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21 July 2003

Mr. Eugene Mattis
Water Protection Division
EPA Region III
MD Team – Mail Code 3WP13
1650 Arch Street
Philadelphia, PA 19103-2029

Dear Mr. Mattis:

Please find enclosed the final report for the U.S. Environmental Protection Agency 104(b)(3) NPDES grant X-983450-01 entitled "Development of a Watershed Model for the Chester River Basin".

If you have any further question, please feel free to contact me at (410) 537-3921 or Narendra Panday at (410) 537-3901.

Sincerely,

Shan Abeywickrama
Watershed Modeling Division
Model Development and Application

Enlcosure

cc: Mr. Lee Currey, MDE
Mr. Narendra Panday, MDE

# Development of a Watershed Model of the Chester River

US EPA Grant X-983450-01

June 30, 2003

Maryland Department of the Environment
Technical and Regulatory Services Agency
1800 Washington Blvd., Suite 540
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# 1 Introduction

This report documents the development of a model for the entire Chester River watershed, which also includes the watersheds of the Wye and Miles Rivers. The model was developed as part of a greater modeling effort of the Chester, Wye and Miles River system in which the watershed model is fed into a hydrodynamic and water quality model. The watershed model was based on, and related, to work done by the Environmental Protection Agency's (EPA's) Chesapeake Bay Program (CBP).

During development of the watershed model several considerations such as consistency with existing models and load allocations had to be addressed. The goal of the overall modeling effort is to calculate the Total Maximum Daily Load (TMDL) for the impairing substances in the water bodies in the region. The Chester, Miles and Wye Rivers are on Maryland's Section 303(d) list as impaired by nutrients, due to signs of eutrophication. Eutrophication is the over enrichment of aquatic systems by excessive inputs of nutrients especially nitrogen and phosphorus. The nutrients act as a fertilizer leading to the excessive growth of aquatic plants, which eventually die and decompose, leading to bacterial consumption of dissolved oxygen.

The Chester River watershed model developed by the Maryland Department of the Environment (MDE) is consistent with the modeling efforts of the EPA's CBP.

# 2 Watershed Characteristics

## *2.1 Basin Description*

The Chester, Wye and Miles River Watersheds are located in the Upper Eastern Shore of Maryland and a portion of Delaware (Figure 1). The watersheds are located within Talbot, Kent and Queen Anne's Counties, Maryland with its headwaters in New Castle and Kent Counties, Delaware (Figure 2).

The upper region of the watershed, near the Maryland/Delaware border, consists of uninhibited forests and wetland, which is part of the Millington Wildlife Management Area. This is an area of approximately 3,800 acres, which drains into Cypress Branch, northeast of the town of Millington.

Talbot, Kent and Queen Anne's Counties are agriculturally diverse with high productions of corn, wheat and soybeans. The Miles and Wye River watersheds have a large amount of waterfront, which is used extensively for fishing, boating and hunting. The area has a large amount of broiler production that contributes to the nutrient loadings to the water. The economic base of the region relies on agriculture and the seafood industry. The Middle Chester has the least impervious surface, lowest population density, the least wetland loss and the highest soil erodibility amongst Maryland's watersheds (Maryland Department of Natural Resources, 2002). The average size of a farm in this region is about 400 acres.

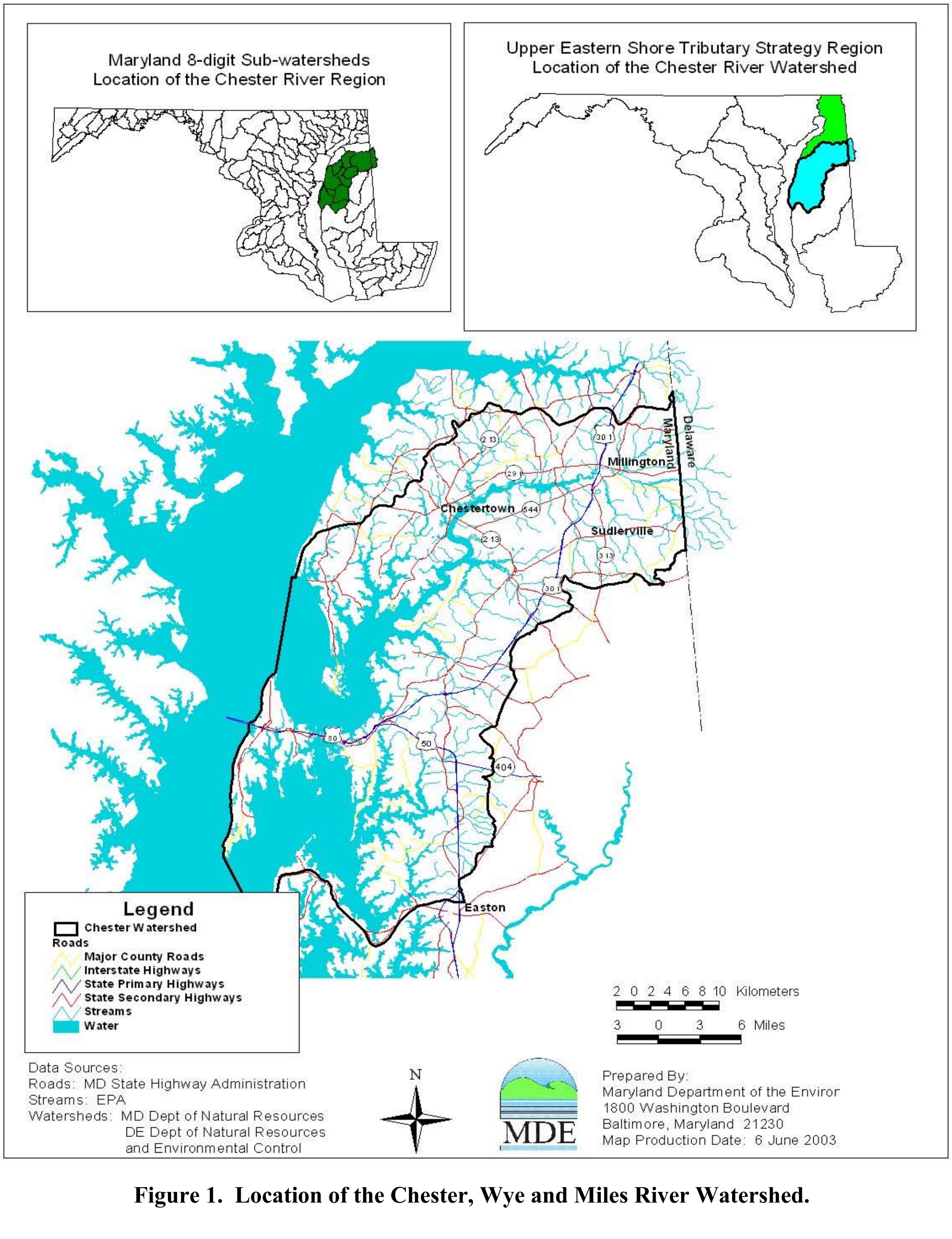



**Figure 1. Location of the Chester, Wye and Miles River Watershed.**

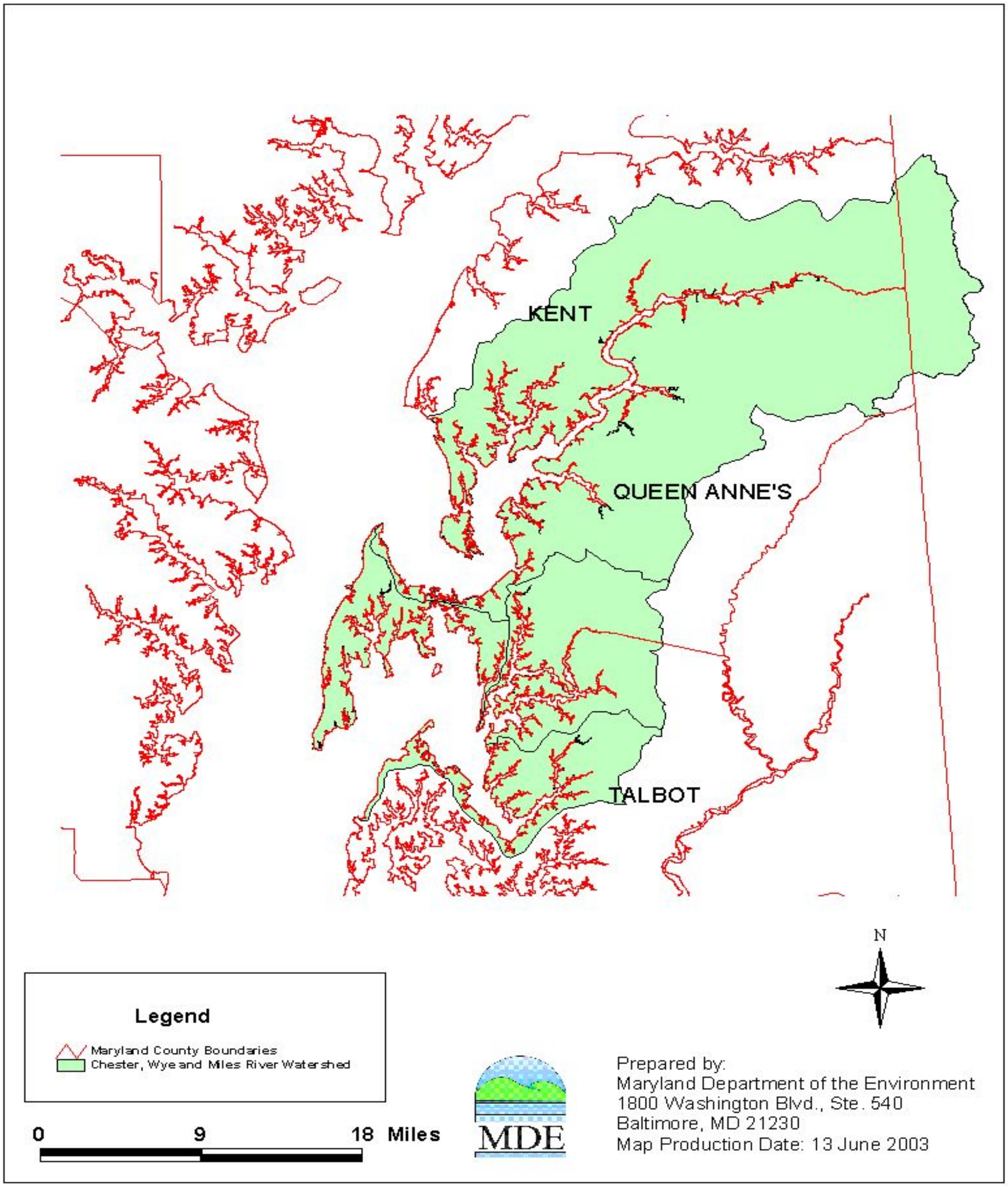



**Figure 2. Maryland County boundaries within Watershed.**

## *2.2 Climate*

The climate of the region is humid, continental with four distinct seasons. The prevailing direction of storms is from the west-northwest from November through April, with the prevailing direction shifting from the south in the months of May through September. The fall, winter and early spring storms tend to be of longer duration and lesser intensity than the summer storms. During the summer, convection storms often occur during the late afternoon and early evening producing scattered high-intensity storm cells that may produce significant amounts of rain in a short time span. Based on National Weather Service (NWS) data, thunderstorms occur approximately 30 days per year, with the majority occurring from June through August.

**Table 1. Climate Data for Chestertown, Kent County.**
**(Source: University of Maryland, College Park, Department of Meteorology)**

| Month | Normal Maximum Temperature | Normal Minimum Temperature | Normal Temperature | Normal Monthly Precipitation |
|---|---|---|---|---|
| January | 41.5 | 24.8 | 33.2 | 3.56 |
| February | 44.9 | 26.9 | 35.9 | 3.03 |
| March | 54.3 | 34.4 | 44.4 | 4.16 |
| April | 65.1 | 43 | 54.1 | 3.34 |
| May | 74.9 | 52.9 | 63.9 | 4.09 |
| June | 83.5 | 61.9 | 72.7 | 4.26 |
| July | 87.8 | 66.9 | 77.4 | 3.94 |
| August | 86.4 | 65.2 | 75.8 | 3.76 |
| September | 79.6 | 58 | 68.8 | 4.3 |
| October | 68.3 | 46 | 57.2 | 3.37 |
| November | 56.9 | 37.2 | 47.1 | 3.34 |
| December | 46.2 | 29 | 37.6 | 3.69 |
| Annual | 65.8 | 45.5 | 55.7 | 44.84 |

Normals are calculated using data collected from 1971-2000.

## *2.3 Geology, Topography and Soils*

Nearly all water supplies in the watershed are derived from groundwater sources, although some irrigation water is taken from surface water ponds and streams. The geologic strata underlying the surface contain layers of clay and silt alternating with layers of sand and gravel. The permeable sand and gravel layers that are saturated with water are called aquifers. These aquifers and associated geologic formations dip gently seaward and generally occur at progressively greater depths going from the northwestern to the southeastern section. Water quality in the aquifers is generally good. Because of the aquifers' proximity to the surface, however, it is susceptible to pollution from livestock production, onsite sewage disposal, applications of fertilizer, and to saltwater intrusion along Chesapeake Bay and tidal rivers.

The soils in the watershed range widely in texture, natural drainage, and other characteristics. The lower part of the watershed, which includes the Kent Island and Grasonville area, is made up of nearly level lowland flats that are characterized by windblown materials overlying alluvial and marine sediments (Maryland Department of Natural Resources, 2002).

The watershed consists of tidal marshes, and many of the upland soils have seasonally high water tables near the surface. A large portion of the watershed is nearly level to strongly sloping with dominantly alluvial sediments, and is well drained. The landscape in the northeastern portion of Queen Anne's County, along the Caroline County line and the Delaware State line, is dominated by closed circular depressions known as potholes, whale wallows, or Delmarva bays. The soils are poorly drained or very poorly drained, and many manmade ditches dissect the cropland (Maryland Department of Natural Resources, 2002).

# 3 HSPF Model Description and Structure

## *3.1 Introduction*

A modeling framework of the Chester, Wye and Miles River Watershed was developed to provide a tool for managers and planners to estimate the effects of various growth scenarios on water quality. The modeling structure consists of a watershed model to generate nutrient loads from the watershed sub-basins and a three-dimensional, time-variable linked hydrodynamic and water quality model for the tidal portions of the rivers. The modeling process involved using an existing Hydrologic Simulation Program FORTRAN (HSPF) watershed model developed by the EPA's CBP that was updated and modified by MDE.

## *3.2 Existing Model Studies*

The Chesapeake Bay HSPF Watershed Model (Version 4.3) divides the 64,000 square mile drainage basin of the Bay's watershed into 94 model segments. The watershed includes six mid-Atlantic States including New York, Pennsylvania, West Virginia, Maryland, Delaware, Virginia and the District of Columbia. The model has been continuously upgraded since the original version in 1982, and presently Version 5 is presently under development.

Each model segment contains information generated by a hydrologic submodel, a nonpoint source submodel and a river submodel. The hydrologic submodel uses rainfall, evaporation and meteorological data to calculate runoff and subsurface flow for all the basin's land uses including forest, agricultural and urban lands. The surface and subsurface flows ultimately drive the nonpoint source submodel, which simulates soil erosion and the pollutant loads from the land to the rivers. The river submodel routes flow and associated pollutant loads from the land through lakes, rivers and reservoirs to the Bay.

### *3.3 Overview of HSPF*

The HSPF model simulates the fate and transport of pollutants over the entire hydrologic cycle. Two distinct sets of processes are represented in HSPF: (1) processes that determine the fate and transport of pollutants at the surface and/or the subsurface of a watershed, and (2) in-stream processes. The former will be referred to as “land” or “watershed” processes, the latter as “in-stream” or “river reach” processes.

Constituents can be represented at various levels of detail and simulated both for land and in-stream environments. These choices are made, in part, by specifying the modules that are used, and thus the choices establish the model structure used for any one situation. In addition to the choice of modules, other types of information must be supplied for the HSPF calculations, including model parameters and time-series of input data. Time-series of input data include meteorological data, point sources, reservoir information, and other type of continuous data as needed for model development.

A watershed is subdivided into model segments, which are defined as areas with similar hydrologic characteristics. Within a model segment, multiple land use types can be simulated, each using different modules and different model parameters. In terms of simulation, all processes are computed for a spatial unit of 1 acre. The number or acres of each land use in a given model segment is multiplied by the values (fluxes and concentrations) computed for the corresponding acre. Although the model simulation is performed on a temporal basis, land use information does not change with time. As a rule of thumb, the land use data that are used to describe the watershed conditions are usually chosen for the middle of the simulation period, so that the average land use conditions are represented.

Within HSPF, the RCHRES module sections are used to simulate hydrology, sediment transport, water temperature, and water quality processes that result in the delivery of flow and pollutant loading to a bay, reservoir, ocean or any other body of water. Flow through a reach is assumed to be unidirectional. In the solution technique of normal advection, it is assumed that simulated constituents are uniformly dispersed throughout the waters of the RCHRES; constituents move at the same horizontal velocity as the water and the inflow and outflow of materials are based on a mass balance. The HSPF model uses a convex routing method to move mass within the reach (equation 3.2-1). Outflow may leave the reach through one of five possible exits (i.e., irrigation, municipal and industrial water use, flowing to a downstream reach, etc), and the processes occurring in the reach will be influenced by precipitation, evaporation, and other fluxes:

$$ROVOL = (Ks * ROS + COKS * ROD) * DELTS \qquad (3.2\text{-}1)$$

Where ROVOL is the total outflow during the interval; Ks is a weighting factor ($0 \leq Ks \leq 0.99$); DELTS is the simulation interval in seconds; COKS is the complement of Ks ($1 - Ks$); ROS is the total rate of outflow at the start of the interval; and ROD is the total rate of demanded outflow at the end of the interval.

## *3.4 Model Assumptions*

The CBP watershed model segments relating to the Chester, Wye and Miles Rivers were analyzed for their land use loading rates. These land use loading rates were then assigned for the detailed MDE segmentation and land use. The MDE and CBP land use loading rates are considered to be the same.

The CBP watershed model Segments 380, 390, 820 and 830 are considered non-reach segments. The losses and gains from the reach within the segment is not considered in the calibration.

Since MDE's watershed model is based on an existing CBP framework, the assumptions made for Version 4.3 of the watershed model also apply here. For a description of detailed modeling assumptions, see Shenk and Linker 2001.

## *3.5 Model Segmentation*

The watershed model was segmented based on the Maryland's 8 digit watershed code. The segmentation was further refined to address various flow and water quality monitoring stations within the watershed (Figure 4). The resulting watershed segmentation is much finer compared to the CBP watershed model segmentation (Figure 3).

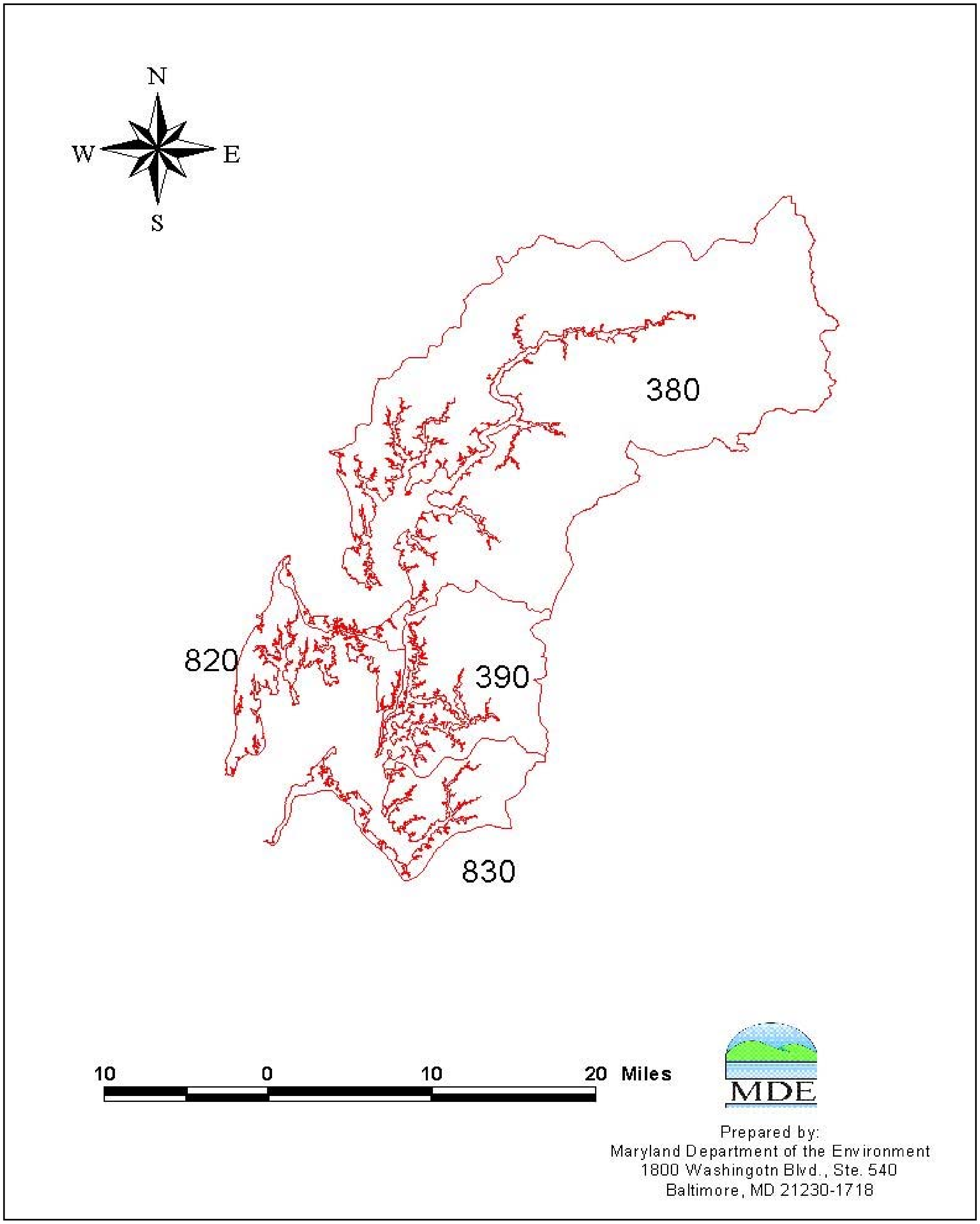



**Figure 3. Chesapeake Bay Program Segmentation for the Chester, Wye and Miles River Watershed.**

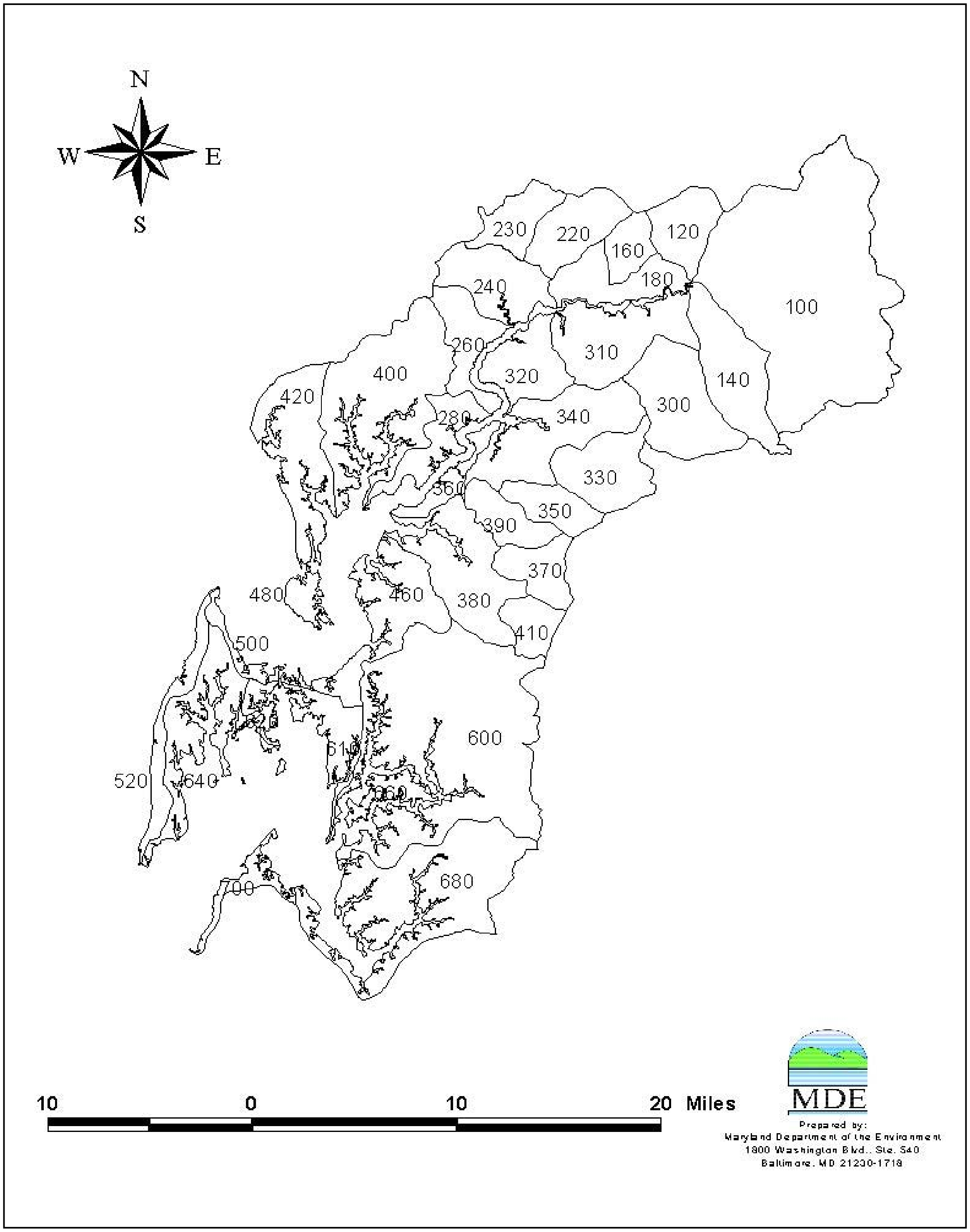



**Figure 4. MDE's Refined Watershed Segmentation for the Chester, Wye and Miles River .**

## *3.6 Land Use*

Land use information was derived from the 1997 Maryland Department of Planning (MDP) land cover database, 1994 Mapping Resolution Land Data (MRLC) for the Delaware segments, data from the Farm Service Agency (FSA), the 1997 Agricultural Census, and information from the 1996 Conservation Technology Information Center (CTIC). A survey conducted by Maryland Department of Agriculture (MDA) indicated that the FSA and the 1997 Agricultural Census were the most accurate agricultural information available in the region. The FSA data was collected at a finer resolution (of 4.32 $mi^2$/cell), and provided a better spatial scale to compute crop acres by model segment than the Agricultural Census data (in which the information is at the County scale). The Agricultural Census data was used to derive the crop types by model segment. Tillage in the crop categories was derived from information provided by the 1996 CTIC. For modeling purposes, land categories were aggregated into five major groups: forest (herbaceous and wetlands), agriculture (hay, high and low till crops), pasture, urban (pervious, impervious and mixed open). The breakdown of the major land categories is seen in Figure 5. The detailed land use information is seen in Table 2.

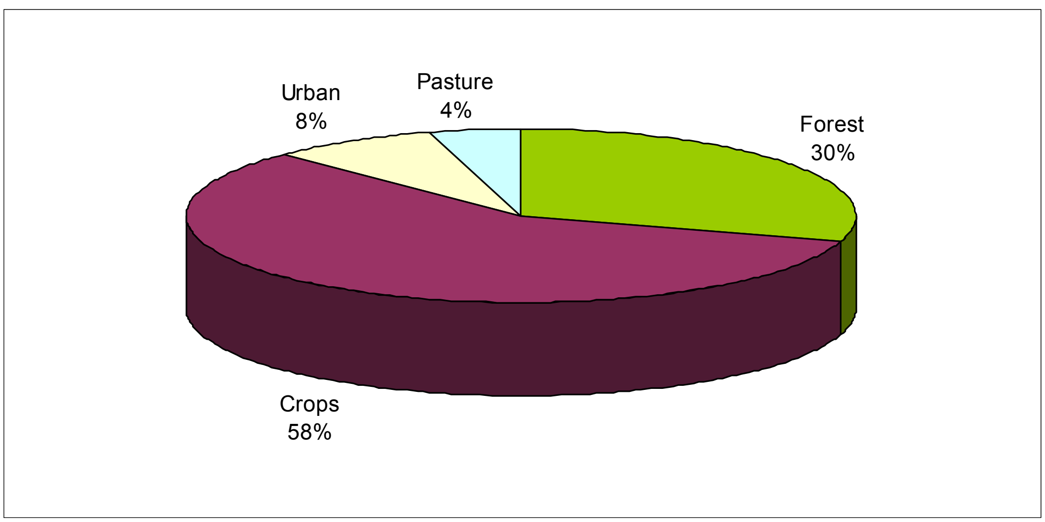



**Figure 5. Percentages of Major Land Use Categories in the Chester, Wye and Miles River Watershed.**

**Table 2. Land Use Distribution per Segment.**

| CBP Segment | MDE Segment | Forest | Hi Till | Lo Till | Pasture | Hay | Pervious Urban | Impervious Urban | Manure | Mixed Open | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 380 | 100 | 25,664.2 | 16,052.6 | 9,716.5 | 4,247.8 | 965.1 | 0.0 | 198.7 | 10.3 | 156.6 | 57,001.5 |
| 380 | 120 | 2,303.0 | 2,265.6 | 1,326.7 | 229.5 | 157.7 | 141.6 | 0.0 | 1.2 | 229.2 | 6,653.3 |
| 380 | 140 | 3,647.3 | 4,339.4 | 3,067.2 | 453.2 | 134.8 | 354.5 | 114.5 | 2.2 | 0.0 | 12,111.0 |
| 380 | 160 | 281.5 | 1,514.0 | 886.6 | 152.8 | 105.4 | 68.9 | 11.1 | 0.7 | 861.7 | 3,882.0 |
| 380 | 180 | 1,799.8 | 3,156.5 | 1,848.4 | 253.6 | 219.7 | 284.0 | 20.2 | 1.4 | 0.0 | 7,582.2 |
| 380 | 220 | 808.4 | 3,907.9 | 2,288.4 | 351.8 | 272.0 | 314.3 | 0.0 | 1.5 | 120.0 | 8,062.7 |
| 380 | 230 | 1,023.0 | 2,387.1 | 1,397.8 | 180.8 | 166.1 | 285.3 | 48.1 | 1.0 | 0.0 | 5,488.2 |
| 380 | 240 | 1,633.4 | 4,005.3 | 2,345.4 | 338.4 | 278.8 | 105.7 | 490.7 | 1.7 | 96.1 | 9,293.8 |
| 380 | 260 | 992.2 | 2,042.4 | 1,196.0 | 259.6 | 142.2 | 0.0 | 772.0 | 1.0 | 22.7 | 5,427.1 |
| 380 | 280 | 1,970.3 | 2,070.9 | 1,212.6 | 240.2 | 144.1 | 185.5 | 72.6 | 1.1 | 0.0 | 5,896.2 |
| 380 | 300 | 3,499.3 | 5,016.3 | 3,545.5 | 357.6 | 155.9 | 353.7 | 116.7 | 2.4 | 131.2 | 13,176.2 |
| 380 | 310 | 4,506.0 | 3,976.0 | 2,810.3 | 355.9 | 123.5 | 1,172.5 | 0.0 | 2.4 | 134.3 | 13,078.5 |
| 380 | 320 | 978.8 | 3,300.5 | 2,332.8 | 241.3 | 102.6 | 591.3 | 241.0 | 1.4 | 0.0 | 7,788.2 |
| 380 | 330 | 2,399.9 | 3,644.1 | 2,575.7 | 433.9 | 113.2 | 218.5 | 115.9 | 1.7 | 0.0 | 9,501.3 |
| 380 | 340 | 4,268.4 | 5,504.0 | 3,890.3 | 625.7 | 171.0 | 454.0 | 0.0 | 2.7 | 17.4 | 14,930.8 |
| 380 | 350 | 1,550.7 | 1,777.5 | 1,256.3 | 299.3 | 55.2 | 99.0 | 36.5 | 0.9 | 0.0 | 5,074.5 |
| 380 | 360 | 636.3 | 1,366.6 | 965.9 | 126.8 | 42.5 | 46.2 | 0.0 | 0.6 | 0.0 | 3,184.4 |
| 380 | 370 | 1,663.9 | 2,053.7 | 1,451.6 | 145.2 | 63.8 | 67.4 | 191.9 | 1.0 | 0.0 | 5,637.6 |
| 380 | 380 | 3,475.4 | 4,947.8 | 3,497.1 | 570.7 | 153.7 | 1,161.4 | 229.6 | 2.5 | 0.0 | 14,035.6 |
| 380 | 390 | 1,808.8 | 1,678.6 | 1,186.5 | 128.4 | 52.2 | 246.7 | 45.3 | 0.9 | 0.0 | 5,146.4 |
| 380 | 400 | 5,922.8 | 9,328.3 | 5,462.4 | 905.5 | 649.3 | 1,049.1 | 217.7 | 4.3 | 30.6 | 23,565.6 |
| 380 | 410 | 1,254.6 | 1,542.2 | 1,090.0 | 142.9 | 47.9 | 0.0 | 71.6 | 0.8 | 0.0 | 4,149.2 |
| 380 | 420 | 5,282.3 | 3,611.7 | 2,114.9 | 343.8 | 251.4 | 1,110.5 | 367.1 | 2.4 | 0.0 | 13,081.7 |
| 380 | 460 | 4,328.3 | 3,568.2 | 2,522.0 | 311.2 | 110.9 | 1,330.1 | 377.0 | 2.3 | 0.0 | 12,547.6 |
| 380 | 480 | 1,175.4 | 478.1 | 279.9 | 34.2 | 33.3 | 0.0 | 58.6 | 0.4 | 0.0 | 2,059.5 |
| 380 | 500 | 323.3 | 541.7 | 382.9 | 35.9 | 16.8 | 141.1 | 262.5 | 0.3 | 0.0 | 1,704.2 |
| 820 | 520 | 1,173.4 | 916.9 | 648.1 | 157.3 | 28.5 | 1,505.5 | 591.5 | 0.5 | 0.0 | 5,021.1 |
| 390 | 600 | 11,954.8 | 16,639.1 | 11,638.2 | 2,417.0 | 422.8 | 3,441.6 | 506.1 | 5.5 | 175.8 | 47,195.3 |
| 820 | 610 | 1,917.1 | 908.6 | 642.2 | 161.6 | 28.2 | 696.4 | 1,080.1 | 0.5 | 0.0 | 5,434.2 |
| 820 | 620 | 417.3 | 528.4 | 373.5 | 44.7 | 16.4 | 0.0 | 239.4 | 0.2 | 0.0 | 1,619.6 |
| 820 | 640 | 2,370.1 | 2,697.8 | 1,906.8 | 282.1 | 83.8 | 2,527.2 | 1,171.1 | 1.0 | 0.0 | 11,039.0 |
| 390 | 660 | 562.2 | 1,159.8 | 819.7 | 98.0 | 36.0 | 0.0 | 121.7 | 0.3 | 0.0 | 2,797.4 |
| 830 | 680 | 7,857.7 | 7,841.3 | 5,413.5 | 1,158.3 | 144.6 | 2,922.4 | 1,463.0 | 2.2 | 18.4 | 26,819.1 |
| 830 | 700 | 877.5 | 915.7 | 632.2 | 76.7 | 16.9 | 213.8 | 57.7 | 0.2 | 9.0 | 2,799.4 |
| Total Area | | 110,327 | 125,684 | 82,724 | 16,161 | 5,506 | 21,088 | 9,290 | 59 | 2,003 | 372,784 |

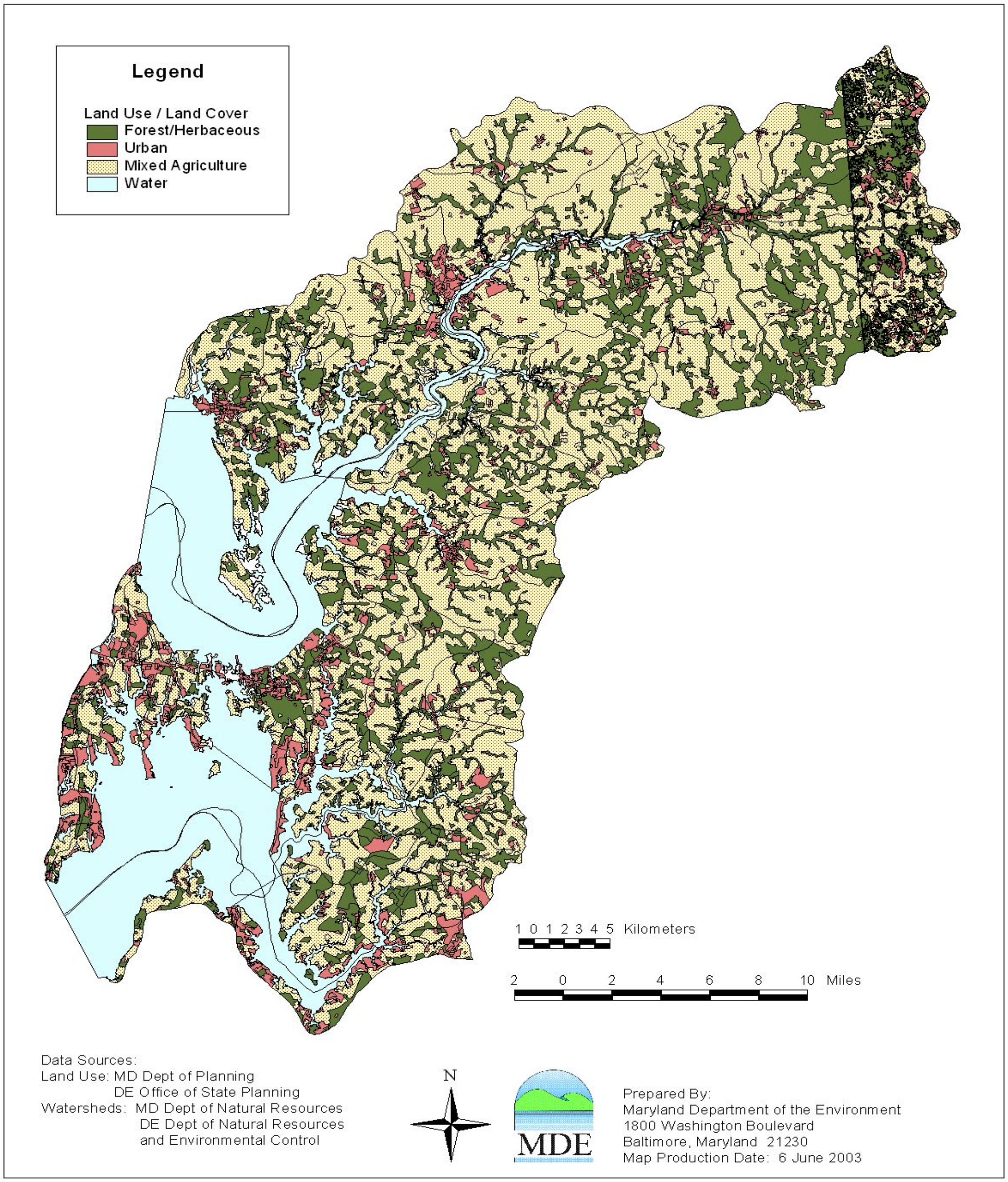



**Figure 6. Landuse Distribution for the Chester, Wye and Miles River Watershed.**

The largest land use category is mixed agriculture followed by forestland. The watershed has little urbanization.

## *3.7 Non Point Sources*

### 3.7.1 Animal Counts and Manure Acres

The animal populations for the CBP watershed model were derived for each model segment from the 1992 Agricultural Census, published by the U.S. Department of Commerce and the Bureau of the Census for the six states within the Chesapeake Bay Basin. The percentage of area in a model segment for each county is used to decide the proportion of animal units within a model segment. Figure 7 shows the total animal units per county in the Chesapeake Bay Watershed model.

The animal counts are used to calculate the manure acres per segment. Different animal species create varied volumes of manure with distinct nutrient concentrations. Four types of animals are included in manure mass balance calculations: beef, dairy, swine, and poultry (which include poultry layers, broilers, and turkeys). Animal types not included were horse and sheep populations. To estimate the amount of manure in a watershed model segment, an animal unit is defined as 1,000 pounds of animal weight. One animal unit corresponds to 0.71 dairy cows, one beef cow, five swine, 250 poultry layers, 500 poultry broilers, or 100 turkeys. A manure acre is defined as 145 Animal Units (AUs) in the confined/susceptible to runoff grouping (Palace *et al*., 1998). The animal waste produced is separated into confined/unconfined and involves detailed calculations of the amount of waste produced.

Distribution of the CBP manure acres to the MDE watershed segments was calculated using an area ratio method. For each MDE segment, the percentage (area fraction) of that segment within the CBP model segment is calculated. The total manure acres for each CBP segment is multiplied by the area fraction for the corresponding MDE segment. The manure acres within the MDE segment are estimated using the following formula:

$$MA_{MDE} = \sum_{i-1}^{\#CBP\_SEG} MA_{CBP} \frac{A_{MDE}}{A_{CBP}}$$

where:

$MA_{MDE}$ = Total manure acres in MDE watershed segment
$MA_{CBP}$ = Total manure acres in CBP watershed segment
$A_{MDE}$ = Area of MDE segment within corresponding CBP Segment
$A_{CBP}$ = Total area of CBP segment

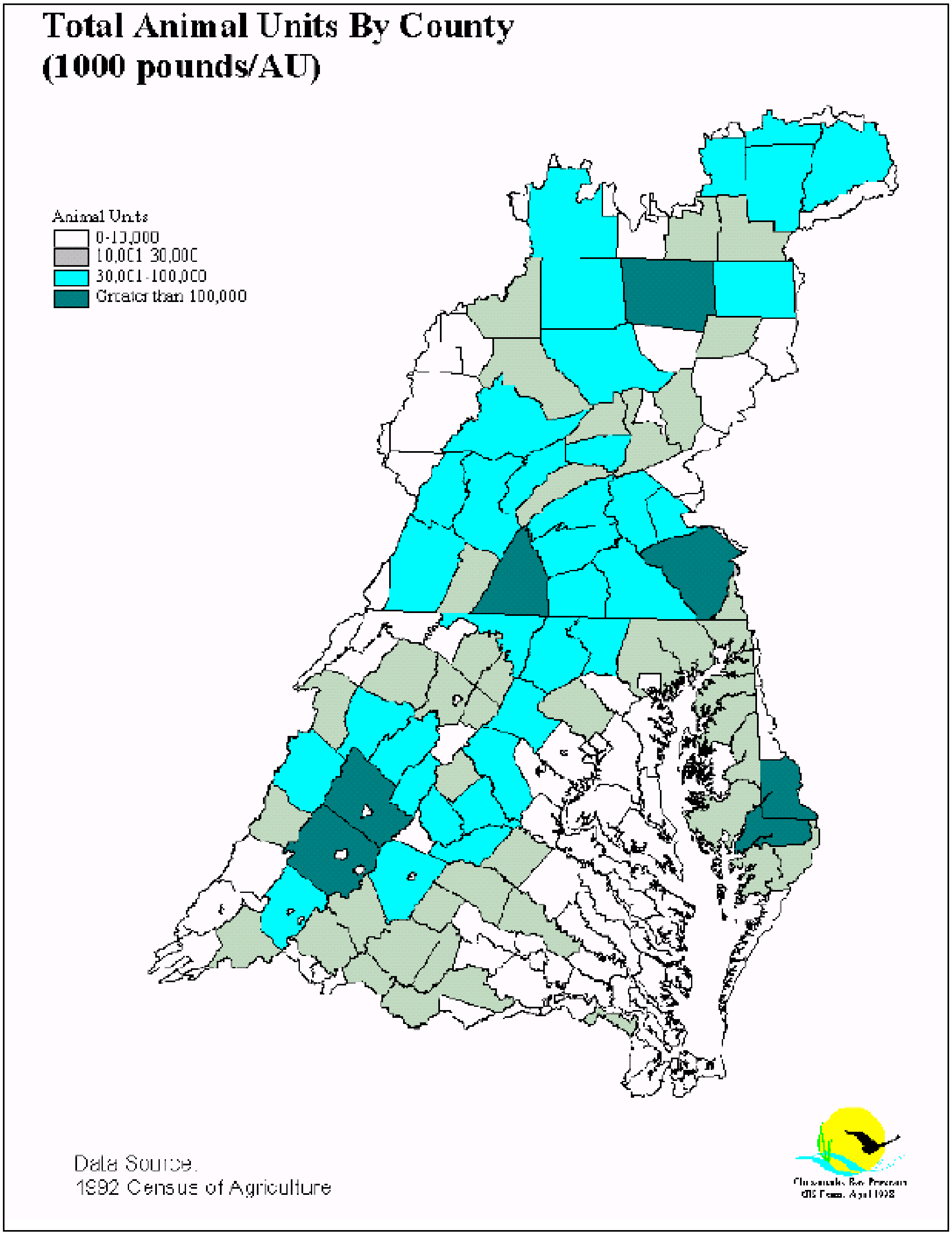



**Figure 7. Animal Counts per CBP Watershed Model (Palace et al.., 1998)**

### 3.7.2 Nutrient Application

The nutrient application for agricultural land is a time variable function depending on the animal population and crop type within that particular basin. Nutrient application also takes into account the amount and the relationship of the quantities of mineral and organic fertilizer utilized.

Mineral and animal waste fertilizer calculations were based on methodologies developed for the Chesapeake Bay Model, and found in Appendix H of the Watershed Model documentation (Palace et al., 1998).

### 3.7.3 Atmospheric Deposition

The atmospheric nutrient deposition inputs for the model are wet nitrate ($NO_3$), dry ($NO_3$), organic nitrogen (OrN), organic phosphorus (OrP), and dissolved inorganic phosphorus (DIP). The total amount of dry ammonia ($NH_4$) deposited is assumed to be negligible.

The wetfall atmospheric deposition of $NO_3$ and $NH_4$ for the Phase IV Chesapeake Bay Watershed Model precipitation segments was calculated according to a regression model which was developed by the Chesapeake Bay Program's Air Subcommittee. The regression model is based principally on the logarithmic relationship between the amount of precipitation and the NH3 and NO3 concentrations in the precipitation. The regression relationship was developed using weekly data collected over an eight-year period at fifteen National Air Deposition Program (NADP) sites. Due to the weekly pooled sampling protocol of NADP and concerns over transformation of the nutrient species over time, the data was quality controlled by selecting those data where the precipitation event occurred only on the last day of the weekly sample. Using this criteria, 265 samples were selected from the approximately 5,000 samples collected at the NADP sites. These selected data was then treated as daily samples and employed in developing the regression model.

The regression equation expresses the wetfall deposition of $NO_3$ and $NH_4$ as a function of daily precipitation, latitude, and month of the year:

$$N[NO_3] = 0.226 * \exp(-0.3852 * \ln(ppn) - 0.0037 * month\ 2 + 0.0744 * latitude - 1.289)$$

$$N[NH_4] = 0.7765 * \exp(-0.3549 * \ln(ppn) + 0.3966 * month - 0.0337 * month\ 2 - 1.226)$$

where: [] is the concentration (in milligrams/liter) as N,
ppn is the precipitation (in millimeters),
the month is expressed as an integer, and
the latitude is the centroid Y component (in decimal degrees) of precipitation segments.

Load of N (in kg/ha) = N[$NO_3$ or $NH_4$] * precipitation = (mg/L * ppn) / 100.

The regression model was applied to the precipitation data to produce daily deposition rates with the same spatial resolution as the Theissen distributed daily precipitation inputs. The annual average wet nitrate and ammonia atmospheric deposition loads during 1984-1994 for the Phase IV Chesapeake Bay Watershed Model precipitation segments are listed in Table 2.

**Table 3. Atmospheric Deposition Rates per Watershed Segment.**

| **Bay Watershed Model Segments** | **Total Nitrogen** lbs/ac/yr | **Total Phosphorus** lbs/ac/yr |
|---|---|---|
| **380** | 10.06 | 0.57 |
| **390** | 10.13 | 0.57 |
| **820** | 10.13 | 0.57 |
| **830** | 10.06 | 0.57 |

### 3.7.4 Septic Information

The septic load for the watershed was not considered. The CBP watershed model provided a total septic load for the associated four segments. The nitrogen load from the septic systems was calculated to be only approximately three percent of the total Non Point Source load.

There are several reasons for not adding the septic load to the final NPS load, the main reason being that the loads from the septic system were insignificant compared to the total load. Another important reason is that the allocation of the septic loads to the finer MDE segments was not possible since there was no information about the spatial distribution of the septic systems.

## *3.8 Point Sources*

Point source information was obtained from Maryland's point source database, which includes elements from the Permit Compliance System (PCS). The PCS is a database management system that supports the National Pollutant Discharge Elimination System (NPDES) regulations. Quality Control is performed by MDE for municipal information and for data from major industrial facilities. The point source data was checked to see if there was any discharge during the period of model calibration. Flow and concentrations are reported as monthly average values in units of million of gallons per day (MGD) for flow and most probable number per 100 milliliters (mpn/100) for Fecal Coliform..

The point sources added to the model were those only that discharged in the calibration period of the water quality model, which is 1997 to 1999. Tables 4 and 5 summarize the industrial and municipal point source average annual loads going into the water quality model. The point sources not added to the model are given in Table 6.

**Table 4. Municipal Point Sources.**

| Name | NPDES | TN Load (lbs/yr) | TP Load (lbs/yr) |
|---|---|---|---|
| Chestertown WWTP | MD0020010 | 24,544 | 6,821 |
| Sudlersville WWTP | MD0020559 | 5,951 | 992 |
| Millington WWTP | MD0020435 | 2,675 | 446 |
| Worton-Butlertown WWTP | MD0060585 | 2,641 | 440 |
| Kennedyville WWTP | MD0052671 | 0 | 0 |
| Talbot County Region II | MD0023604 | 14,326 | 3,714 |
| Total | Municipal | 50,136 | 12,413 |

**Table 5. Industrial Point Sources.**

| Name | NPDES | TN Load (lbs/yr) | TP Load (lbs/yr) |
|---|---|---|---|
| Chestertown Foods, Inc. | MD0002232-001A | 2,408 | 1,237 |
| | MD0002232-002A | 888 | 121 |
| | MD0002232-003A | 730 | 34 |
| | MD0002232-005A | 1,292 | 802 |
| Velsicol Chemical Corp. | MD0000345-002A | 2,219 | 251 |
| Total | Industrial | 7,538 | 2,445 |

**Table 6. Point Sources Not Considered for Model.**

| Name | NPDES |
|---|---|
| Sudlersville Frozen Meat | MD0054933 |
| George Jr. Hill & Sons Seafood | MD0064882 |
| Gordon S. Crouch Seafood | MD0002976 |
| Wehrs, David W. Seafood | MD0061697 |
| U. of MD Wye Research Lab | MD0065170 |
| S.E.W. Friel (Lower Chester) | MD0000035 |
| S.E.W. Friel (Wye) | MD0000043 |
| MD State Military Facility | MD0065731 |

## *3.9 Meteorological Data (Precipitation and Evaporation)*

The precipitation and evaporation data are those that were used in the CBP watershed model Version 4.3. The model requires hourly input for the calibration period.

A total of 147 precipitation stations were used, of which 88 are hourly and 59 are daily records of rainfall. Data gaps exist in these observed stations, but overall the observed stations used are relatively continuous over the entire simulation period (Wang et al., 1997). Precipitation segments were developed that are primarily based upon the Phase IV Watershed Model Segments. The precipitation segments are larger than the model segments in most cases since some of the model segments were too small to have sufficient hourly stations fall within them and they were therefore aggregated (Wang et al., 1997).

Meteorological data was obtained from the National Oceanic and Atmospheric Administration (NOAA). The data used are daily maximum air temperature, minimum air temperature, dew point temperature, cloud coverage and wind speed.

Hourly potential evaporation was generated by applying the Penman method, using daily maximum air temperature, daily minimum air temperature, daily dew point temperature, daily wind speed, and hourly solar radiation. Monthly correction factors to the potential evaporation for the seven regions were estimated by examination of observed evaporation records and used on the potential evaporation data calculated with the Penman method (Wang et al., 1997). Detailed methodology can be obtained from Wang et al (1997).

### *3.10 Calibration Data (Hydrology and Water Quality)*

## 3.10.1 USGS Flow Data

There are five USGS flow gages within the Chester, Miles and Wye River watershed (Table 7 and Figure 8), of which three; 01493000, 01493500 and 01492500 are active gages for daily flow values. Two of the gages, 01493000 and 01493500, have been active since the early 1950s and can be used for long term flow analysis.

**Table 7 USGS Flow Gages within Watershed.**

| Station Number | Name | Dates |
|---|---|---|
| 01493000 | Unicorn Branch near Millington | 1/1/1948 to 9/30/2002 |
| 01493112 | Chesterville near Crumpton | 7/23/1996 to 9/30/2002 |
| 01493500 | Morgan Creek near Kennedyville | 5/31/1951 to 9/30/2002 |
| 01494000 | Southeast Creek at Church Hill | 7/1/1951 to 9/30/1956 |
| 01492500 | Sallie Harris Creek near Carmicheal | 6/26/1951 to 09/30/1956 and 1/10/2000 to 9/30/2002 |

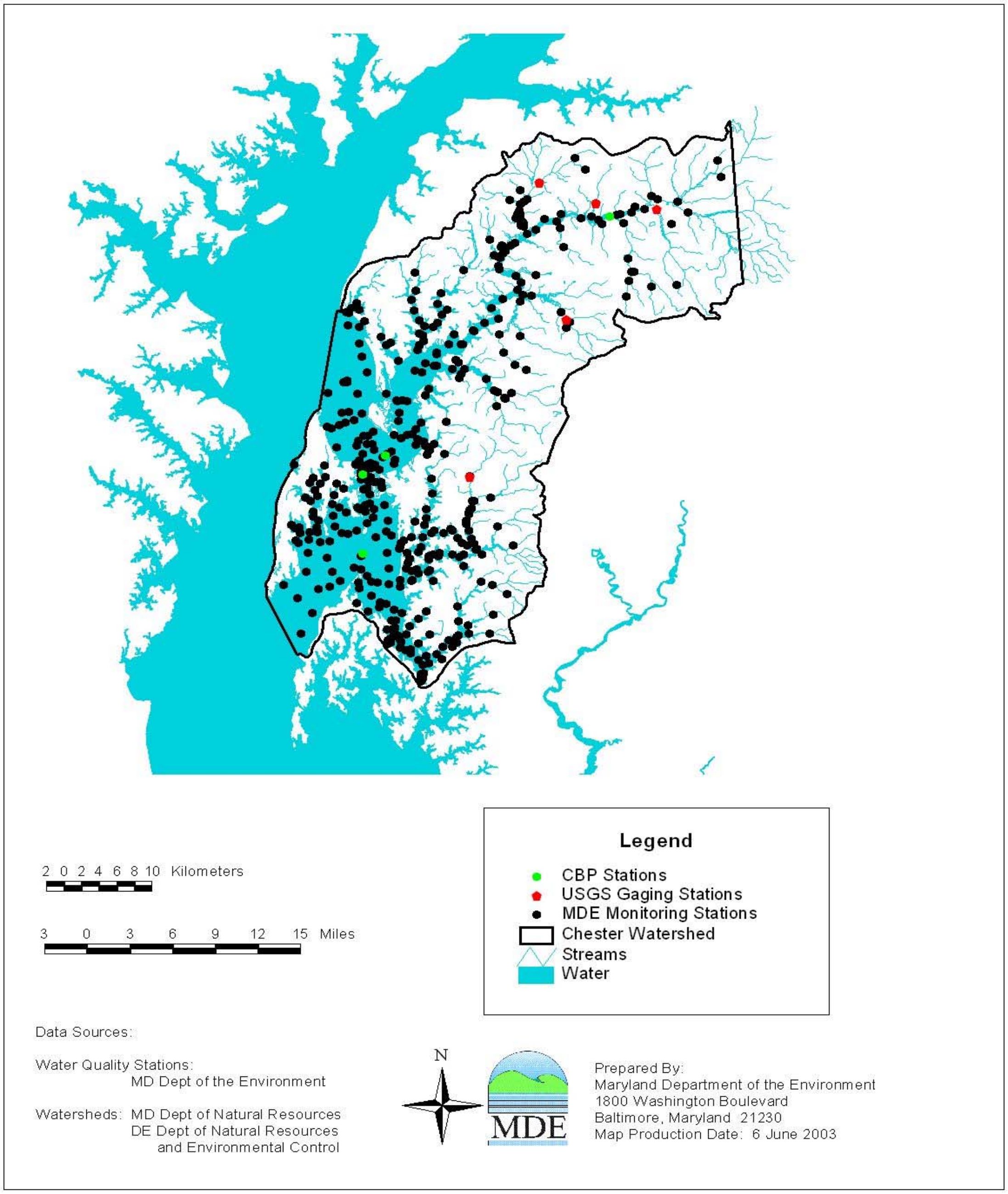



**Figure 8. Flow and Water Quality Monitoring Stations in the Chester, Wye and Miles River Watershed.**

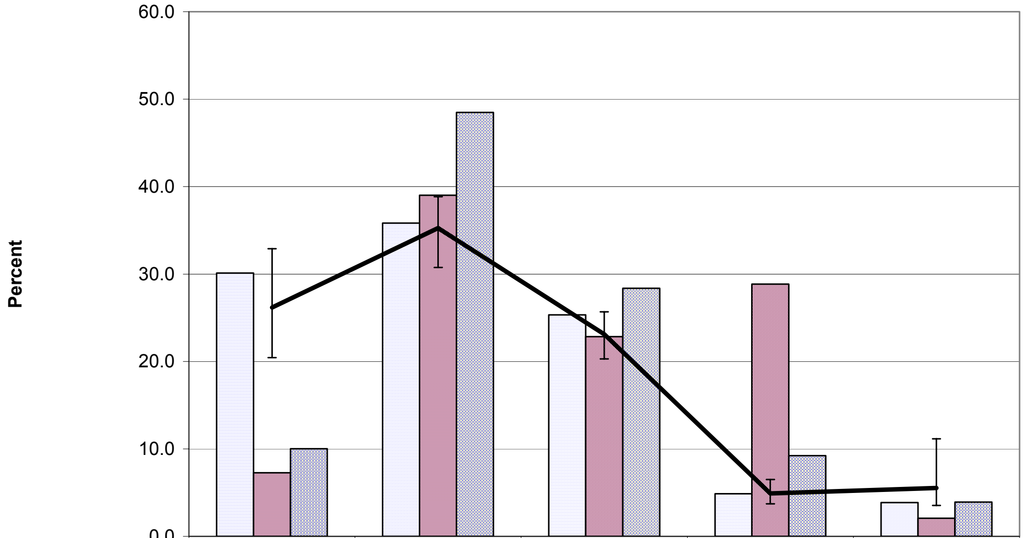
### 3.10.1.1 USGS Gage Hydrology

For this study, only gages 01493000, 01493112 and 01493500 were considered, with the predominant focus being on the two gages with long term flow records. This decision for selecting these three gages is based on the calibration years of the estuary model (receiving water quality model), which are through 1997 and 1999. Watershed model segments were delineated to all three gages. The relationships between USGS flow gages and model segments are listed in Table 8.

**Table 8. USGS Flow Gage and MDE Watershed Model Segment.**

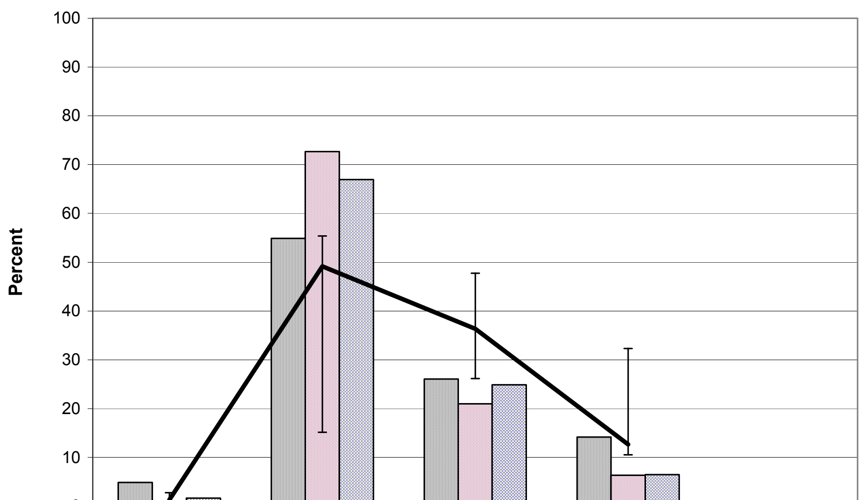
| Station Number | Model Segment | Watershed Area (Square Miles) | Watershed Area (Acres) |
|---|---|---|---|
| 01493000 | 140 | 22.3 | 14,272 |
| 01493112 | 160 | 6.12 | 3,917 |
| 01493500 | 220 | 12.7 | 8,128 |

Land use distributions were estimated for the three USGS gage watersheds and are presented in detail in Table 2 of Section 3. A relative comparison of lumped land uses for the three USGS gages segments to the median and inter-quartile range of all segments is presented in Figure 9.
In addition, statistics on the distribution of hydrologic soil groups are presented in Table 10. As with the land use, statistics include median and the inter-quartile range for all model segments.




| | Forest | Hitill | Lowtill | Hay/Veg/Pas | Urban |
|---|---|---|---|---|---|
| 140 | 30.1 | 35.8 | 25.3 | 4.9 | 3.9 |
| 160 | 7.3 | 39.0 | 22.8 | 28.8 | 2.1 |
| 220 | 10.0 | 48.5 | 28.4 | 9.2 | 3.9 |
| All Segments | 26.2 | 35.3 | 23.1 | 4.9 | 5.5 |

**Figure 9. Chester River HSPF Model Segments Land Use. Summary Statistics include Median, 25th Percentile and 75th Percentile for all MDE Watershed Model Segments.**




| | Pct A | Pct B | Pct C | Pct D | Pct Other |
|---|---|---|---|---|---|
| s140 | 5 | 55 | 26 | 14 | 0 |
| s160 | 0 | 73 | 21 | 6 | 0 |
| s220 | 2 | 67 | 25 | 6 | 0 |
| All Segments | 1 | 49 | 36 | 13 | |

**Figure 10. Chester River HSPF Model Segments Percent Soils Groups Estimated from STATSGO Soil Coverage. Summary Statistics Include Median, 25th Percentile and 75th Percentile for all MDE Watershed Model Segments.**

Unit flow volumes were calculated for gage 0149300 (segment 140) and 01493500 (segment 220). The calculation procedure summed the cumulative flow volume per calendar year and then divided this total by the watershed area as defined by USGS. The results are presented in the following table.

**Table 9. USGS Gage Calendar Year Unit Flow Volumes.**

| Summary Years | 01493000<br>Unit Flow (in) | 01493500<br>Unit Flow (in) |
|---|---|---|
| 1951 - 2001 | 15.5 | 11.6 |
| 1984 - 1999 | 15.6 | 12.6 |

The long term unit water yield (1951 to 2001) was evaluated, and the period from 1984 to 1999 was also included for comparison to the CBP Phase 4.3 watershed model results. The unit flow volumes reported from the two calibration gages for MDE Segments 140 (01493000) and 220 (01493500) show significant differences in annual unit flow volumes. Soil infiltration rates between the two watersheds are similar as per analysis of the STATSGO soil coverage. Both watersheds exhibit a similar composition of SCS types A, B, C and D soil groups. Land use distribution within the two watersheds are also similar with the only difference being that Segment 140 contains more forest and Segment 220 has more cropland. Topography is similar between the two segments and given their close proximity to each other, the precipitation tends to be similar.

With the differences in land cover, it would be expected that the larger amount of forest area in Segment 140 would produce less unit runoff and have increased interception and evapotransporation rates. However, based on the flow gage monitoring data, the opposite is true. Segment 140 has a significantly larger annual unit water yield than Segment 220.

Additional analysis included a time series plot of the annual unit flow volumes and a correlation plot comparing gages 01493000 and 01493500. These plots are identified in this report as Figures 11 and 12, respectively. Both plots show that on average the unit flow volume from gage 01493000 is higher than 01493500.

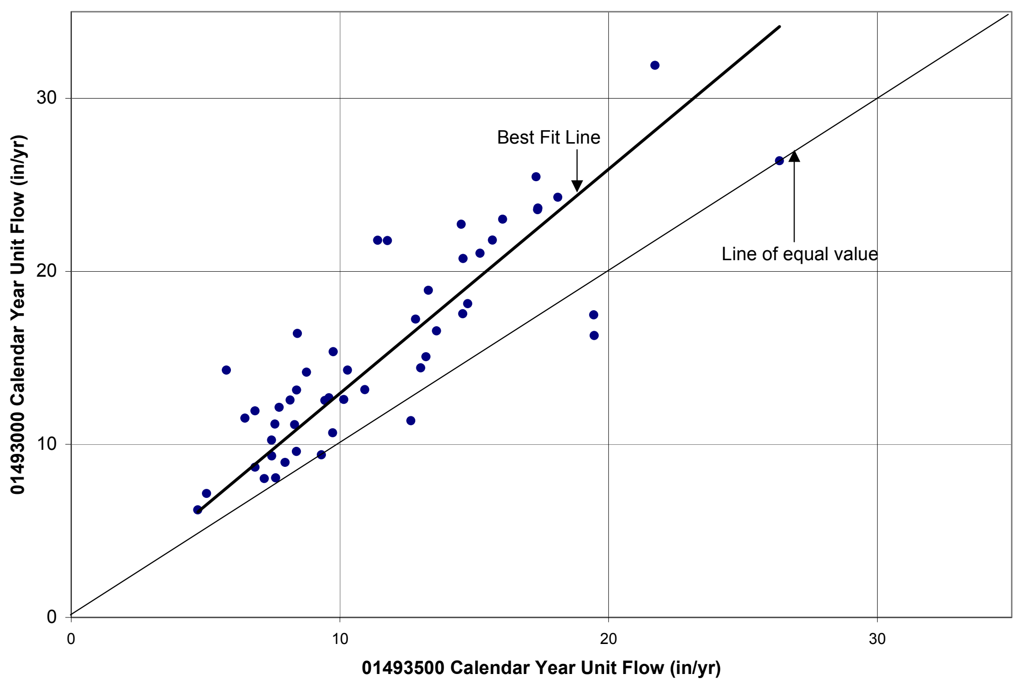



**Figure 11. Chester River Long Term Flow Gage Correlation. Analysis Based on Calendar Year Total Flows Normalized to Watershed Area. Period of Record from Water Year 1951 to 2000.**

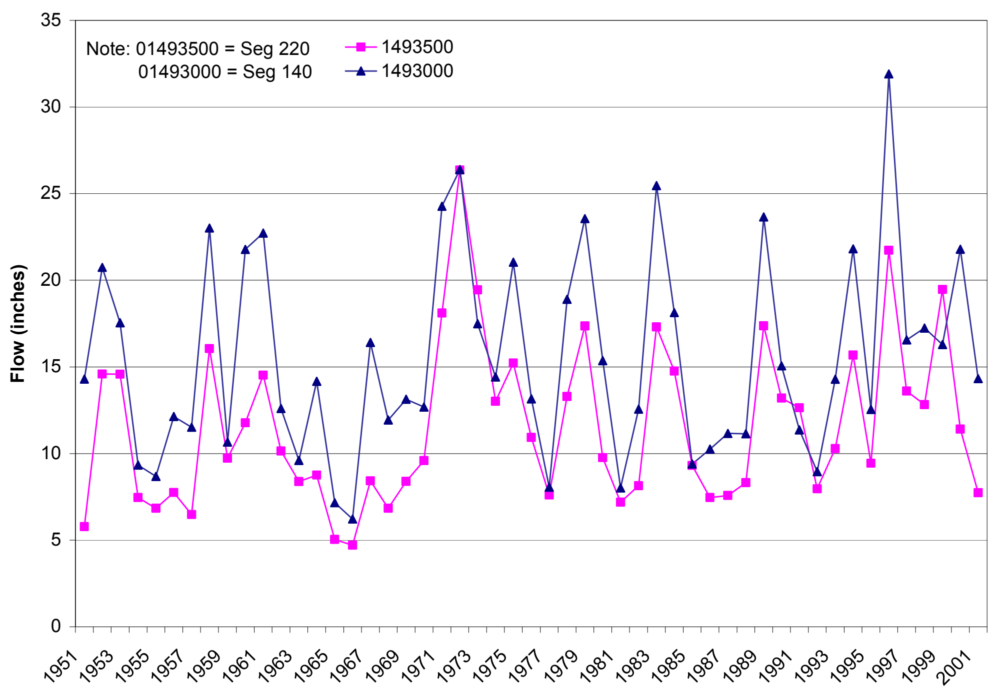



**Figure 12. Chester River Long Term Flow Gage Comparison of Calendar Year Total Flows Normalized to Watershed Area. Period of Record from Calendar Year 1951 to 2000.**

### 3.10.1.2 Comparison of USGS Gaged Watersheds to CBP Hydrology Estimates

Segment 380 of the CBP Phase 4.3 watershed model covers the majority of the Chester River Basin. Therefore, this segment was used in conjunction with the MDE land uses to estimate the average water yield for the two USGS flow gaged watersheds with long term records (01493000 and 01493500).

To estimate the average annual calendar year unit flow rates, the land uses were lumped into forest, high till crops, low till crops, hay/vegetables/pasture, pervious urban and impervious urban. The CBP individual hay, vegetables and pasture land uses were lumped into one land use due to the similar hydrological characteristics. A list of these relationships is presented in Table 10.

**Table 10. Relationship Between MDE Land Use and CBP Land Use categories.**

| MDE Landuse | CBP Landuse |
|---|---|
| Forest | Forest |
| Hitill Corn | Hi till |
| Double Crops | |
| Low till corn | Low till |
| Full season Beans | |
| Hay | Hay/ Vegetables/ Pasture |
| Vegetables | |
| Pasture | |
| Pervious Urban | Pervious Urban |
| Impervious Urban | Impervious urban |

Next, the CBP model Segment 380 hydrology output was summarized for calendar years. A summary for each year included individual land use annual unit flow volumes from years 1984 to 1999. The individual land use unit flows were averaged over the 1984 to 1999 duration and results are presented in Table 11. To estimate the average annual unit flow for the gaged watersheds, the percentage of contributing land uses were multiplied by the corresponding land use unit flow and then summed. Results of this are also presented in Table 11.

**Table 11. CBP Segment 380 Below Fall Line Average Flow (1984 to 1999).**

| | | Fraction of Landuse | |
|---|---|---|---|
| | **Flow (in/yr)** | **01493000 MDE 140** | **01493500 MDE 220** |
| Forest | 9.85 | 30% | 10% |
| High Till Crop | 14.47 | 36% | 48% |
| Low Till Crop | 13.76 | 25% | 28% |
| Hay/Veg/Pasture | 13.59 | 5% | 9% |
| Pervious Urban | 16.80 | 3% | 4% |
| Impervious Urban | 37.15 | 1% | 0% |
| | | | |
| **Average flow (In/yr)** | | **13.1** | **13.8** |

The average annual unit flows for gages 01493000 (MDE segment 140) and 01493500 (MDE Segment 220) are 13.1 in/yr and 13.8 in/yr, respectively. Annual unit flow estimates suggest that MDE Segment 220 has a slightly higher unit water yield. This is explained by Segment 220 containing more crop land that has a high unit flow and segment 140 having a higher percentage of forest, which has a low unit flow. However, analysis of recorded USGS flow data concludes the opposite results, Segment 140 having a higher unit flow than Segment 220.

## 3.10.2 Stream Water Quality Data

The three main sources for water quality information are the Chesapeake Bay Program's long term monitoring stations, MDE's intensive study and the Chester River Association's monitoring program (Figure 8). This data is primarily used in the quality model.

# 4 Hydrology Calibration

The CBP watershed model hydrology for the Eastern Shore Maryland Basin was calibrated at Model Segment 780 to USGS Station 1487000 at Bridgeville, Delaware, and Model Segment 770 to USGS Station 1491000 at Greensboro, Maryland. Details of the CBP hydrology calibration are given in Greene and Linker, 1998.

## *4.1 Hydrology Calibration Procedure*

Before deciding to use the CBP Phase 4.3 model output, MDE developed a HSPF hydrology calibration using segments 140 and 220 with calibration years from 1992 to 1999. Calibration flow gages used for comparison were USGS 01493000 for model segment 140, and USGS 01493500 for model segment 220. To statistically assess the model calibration, summary plots and error reports were developed for daily flow values, monthly flow volumes, seasonal flow volumes, and annual (water/calendar) flow volumes.

The hydrology calibration process resulted in two rounds using two distinct methods. The first round was a hydrology model calibration using a trial and error approach to parameter estimates. With this method, sensitive model input parameters were identified and then changed in a stepwise sequence to better match the observed flow statistics. All model parameters were kept within their valid ranges as recommended by the HSPF User's Manual. After several trials, it was determined that it would not be possible to maintain consistent land use parameterization for each of the calibration watersheds (Segments 140, 160 and 220). As mentioned in Section 3, the unit flow volumes reported from the two calibration gages for Segments 140 (01493000) and 220 (01493500), show significant differences in annual unit flow volumes, although they have similar watershed characteristics.

The second round of hydrology calibration efforts utilized a non-linear Parameter Estimation Software Program (PEST) developed by John Dougherty (Watermark

Numerical Computing). PEST is a model independent (general) least squares optimization program that allows specification of parameter bounds. To use PEST, an objective function must first be defined. This objective function can contain multiple objectives, however, appropriate weights must be defined given that units and number of observations typically differ between the objectives. Input parameters are user defined and it is up to the modeler to select the appropriate parameters based on experience. For model parameter estimation, it is best to limit the total number of parameters by removing non-sensitive parameters and parameters that co-vary. For this study, the parameters listed in Table 12 were identified as parameters to be estimated by PEST. Parameters not identified in this table were selected based on values used in existing studies, watershed topography and best professional judgment.

**Table 12. HSPF Parameters Used in PEST.**

| Parameter | Description | Comments |
|---|---|---|
| INFILT | Index to the infiltration capacity of the soil | crop land and open land specified as fraction of forest |
| AGWRC | Groundwater recession rate | same for all land uses (transformed) |
| LZSN | Lower zone nominal storage | same for all land uses |
| IRC | Interflow recession parameter | same for all land uses (transformed) |
| MON-INTERCEP | Monthly interception storage capacity | crop land and open land specified as fraction of forest. Variance held constant |
| MON-UZSN | Monthly upper zone nominal storage | crop land and open land specified as fraction of forest. Variance held constant |
| MON-LZETPARM | Monthly lower zone E-T parameter | crop land and open land specified as fraction of forest. Variance held constant |

Monthly varying HSPF parameters were estimated based on a sinusoidal function whereby PEST estimated only the phase and the amplitude was estimated based on review of existing model inputs (i.e. CBP). To reduce the number of total parameters, HSPF land use parameters were lumped into hydrological similar groups which included forest, crop, pervious urban and impervious urban categories.

The objective function for the hydrology calibration included the daily flow, monthly flow and selected points on the flow frequency curve. Selecting weights of the objective function is up to the model developer. For this study the following weighting method was applied:

<u>Daily flow</u> $$W_Q = \frac{1}{Q + 0.001} \text{ Q}$$

Where
$W_Q$ = Weighting factor applied to each value
Q = Daily flow rate

<u>Montly flow</u> $$W_M = \frac{0.01}{\sqrt{M}} \text{ M}$$

Where
$W_M$ = Weighting factor applied to each value
M = Monthly flow volume

<u>Flow Frequency</u> $$W_F = 300 * Q_f$$

Where
$W_F$ = Weighting factor applied to each value
$Q_f$ = Daily flow rate for a specified flow frequency

Model runs were controlled by PEST where the HSPF model was run multiple times to determine parameter sensitivities and gradients for parameter adjustment. All of this was performed automatically within PEST. Non-sensitive parameters were identified and then manually held constant at recommended values.

Results from this analysis indicated that it was not possible to use similar land use parameter values for both segments 140 and 220, and obtain an acceptable hydrology calibration. Not maintaining similar parameters reduces the model calibration to curve fitting and limits the usefulness of the model.

It was then decided to hold all landuse parameters the same between segments 140 and 220 and only allow the deep fraction parameter within HSPF to vary between segments.

This greatly improved the calibration, however the deep fraction values went above the recommend upper limit of 0.3 for segment 220. For MDE watershed segment 140, the deep fraction parameter value was set to zero. Deep fraction allows a fraction of the groundwater to be lost from the system and is essentially a flow sink term used in the model.

# 5 Water Quality Calibration

Based on the work done on the hydrology calibration for the Chester River watershed, it was not possible to develop a HSPF water quality model for the non-tidal regions. It was determined that the modeling framework setup by EPA's Chesapeake Bay Program would be a better alternative.

## *5.1 Recommendation for use of CBP Phase 4.3 watershed model*

After review of model results from the efforts of MDE staff, it was decided that MDE should not proceed with the hydrology calibration. Reasons for this decision are listed below:

- Conflicting results with estimated unit surface water yield from calibration gages and actual unit surface water yield. Further investigation is needed. USGS is currently conducting additional monitoring within this watershed, and is aware of these hydrology issues (Fisher, Gary, 2003).
- Inter-agency cooperation with Chesapeake Bay Program Phase V watershed model development. Continuation of the Chester River model would be duplicative in effort. Estimated completion date of the CBP Phase V watershed model is January 2005.
- Existing Chesapeake Bay Program Phase 4.3 model developed and calibrated based on regional data.

Based on the above listed reasons, it was decided that the Phase 4.3 model output would be used as input into the Chester, Wye and Miles River sections of the water quality model. Moreover, the water quality model extent covers the Upper Chesapeake Bay and watershed inputs from outside the Chester, Wye and Miles River are also based on the Phase 4.3 outputs.

Since more detailed segmentation and corresponding land use distributions were estimated for the 34 MDE model segments within the Chester, Wye and Miles River watersheds, MDE developed postprocessing utilities to disaggregate the output from the four CBP Phase 4.3 segments. The post -processing utilities included programs to relate MDE segments to CBP segments, relate MDE land uses to CBP land uses, create MDE segment daily loading rates, and produce MDE segment flow/loading summaries.

In post-processing the CBP Phase 4.3 land use data, relationships were developed between the MDE landuse categories and the CBP landuse categories. The following table lists the MDE landuse with corresponding CBP land use.

**Table 13. Relationship Between MDE Landuse and CBP Landuse categories.**

<table>
<tr><th>MDE Landuse</th><th>CBP Landuse</th></tr>
<tr><td>Forest</td><td>Forest</td></tr>
<tr><td>Hitill Corn</td><td rowspan="2">Hi till</td></tr>
<tr><td>Double Crops</td></tr>
<tr><td>Low till corn</td><td rowspan="2">Low till</td></tr>
<tr><td>Full season Beans</td></tr>
<tr><td>Hay</td><td>Hay</td></tr>
<tr><td>Vegetables</td><td>Mixed Open</td></tr>
<tr><td>Pasture</td><td>Pasture</td></tr>
<tr><td>Pervious Urban</td><td>Pervious Urban</td></tr>
<tr><td>Impervious Urban</td><td>Impervious urban</td></tr>
<tr><td>Manure</td><td>Manure</td></tr>
</table>

Using the above table, the land use acres within a MDE model segment were multiplied by the corresponding land use unit flow and load daily time series from the CBP Phase 4.3 model. All land uses except manure were calculated using this method.

# 6 Watershed Load Summary

The time series loads from the CBP version 4.3 watershed model and MDE's refined model were analyzed (Tables 14 and 15). The percent differences in the final loads between these models for Total Nitrogen (TN), Total Phosphorus (TP) and Biochemical Oxygen Demand (BOD) are approximately 10%, and for sediment approximately 20%. There is a small difference in the total area of the watershed (approximately 580 acres), which can be attributed to the refined land use of the MDE model. The difference in the land use would explain the consistent discrepancy in the final loads for TN, TP and BOD.

**Table 14. Annual Average Loads from CBP Watershed Model.**

| Segments 380, 390, 820 and 830 - Area 372,205 ac | | | | |
|---|---|---|---|---|
| | TN (lb/yr) | TP (lb/yr) | BOD (lb/yr) | Sediment (ton/yr) |
| 1997 | 3,705,330 | 204,500 | 5,482,290 | 21,182 |
| 1998 | 4,467,280 | 418,642 | 9,577,310 | 103,262 |
| Annual Average | 4,086,305 | 311,571 | 7,529,800 | 62,222 |

**Table 15. Annual Average Loads from MDE Watershed Model.**

| Watershed Area 372,784 ac | | | | |
|---|---|---|---|---|
| | TN (lb/yr) | TP (lb/yr) | BOD (lb/yr) | Sediment (ton/yr) |
| 1997 | 4,039,988 | 235,254 | 6,046,625 | 27,718 |
| 1998 | 4,778,803 | 460,617 | 10,866,330 | 126,991 |
| Annual Average | 4,409,396 | 347,935 | 8,456,478 | 77,354 |

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