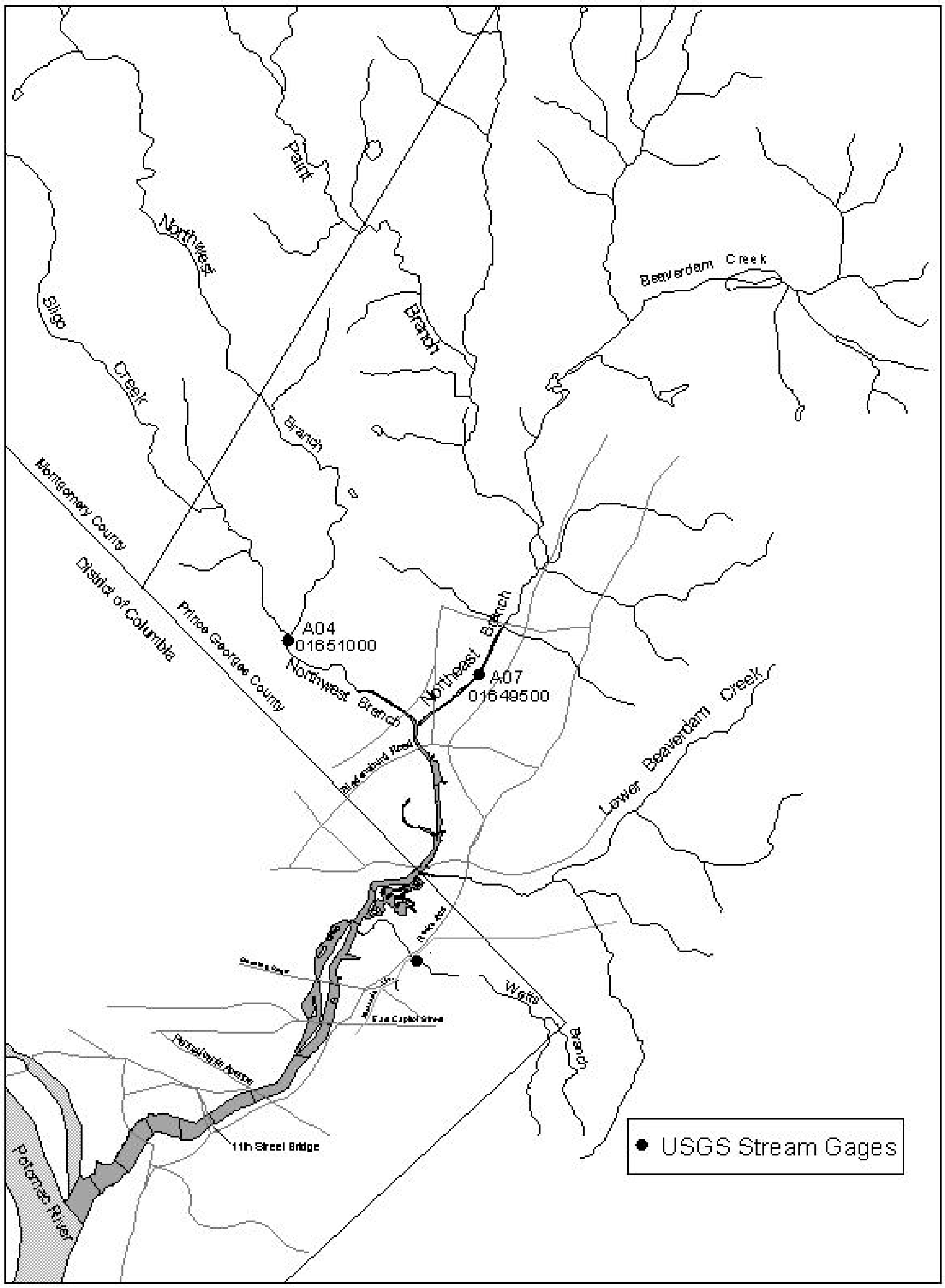


Figure 2.1. Model Segmentation

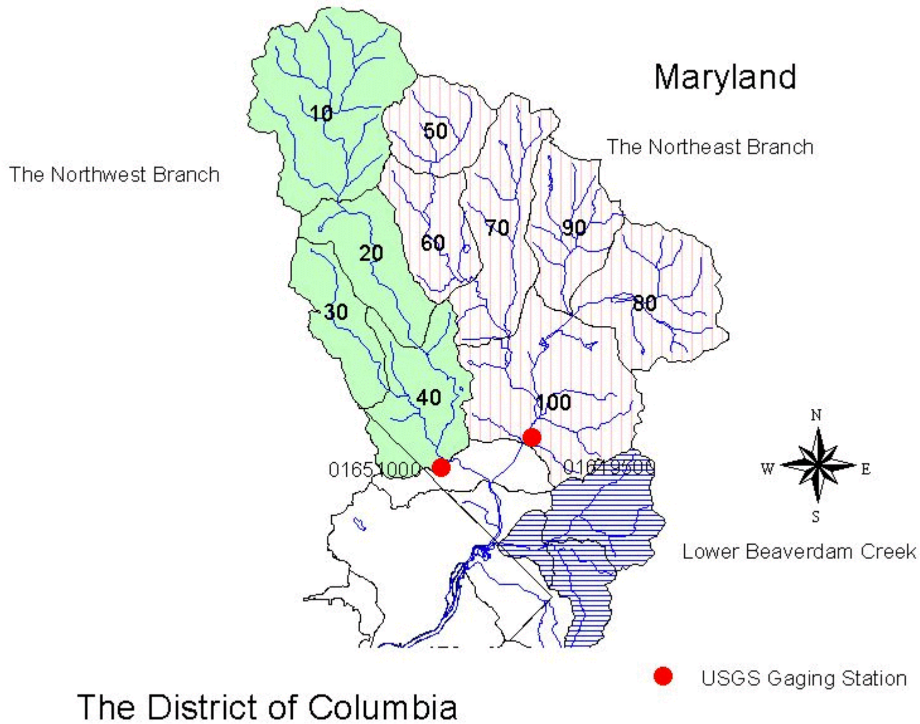


Figure 2.2. Phase I and Phase II Land Uses Northeast Branch

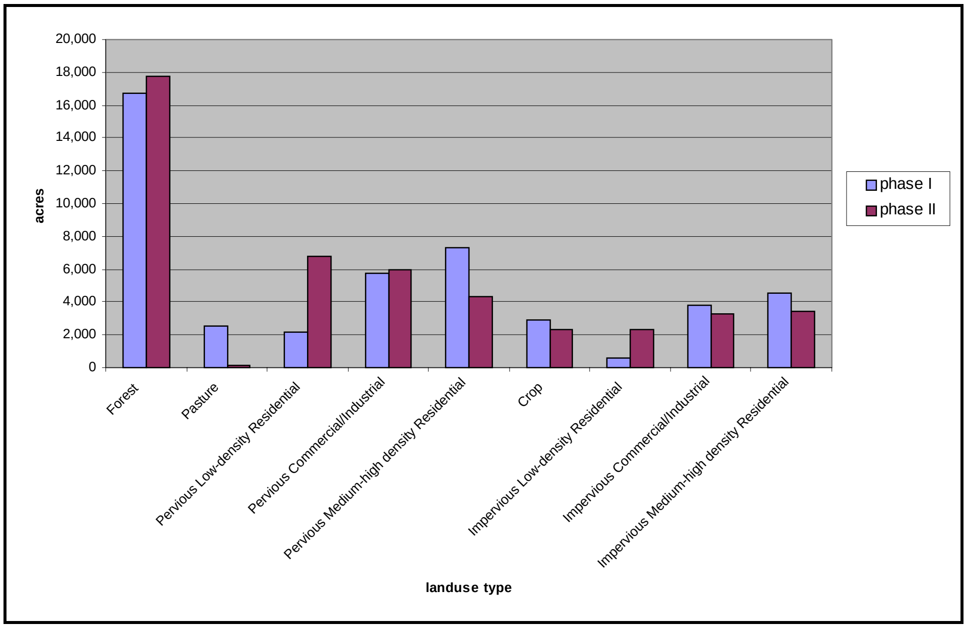


Figure 2.3. Phase I and Phase II Land Uses Northwest Branch

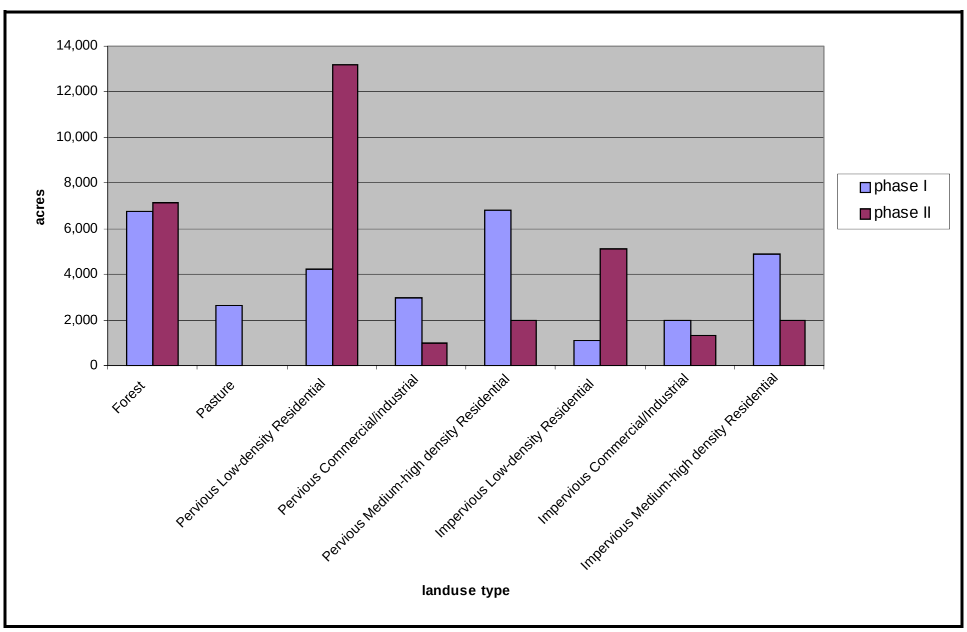


Figure 3.1. Average Monthly Synthetic Pan Evaporation (inches)

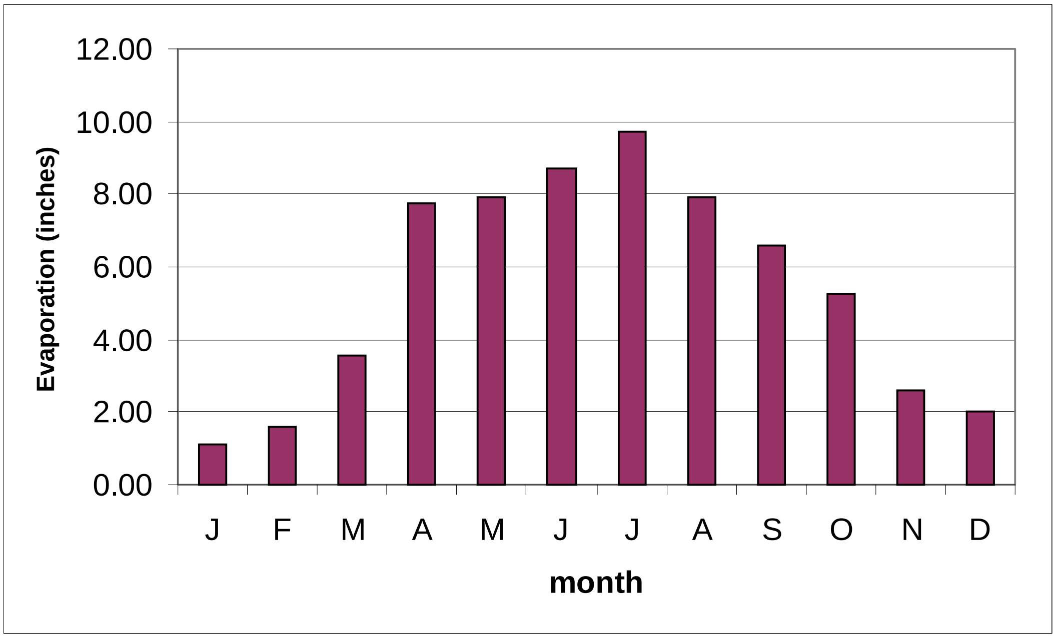


Figure 3.2. Average Daily Simulated and Observed Flows, Northeast Branch

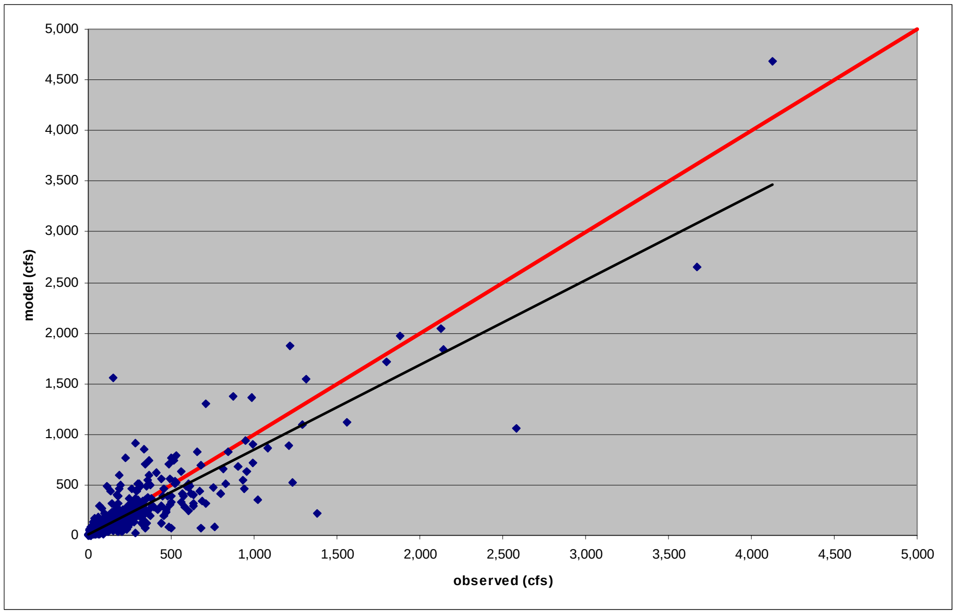


Figure 3.3. Average Monthly Simulated and Observed Flows, Northeast Branch

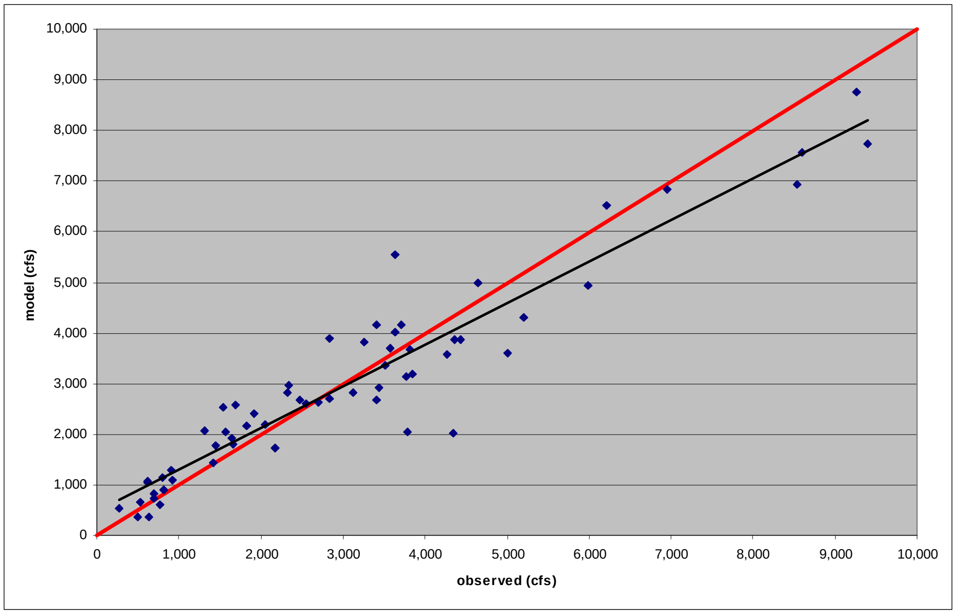


Figure 3.4. Average Seasonal Simulated and Observed Flows, Northeast Branch

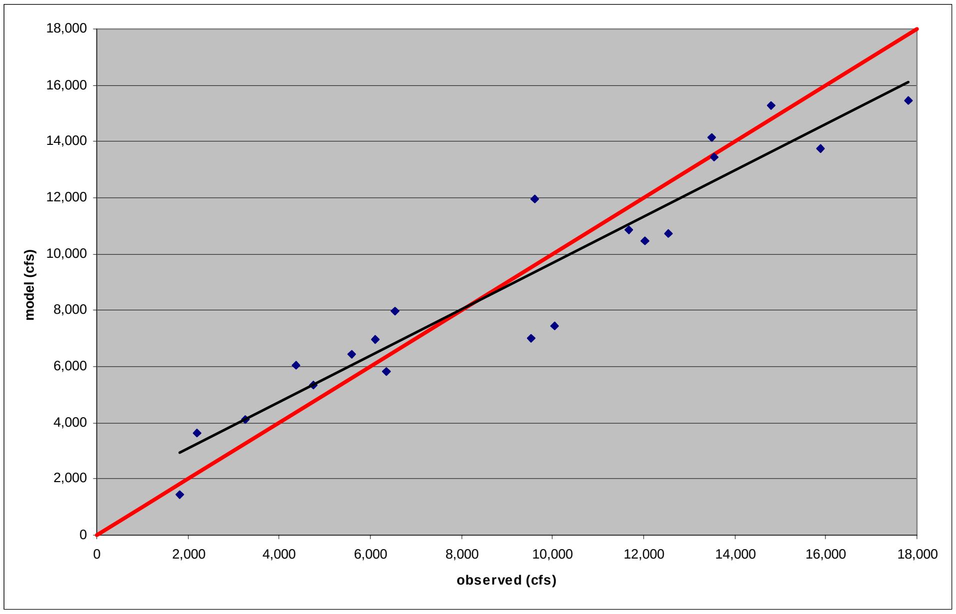


Figure 3.5. Average Daily Simulated and Observed Flows, Northwest Branch

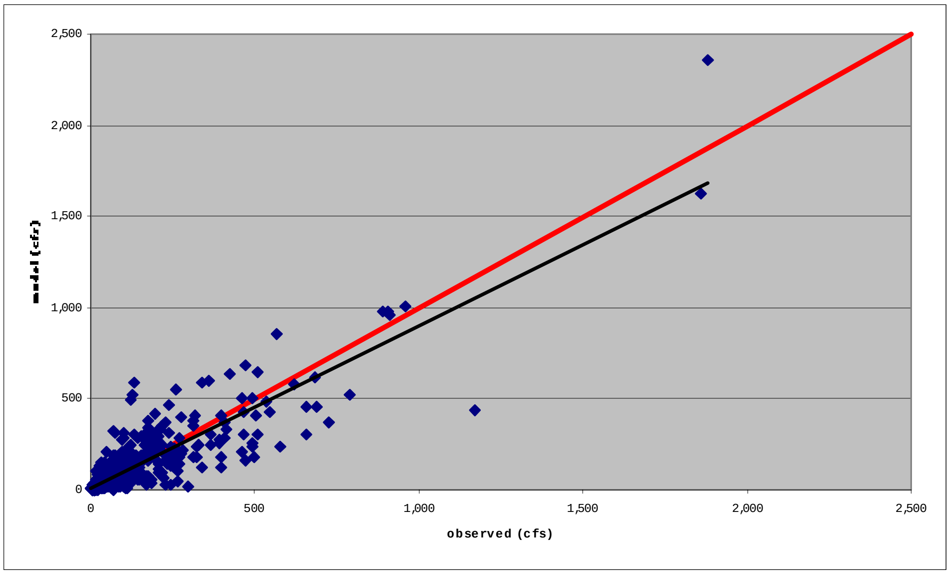


Figure 3.6. Average Monthly Simulated and Observed Flows, Northwest Branch

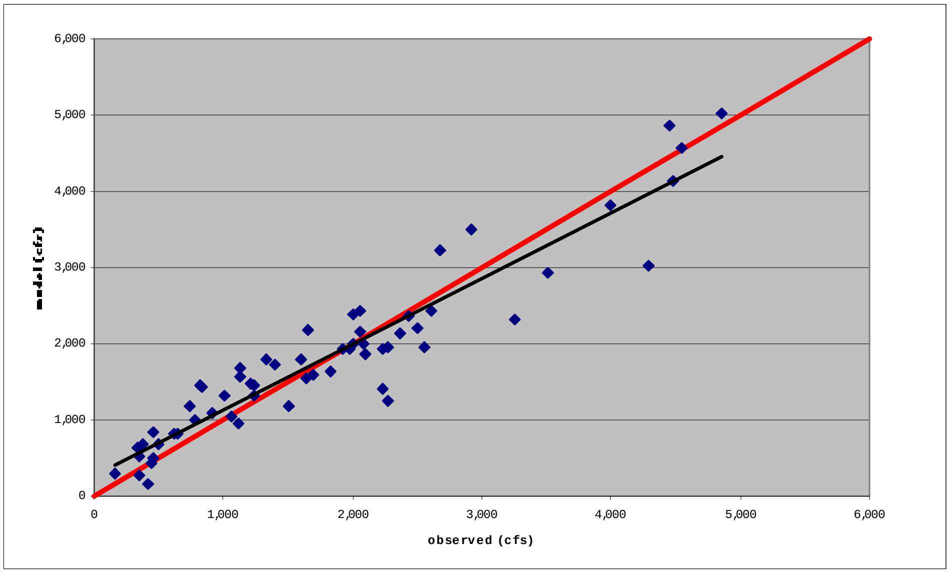


Figure 3.7. Average Seasonal Simulated and Observed Flows, Northwest Branch

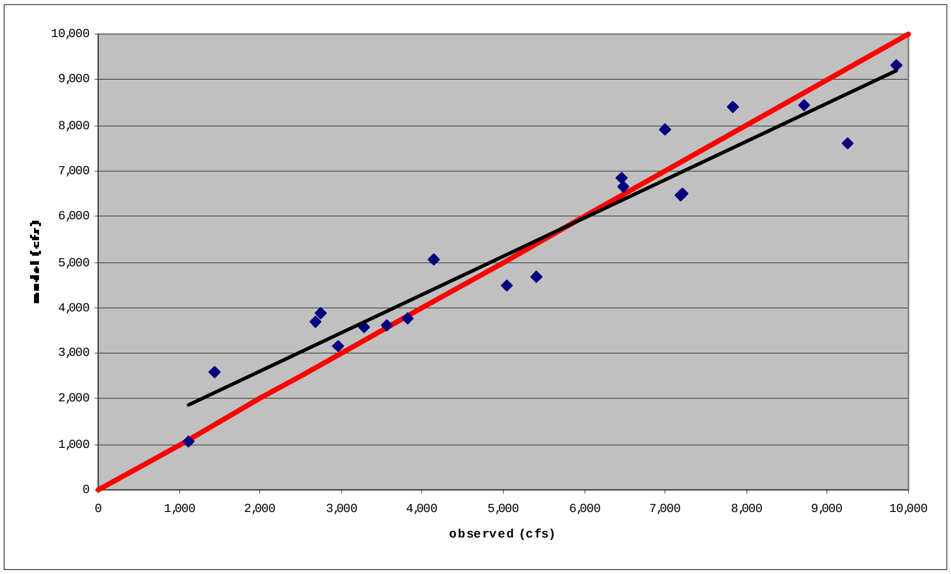


Figure 3.8. Cumulative Distribution of Simulated and Observed Flows, Northeast Branch

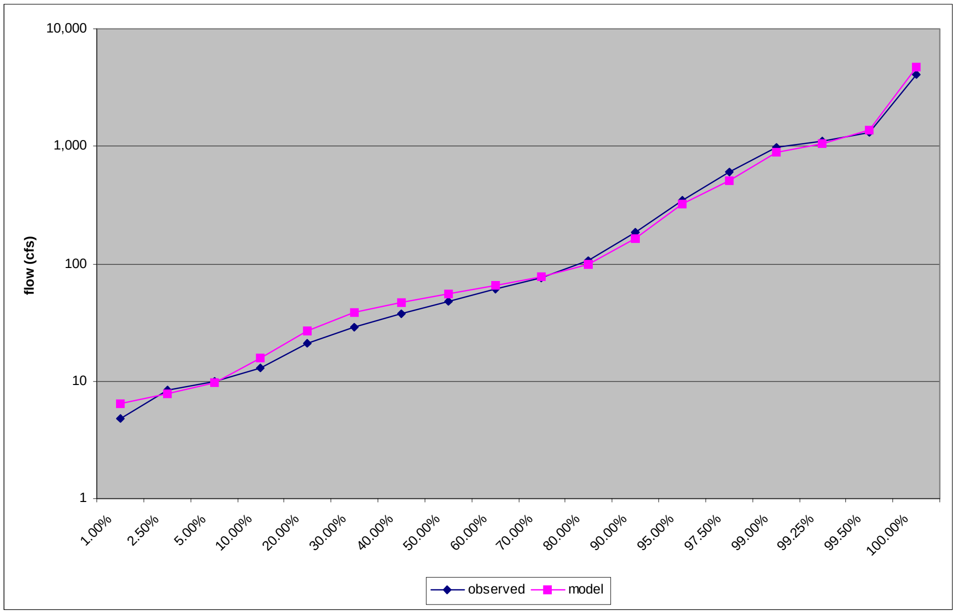


Figure 3.9. Cumulative Distribution of Simulated and Observed Flows, Northwest Branch

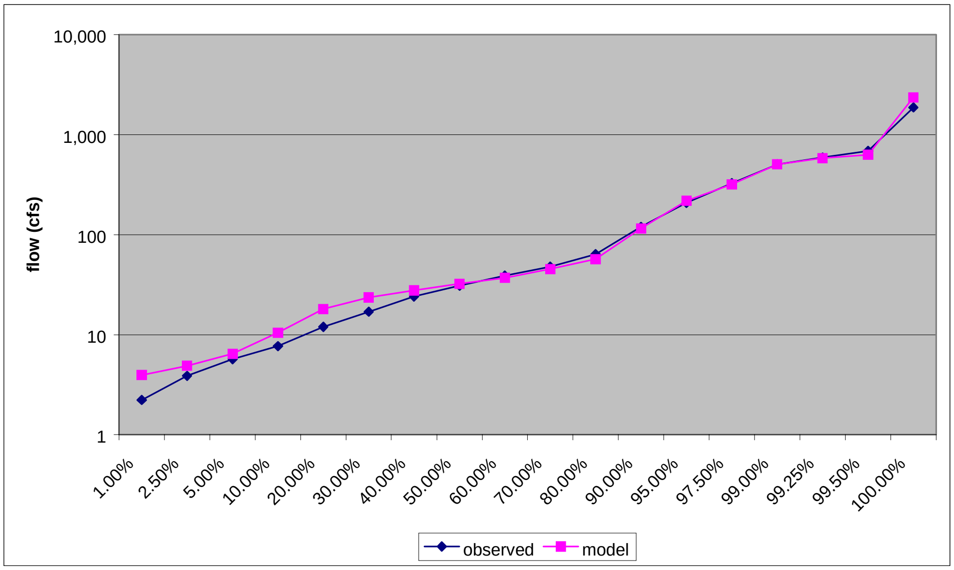


Figure 3.10. Observed and Simulated Flows Northeast Branch

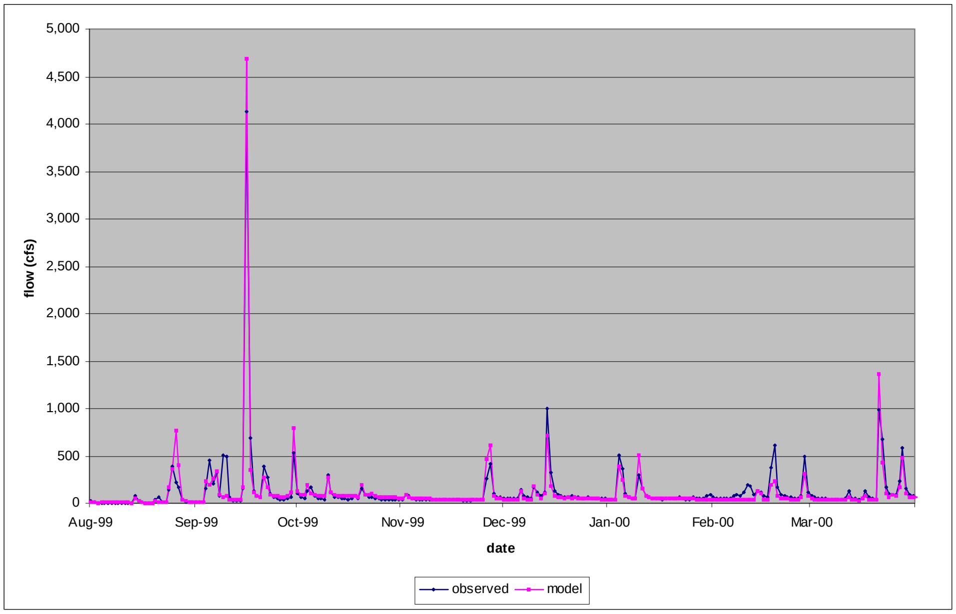


Figure 3.11. Observed and Simulated Flows Northwest Branch

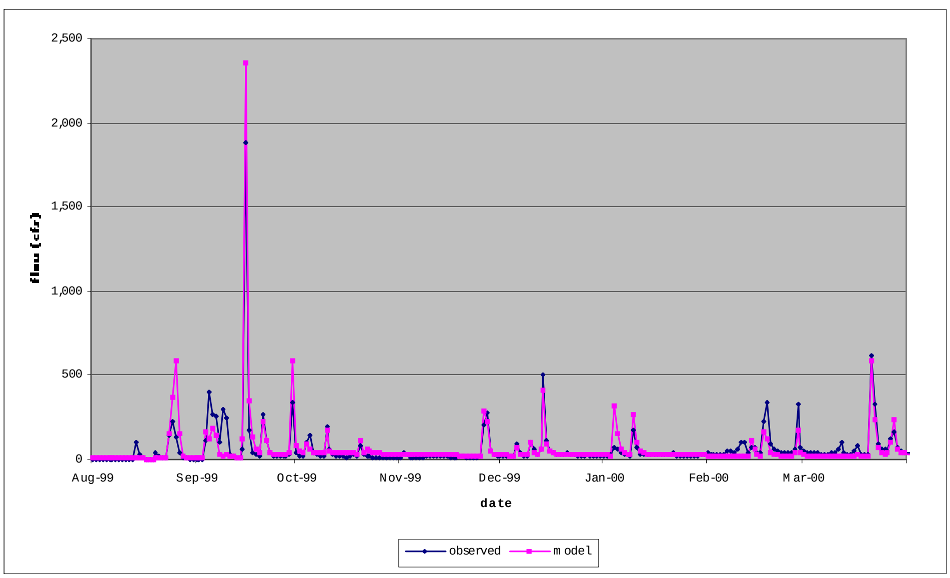


Figure 3.12 Minimum and Maximum Simulated Flow and Observed Instantaneous Flow, Lower Beaverdam Creek

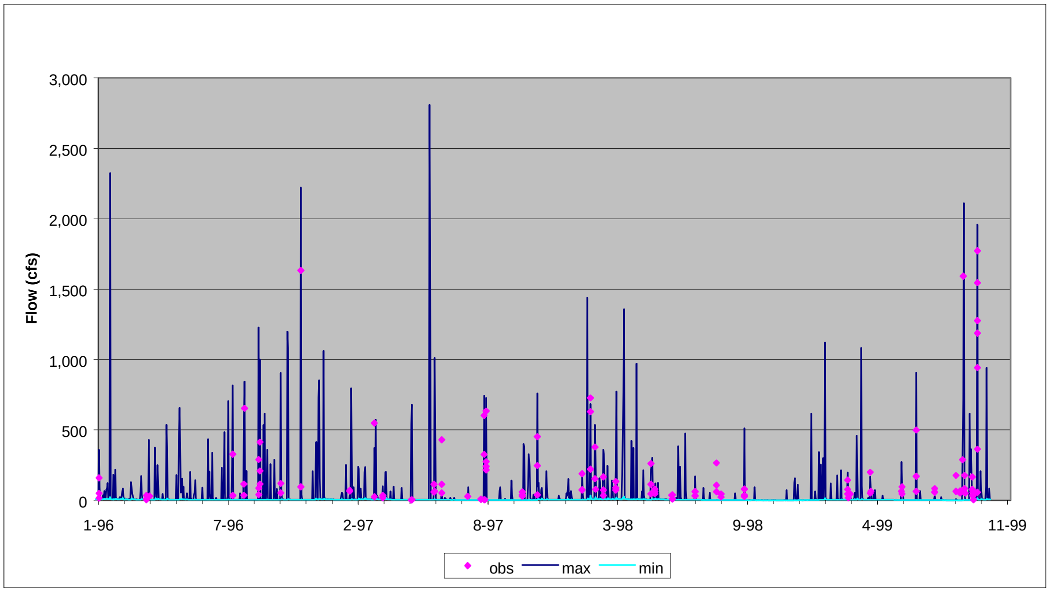


Figure 4.1. Flow-weighted Sediment Concentrations Vs. Average Stormflow, Northeast Branch

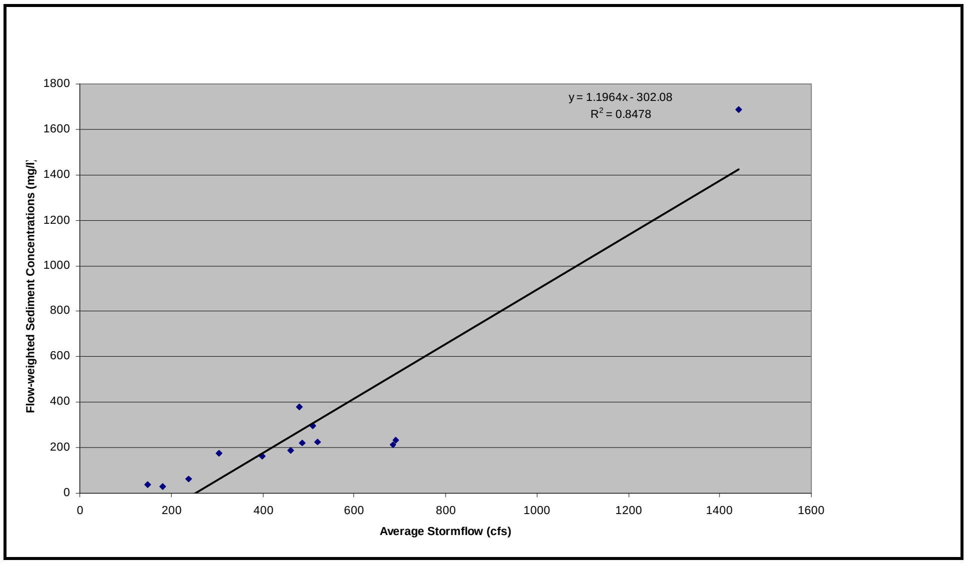


Figure 4.2. Flow-weighted Sediment Concentrations Vs. Average Stormflow, Northwest Branch

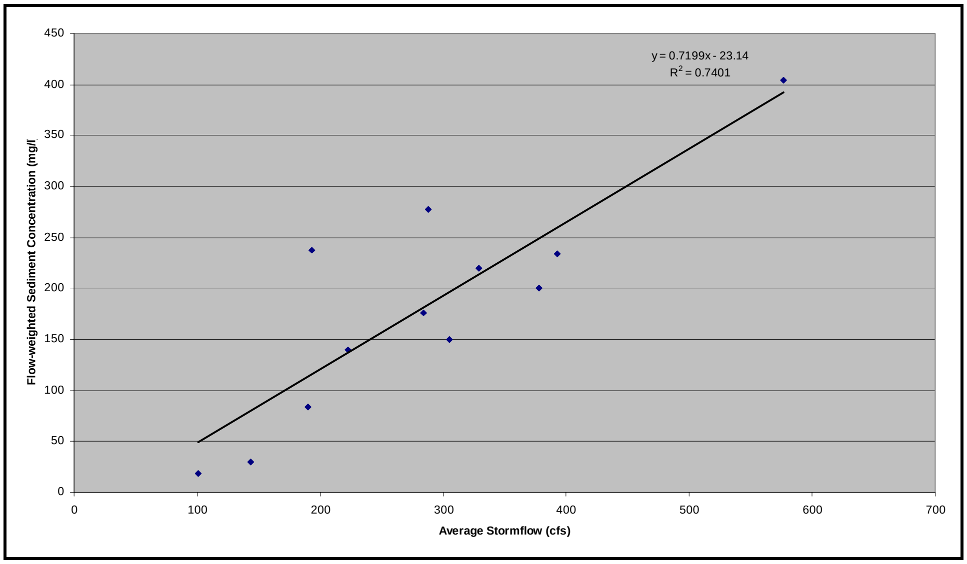


Figure 5.1. Simulated and Observed Temperature Northeast Branch

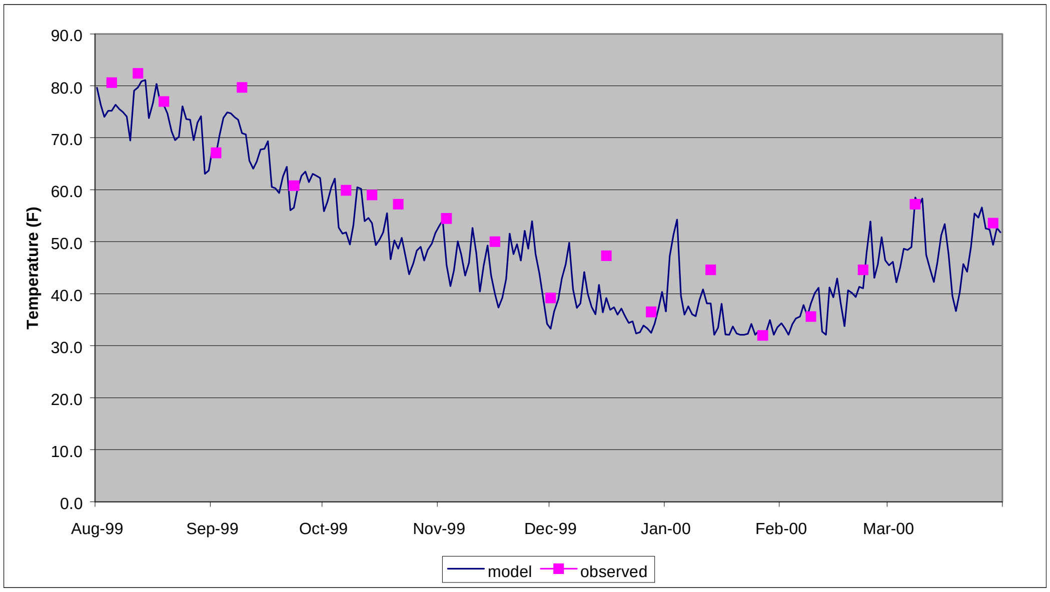


Figure 5.2. Simulated and Observed Dissolved Oxygen Concentrations Northeast Branch

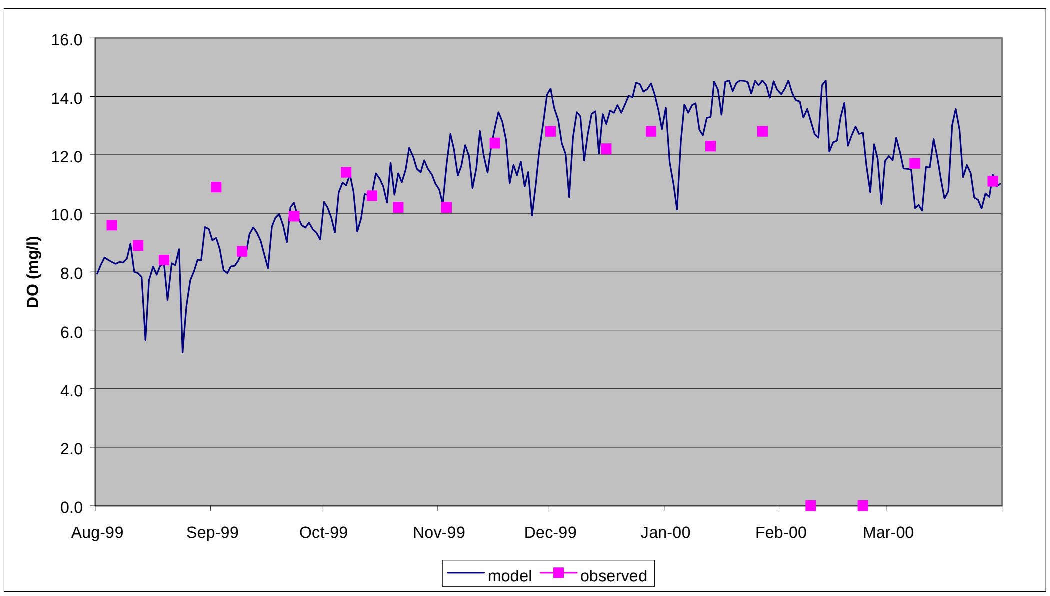


Figure 5.3. Simulated and Observed Sediment Concentrations Northeast Branch

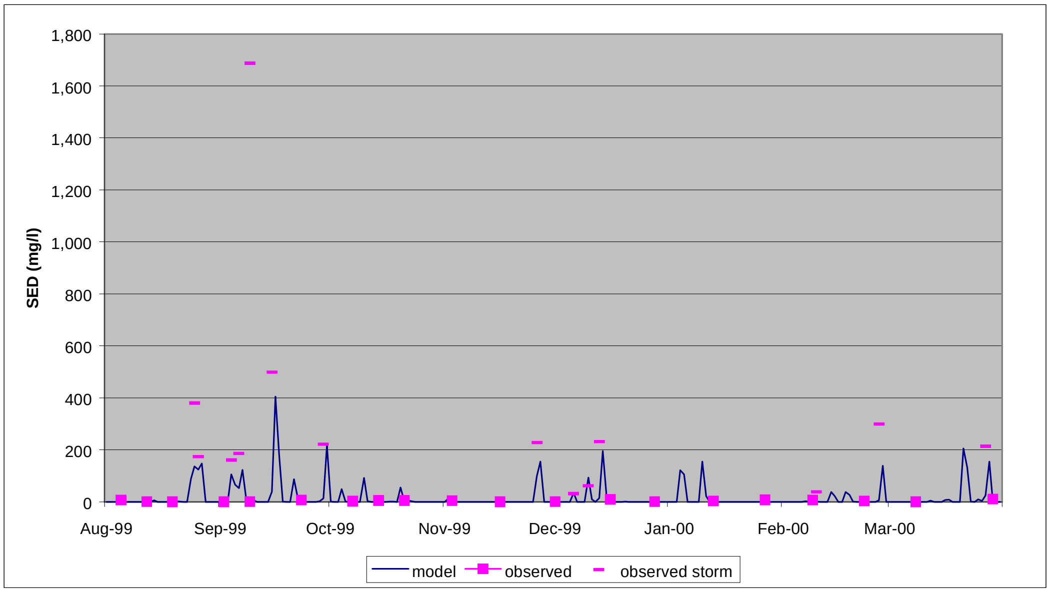


Figure 5.4. Simulated and Observed Sediment Loads (tons) Northeast Branch

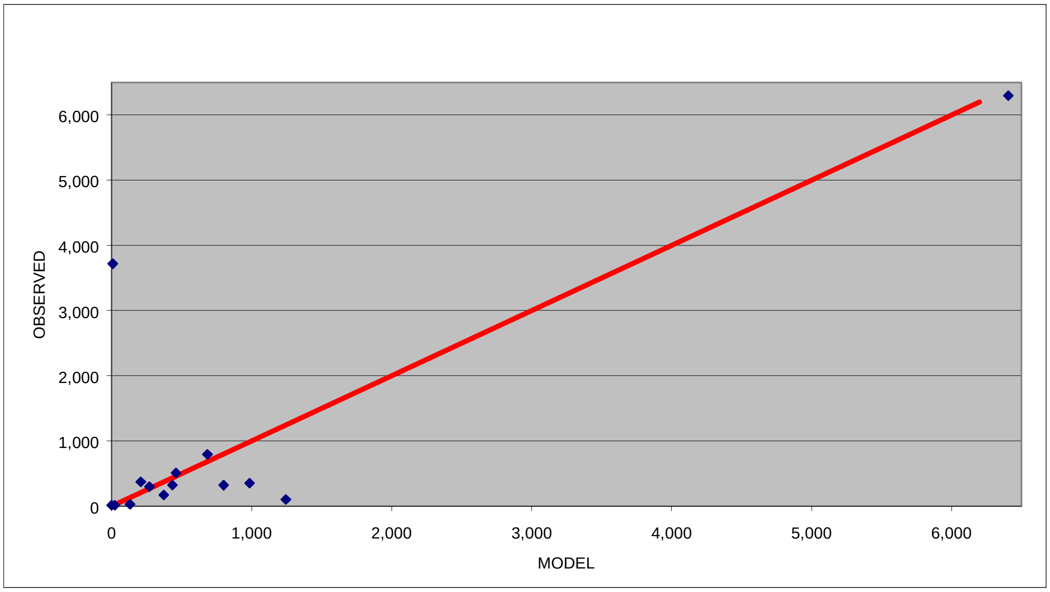


Figure 5.5. Simulated and Observed Biochemical Oxygen Demand Concentrations Northeast Branch

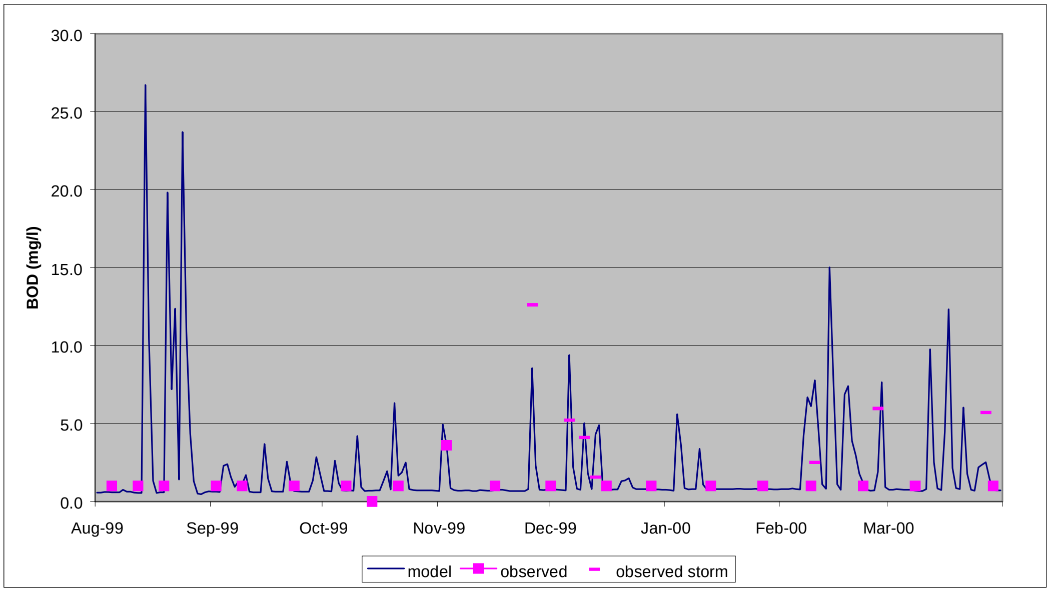
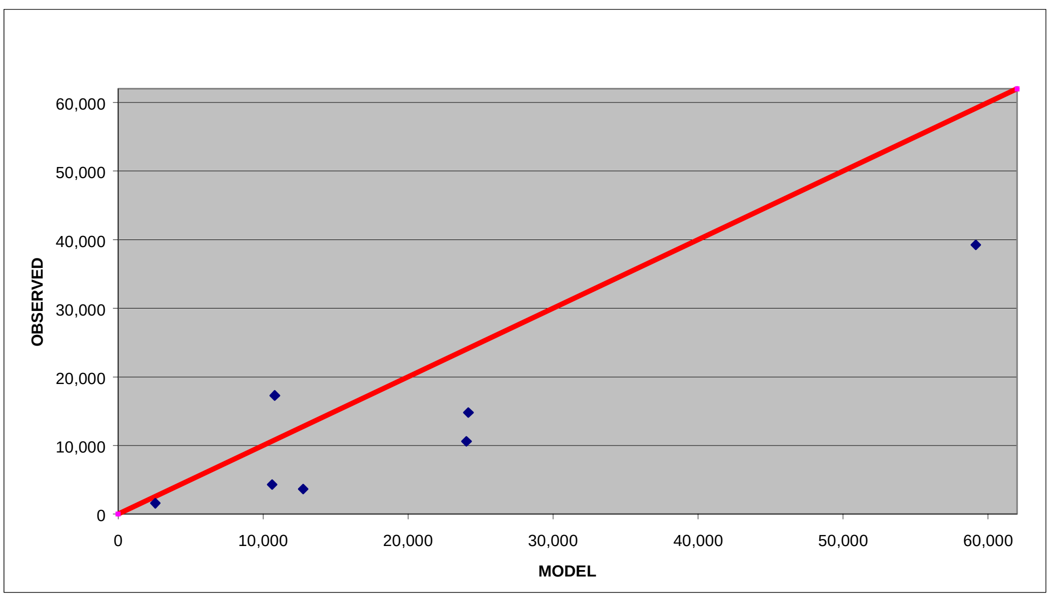


Figure 5.6. Simulated and Observed Biochemical Oxygen Demand Loads (lbs) Northeast Branch



5.7. Simulated and Observed Total Phosphorus Concentrations Northeast Branch

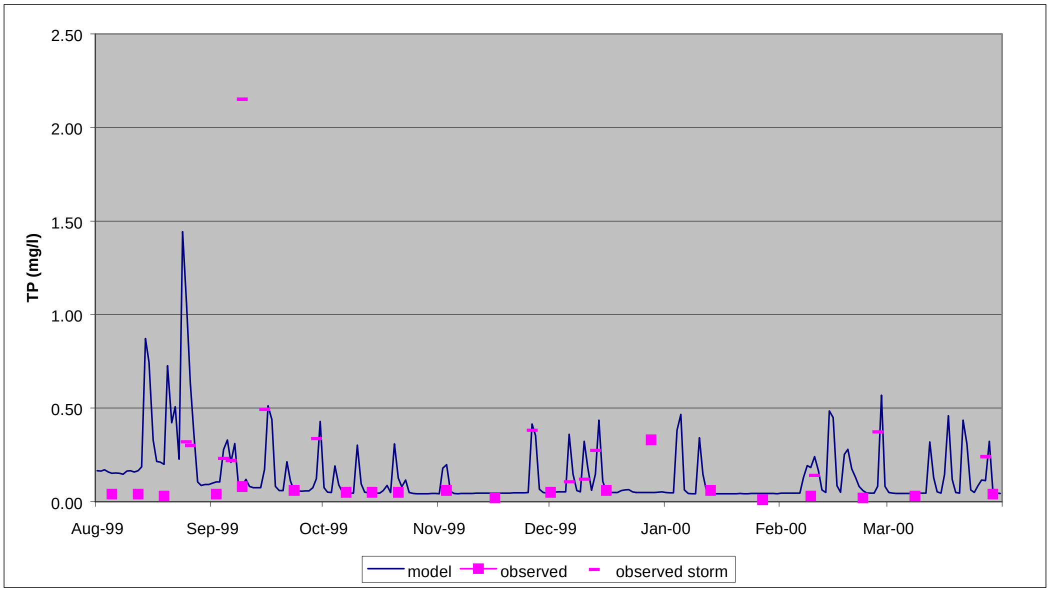


Figure 5.8. Simulated and Observed Total Phosphorus Loads (lbs) Northeast Branch

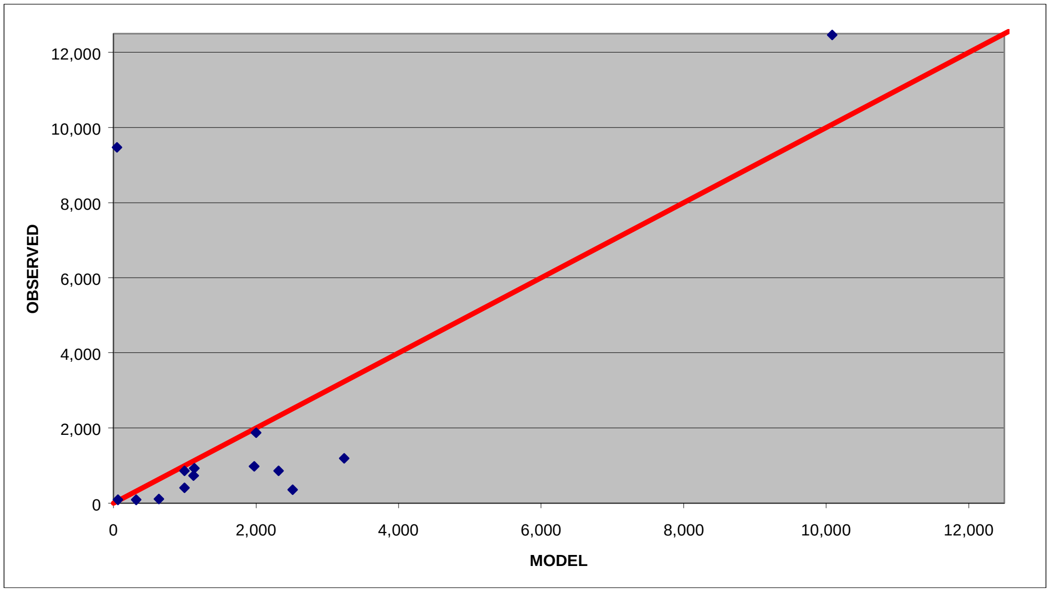


Figure 5.9. Simulated and Observed Nitrate Concentrations Northeast Branch

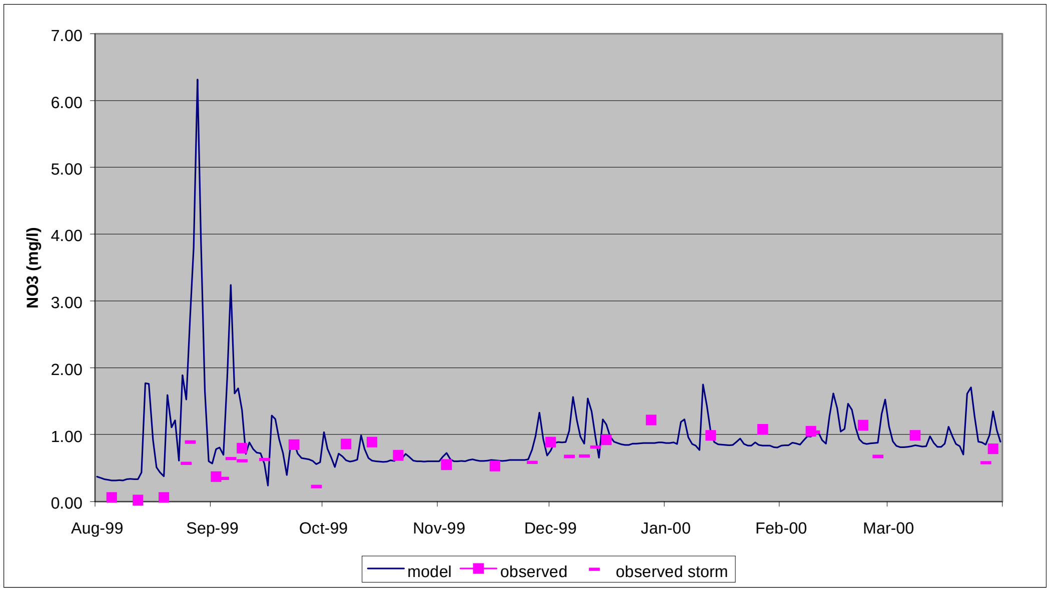


Figure 5.10. Simulated and Observed Nitrate Loads (lbs) Northeast Branch

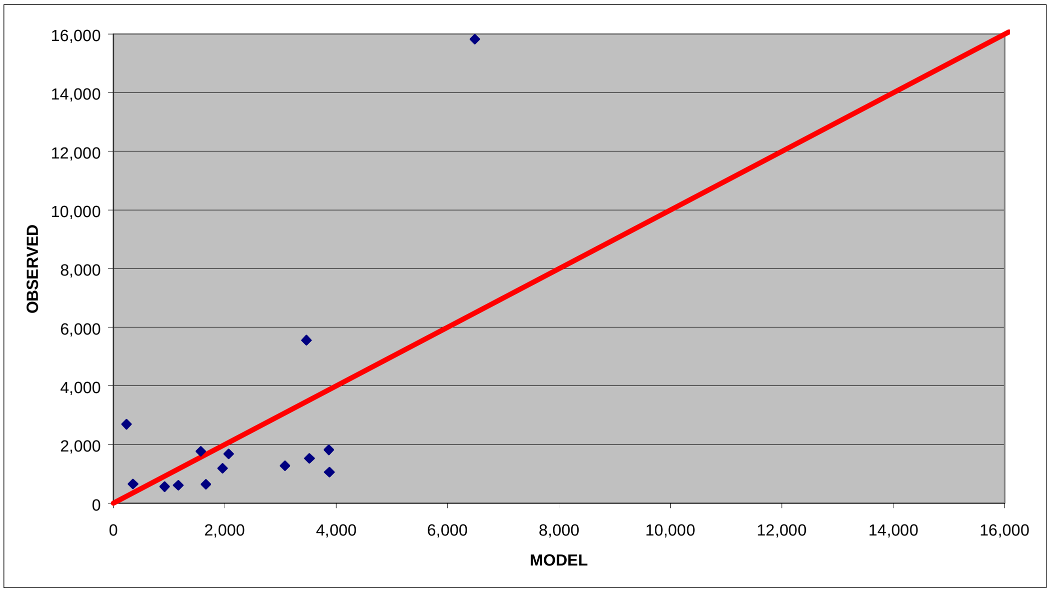


Figure 5.11. Simulated and Observed Ammonium Concentrations Northeast Branch

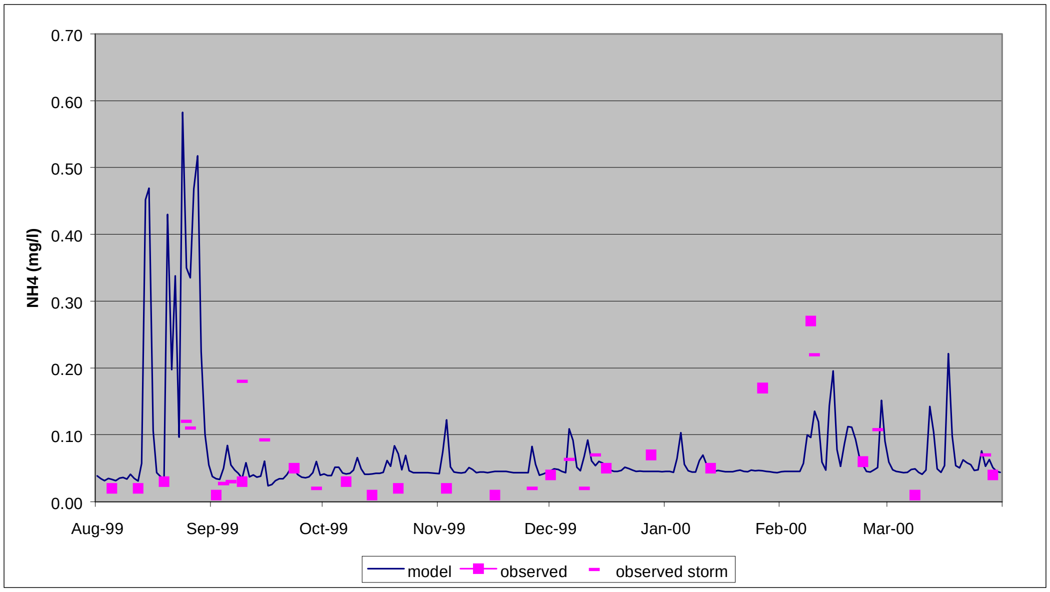


Figure 5.12. Simulated and Observed Ammonium Loads (lbs) Northeast Branch

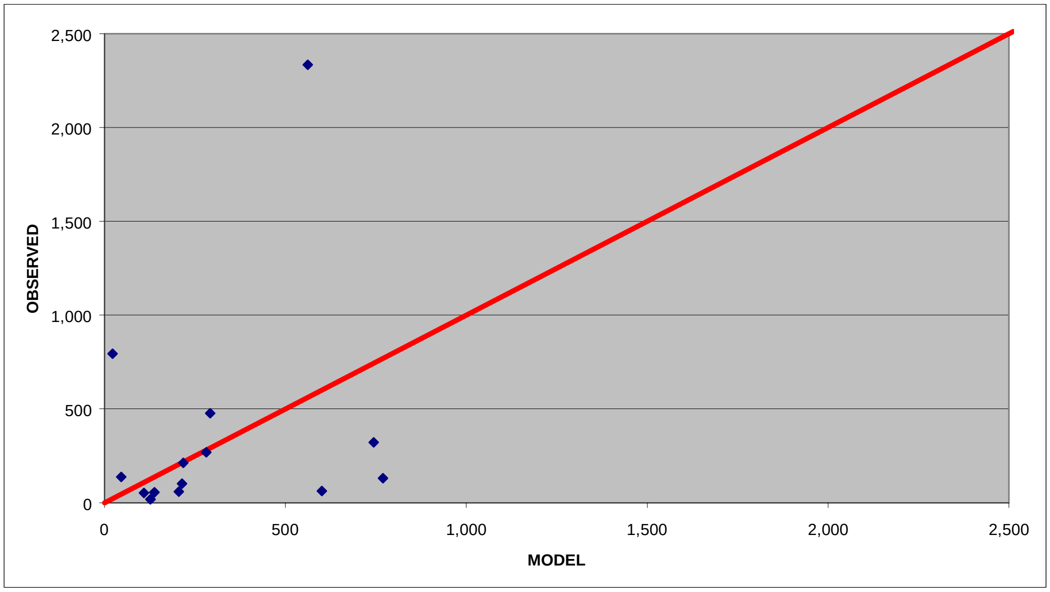


Figure 5.13. Simulated and Observed Organic Nitrogen Concentrations Northeast Branch

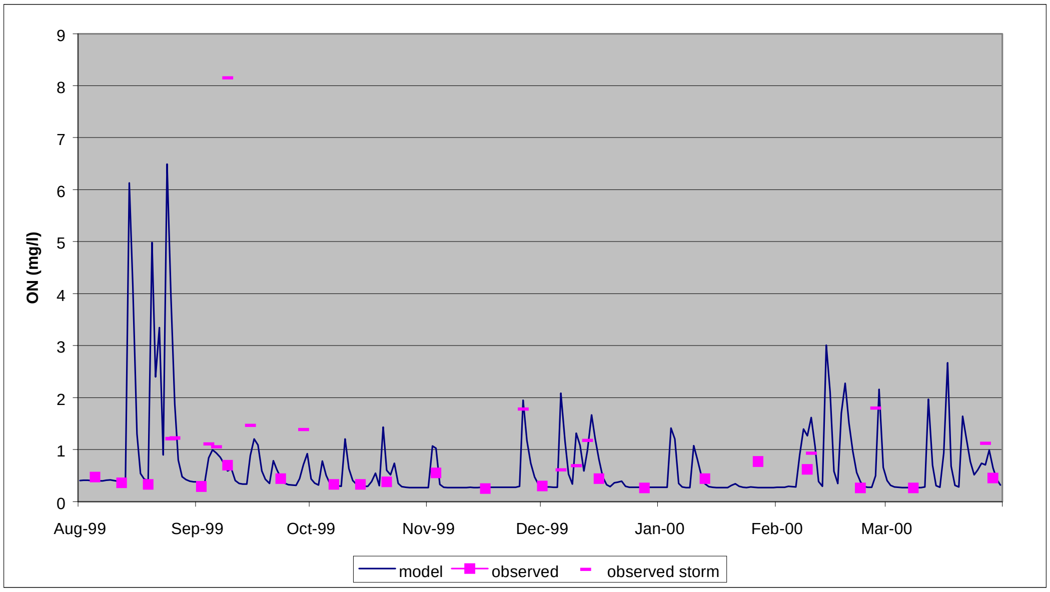


Figure 5.14. Simulated and Observed Organic Nitrogen Loads (lbs) Northeast Branch

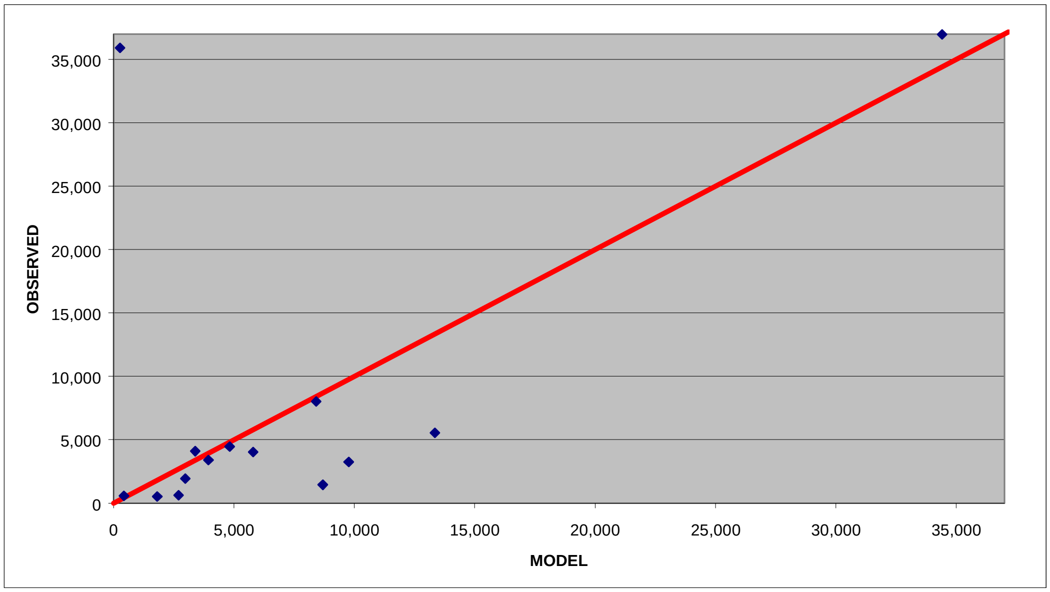


Figure 5.15. Simulated and Observed Chlorophyll Concentrations Northeast Branch

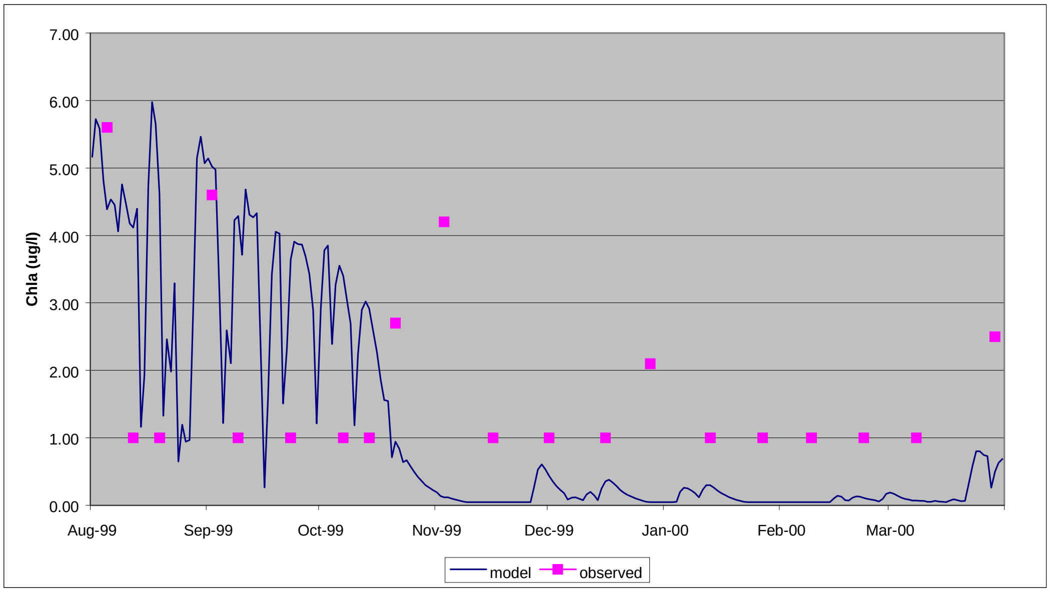


Figure 5.16. Simulated and Observed Temperature Northwest Branch

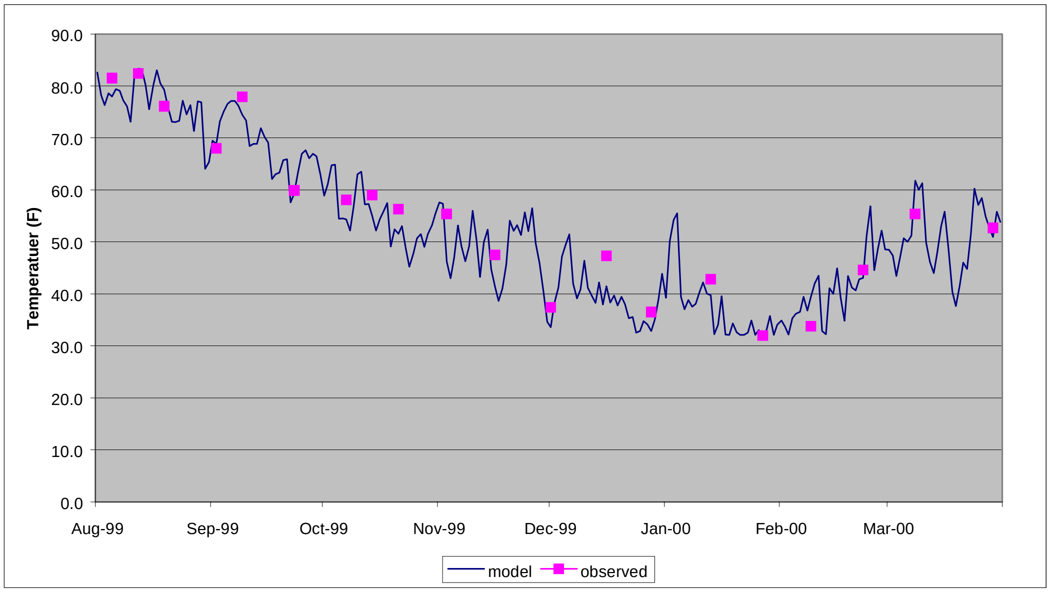


Figure 5.17. Simulated and Observed Dissolved Oxygen Concentrations Northwest Branch

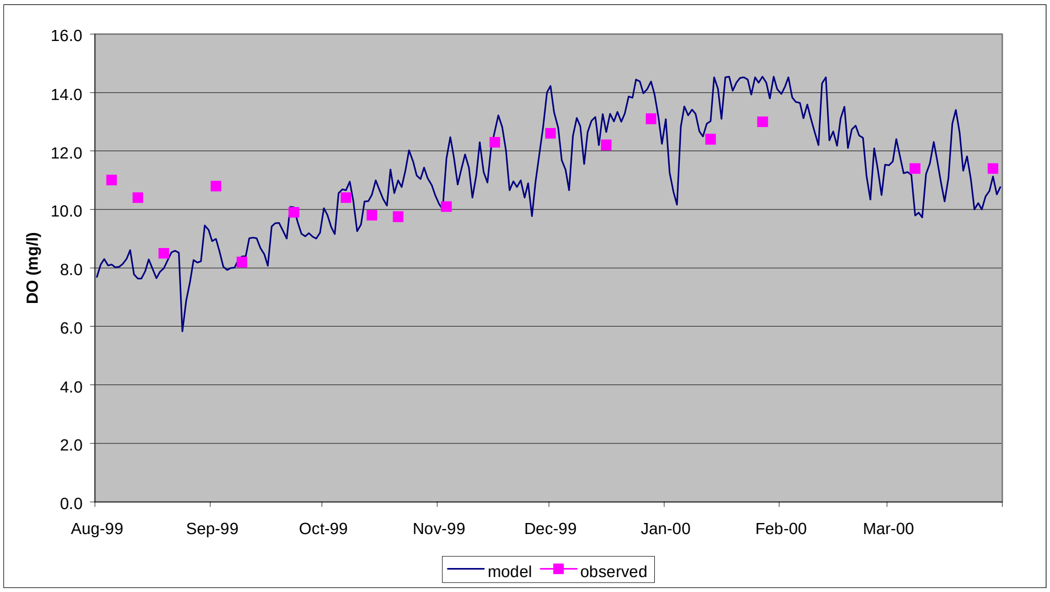


Figure 5.18. Simulated and Observed Sediment Concentrations Northwest Branch

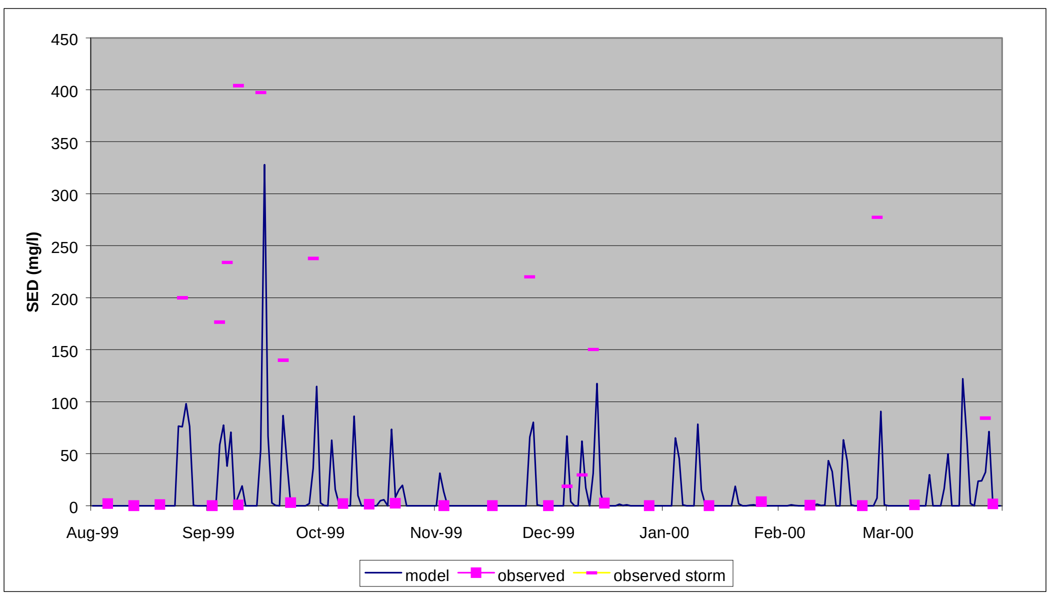


Figure 5.19. Simulated and Observed Sediment Loads (tons) Northwest Branch

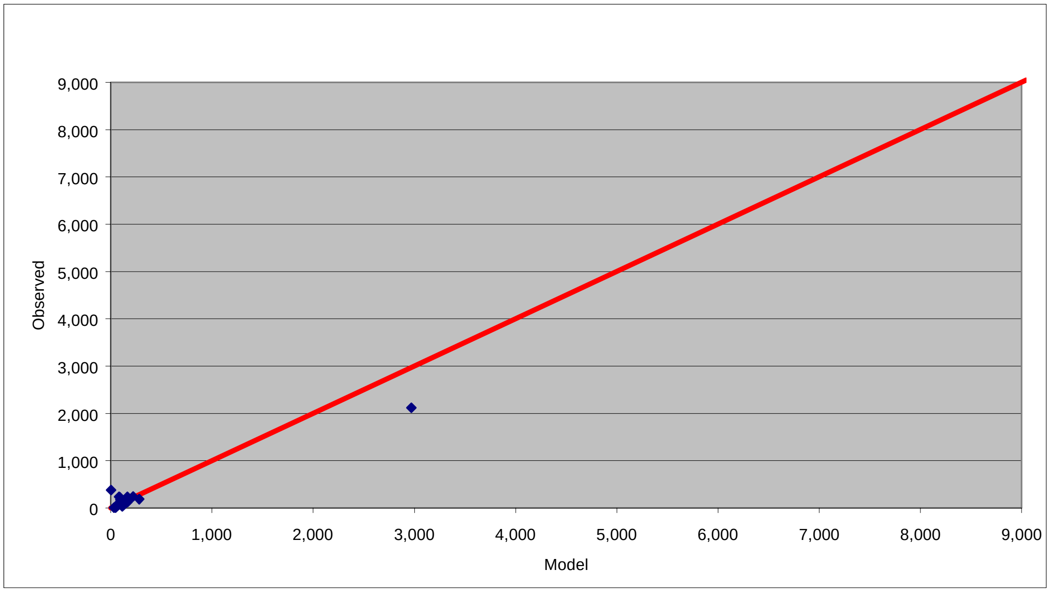


Figure 5.20. Simulated and Observed Biochemical Oxygen Demand Concentrations Northwest Branch

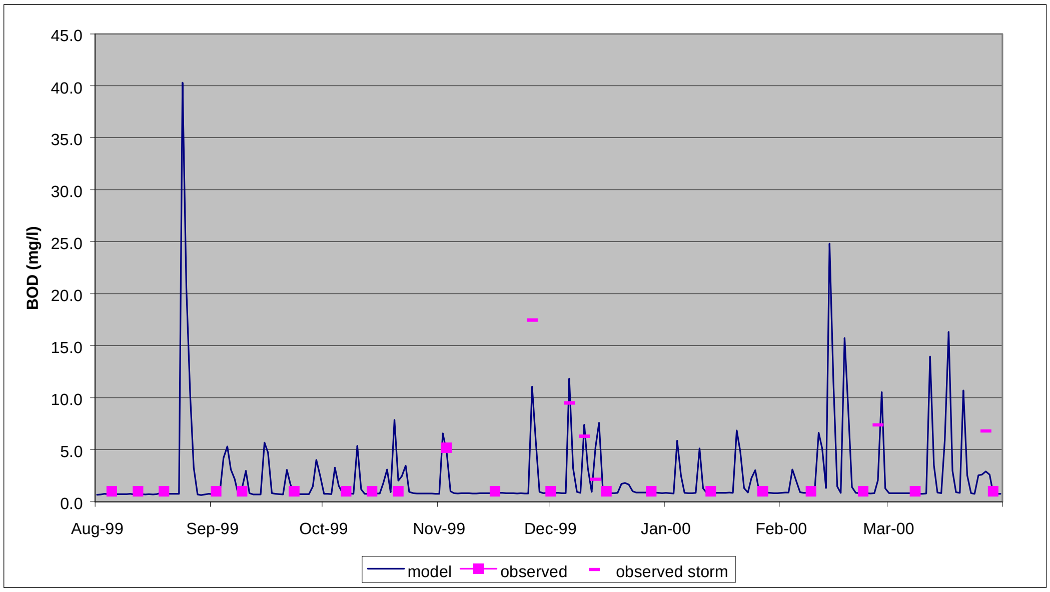


Figure 5.21. Simulated and Observed Biochemical Oxygen Demand Loads (lbs) Northwest Branch

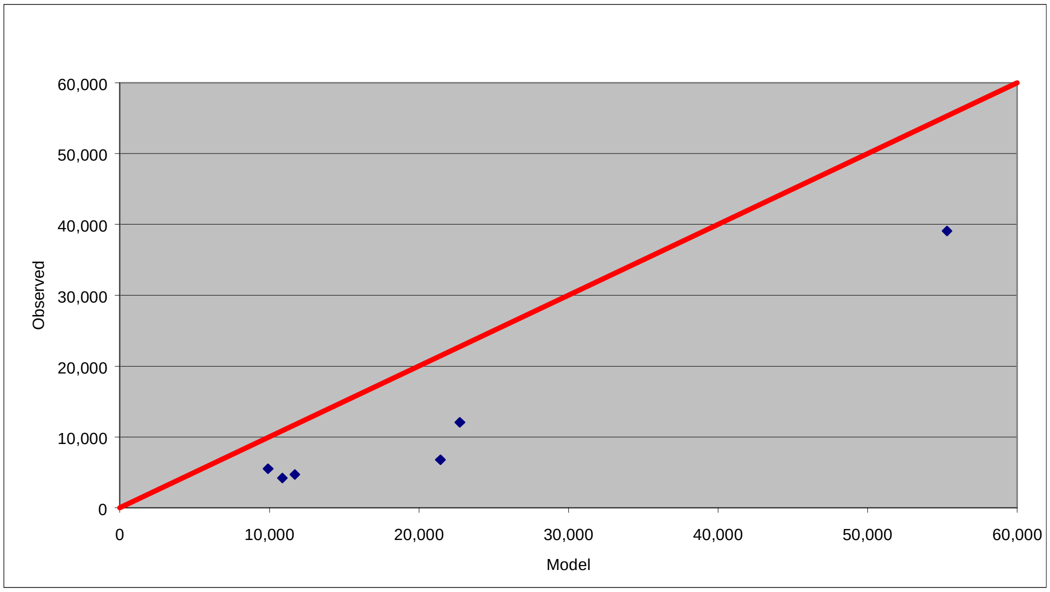


Figure 5.22. Simulated and Observed Total Phosphorus Concentrations Northwest Branch

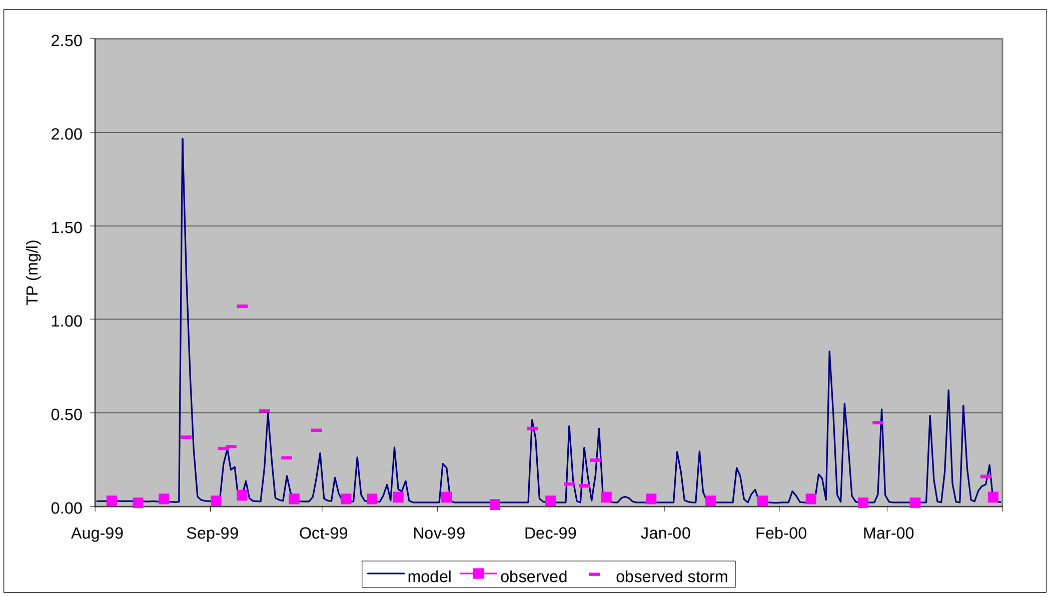


Figure 5.23. Simulated and Observed Total Phosphorus Loads (lbs) Northwest Branch

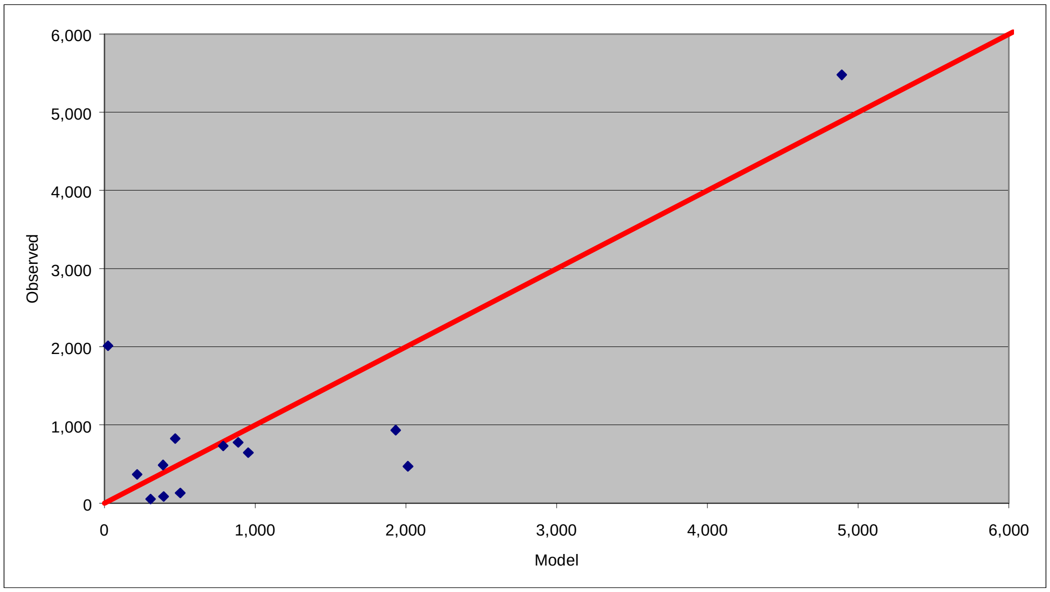


Figure 5.24. Simulated and Observed Nitrate Concentrations Northwest Branch

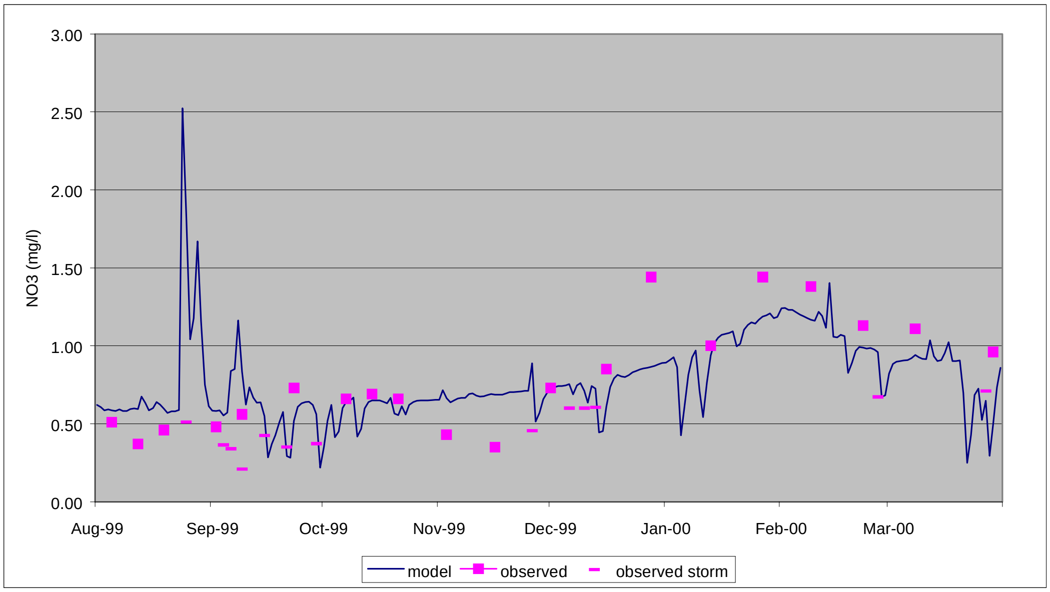


Figure 5.25. Simulated and Observed Nitrate Loads (lbs) Northwest Branch

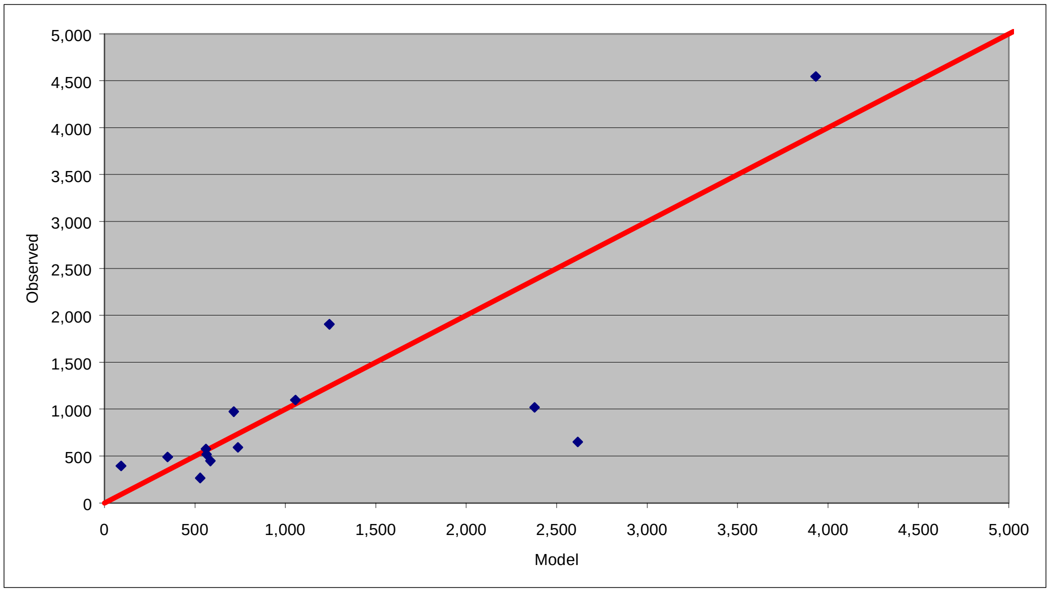


Figure 5.26. Simulated and Observed Ammonium Concentrations Northeast Branch

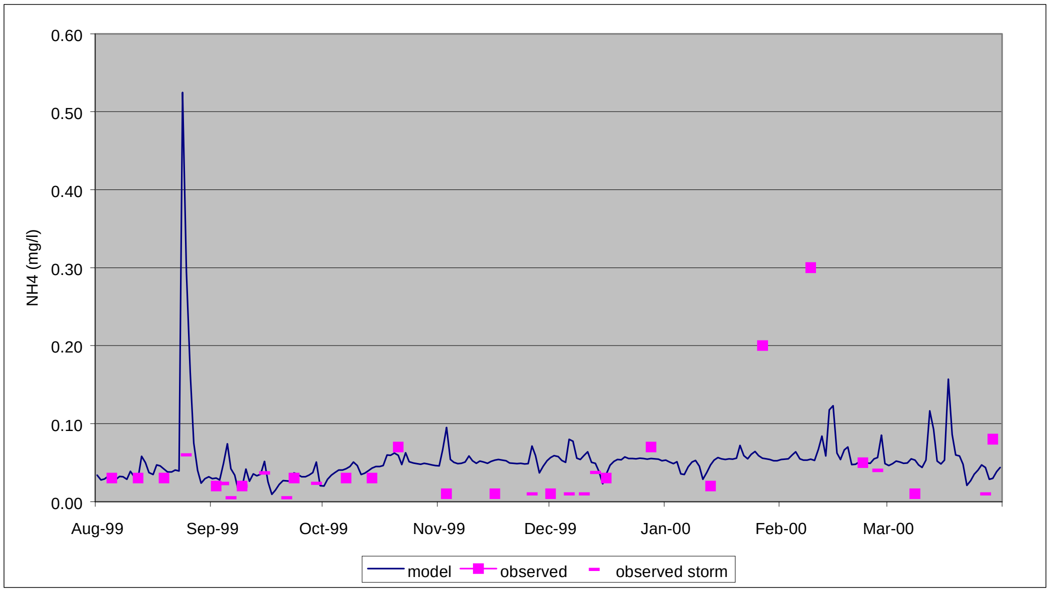


Figure 5.27. Simulated and Observed Ammonium Loads (lbs) Northwest Branch

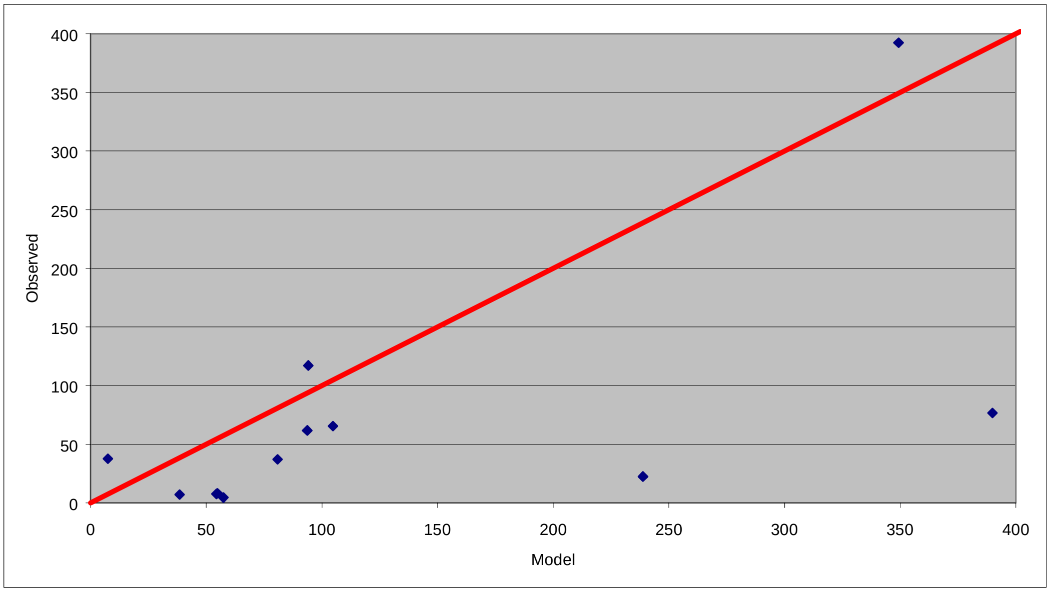


Figure 5.28. Simulated and Observed Organic Nitrogen Concentrations Northeast Branch

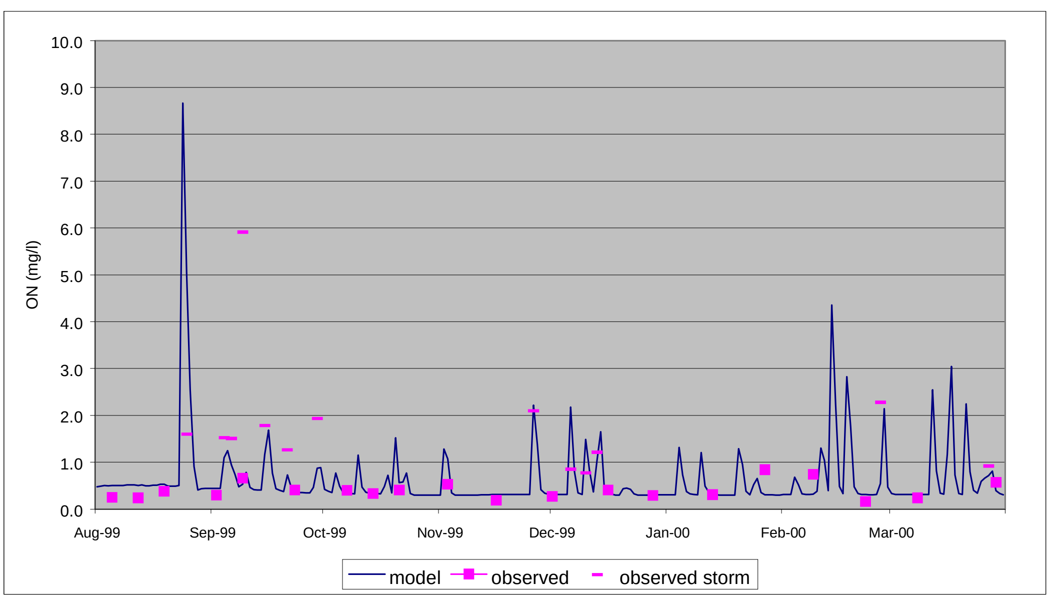


Figure 5.29. Simulated and Observed Organic Nitrogen Loads (lbs) Northwest Branch

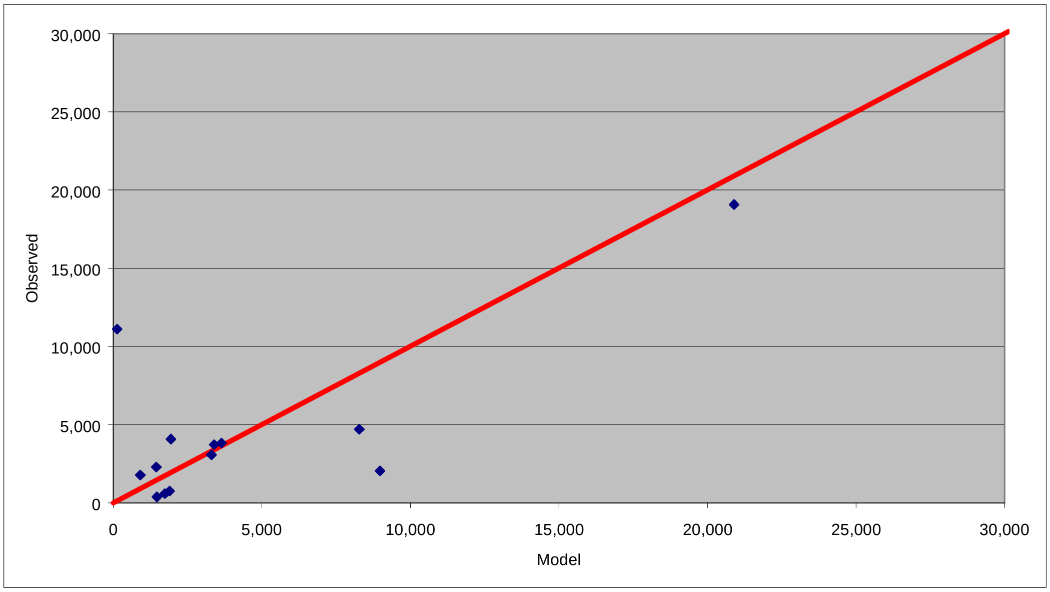


Figure 5.30. Simulated and Observed Chlorophyll Concentrations Northwest Branch

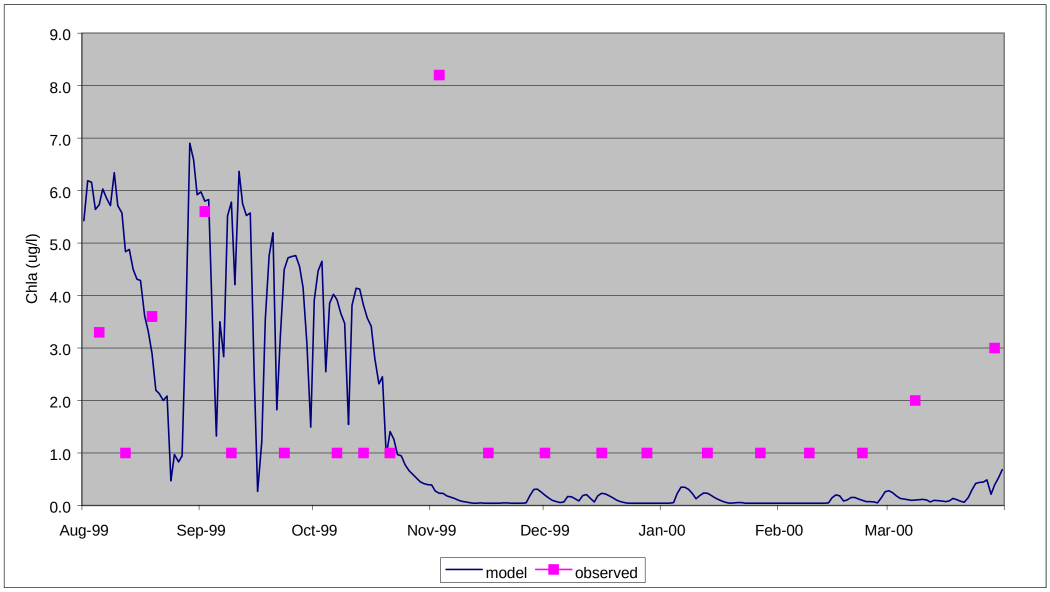


Figure 5.31. Simulated and Observed Sediment Loads (lbs) Lower Beaverdam Creek

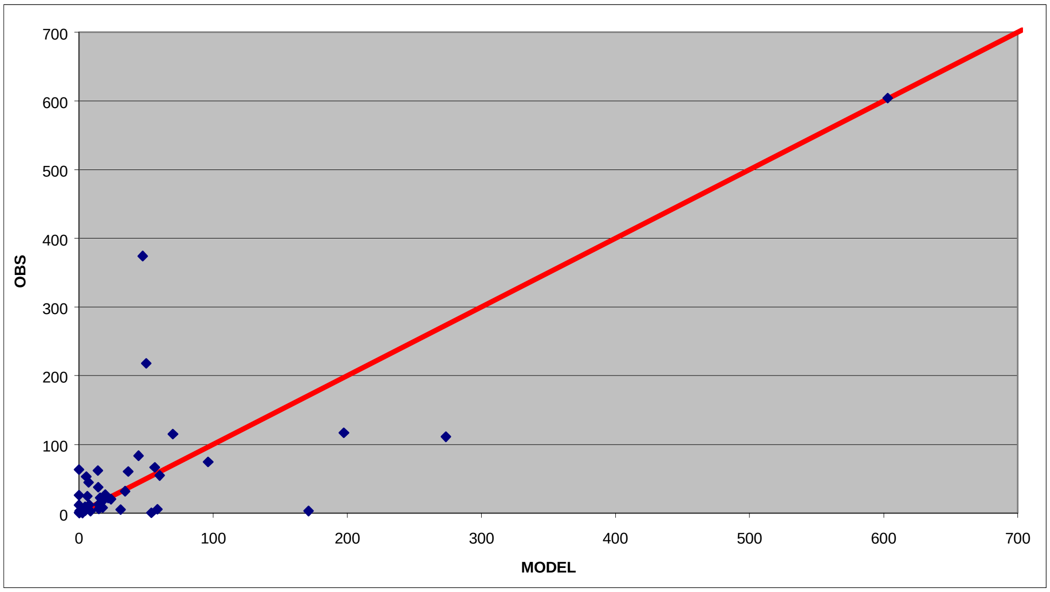


Figure 5.32. Simulated and Observed Total Phosphorus Loads (lbs) Lower Beaverdam Creek

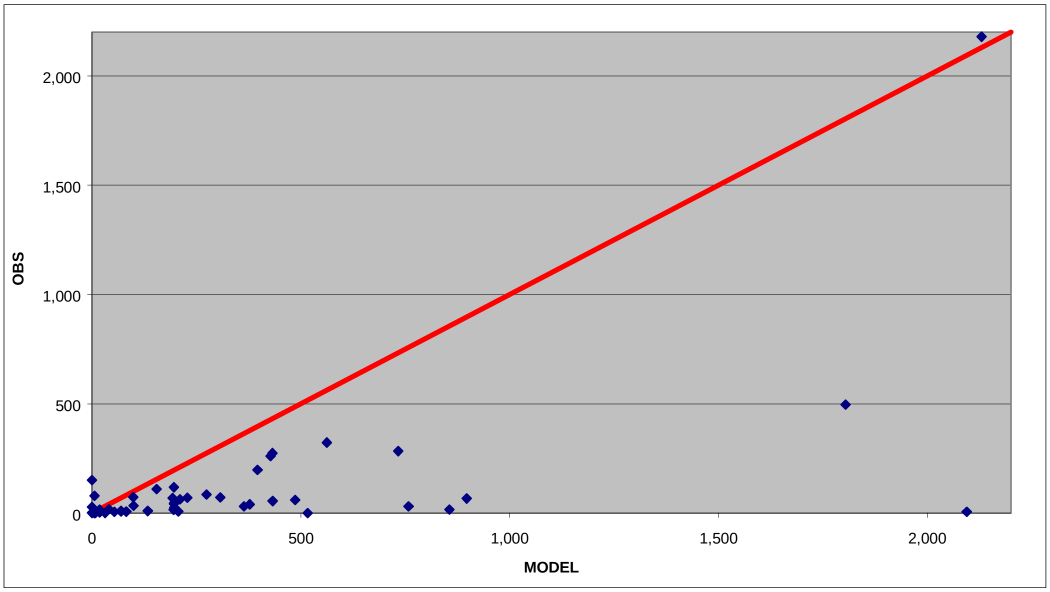


Figure 5.33. Simulated and Observed Total Kjeldahl Nitrogen Loads (lbs) Lower Beaverdam Creek

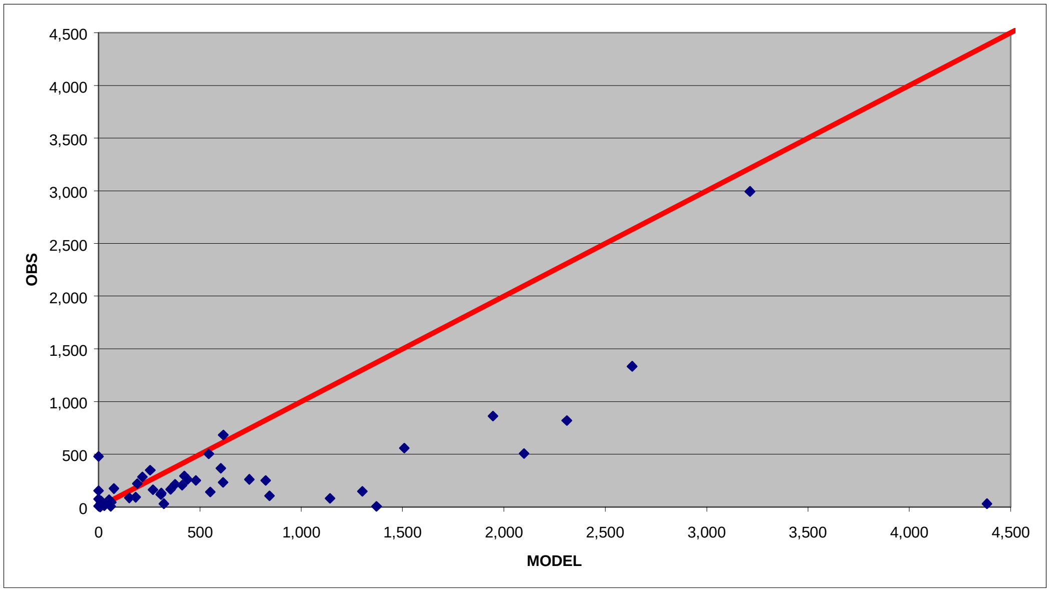


Figure 5.34. Simulated and Observed Biochemical Oxygen Demand Loads (lbs) Lower Beaverdam Creek

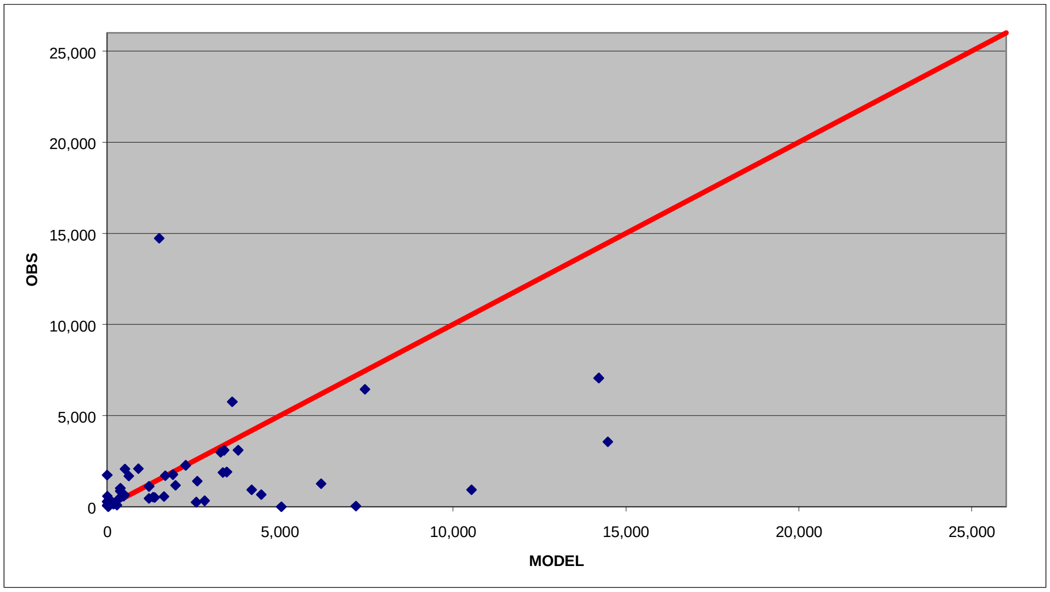


Figure 5.35. Simulated and Observed Nitrate Loads (lbs) Lower Beaverdam Creek

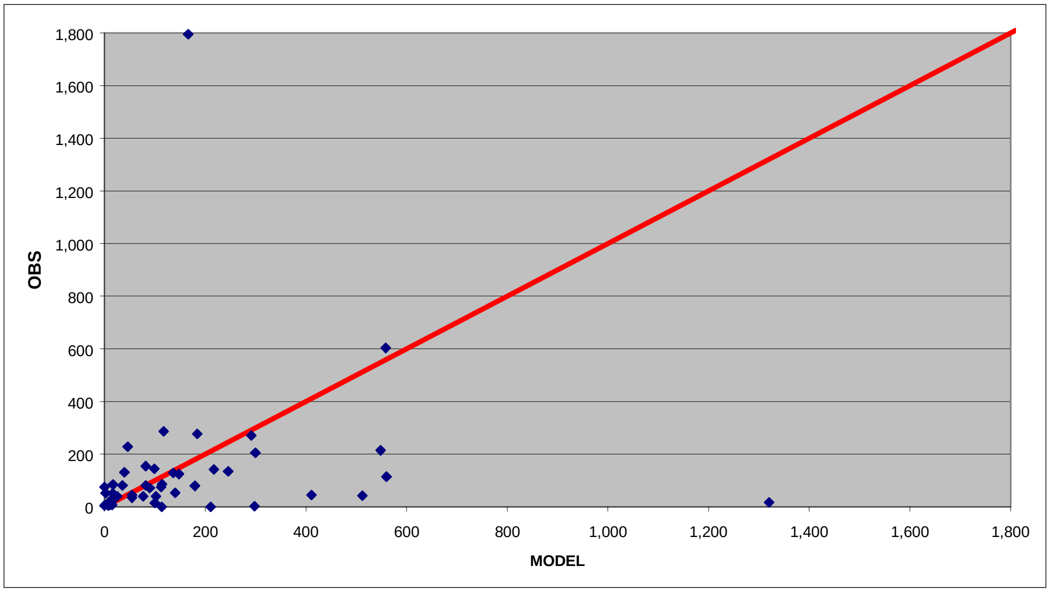


Figure 6.1. Comparison of Percent of Observed Total Suspended Solids Concentrations Exceeding Given Value, Northwest Branch 1999-2000 and Lower Beaverdam Creek 1996-1999

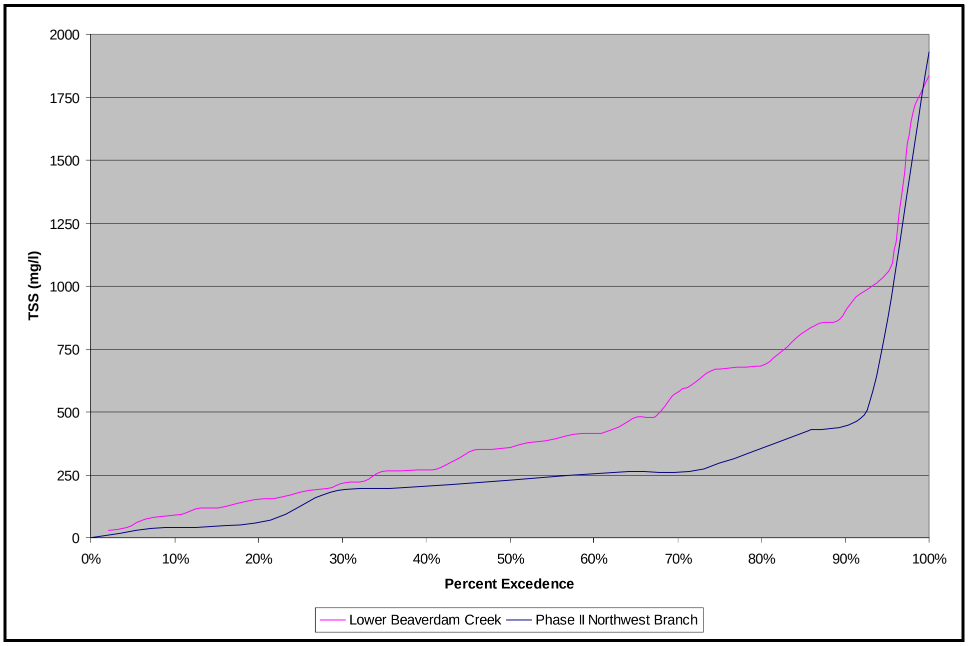


Figure 6.2. Comparison of Percent of Observed Total Suspended Solids Concentrations Exceeding Given Value, Northwest Branch, Phase I (1989-1991) and Phase II (1999-2000).

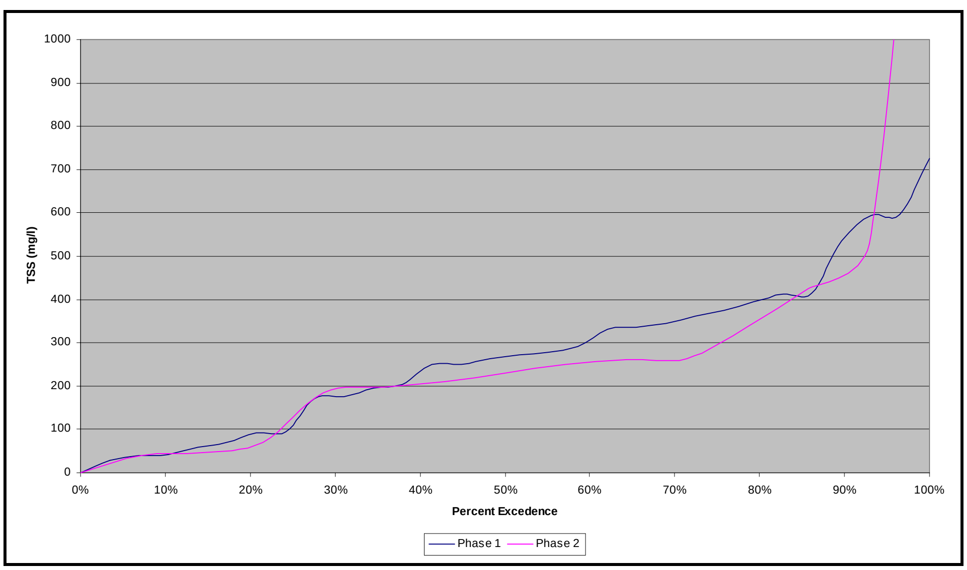


Figure 6.3. Comparison of Percent of Observed Total Phosphorus Concentrations Exceeding Given Value, Northwest Branch, Phase I (1989-1991) and Phase II (1999-2000).

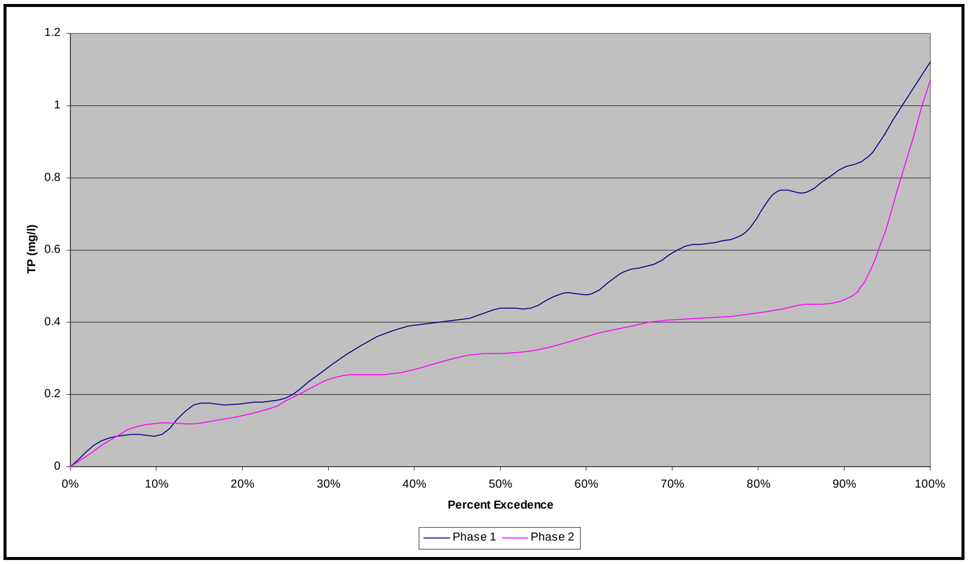


Figure 6.4. Comparison of Percent of Observed Total Kjeldahl Nitrogen Concentrations Exceeding Given Value, Northwest Branch, Phase I (1989-1991) and Phase II (1999-2000).