GIS and Water Quality Modeling

for

Watershed Management

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Four Components

- Watershed Protection System

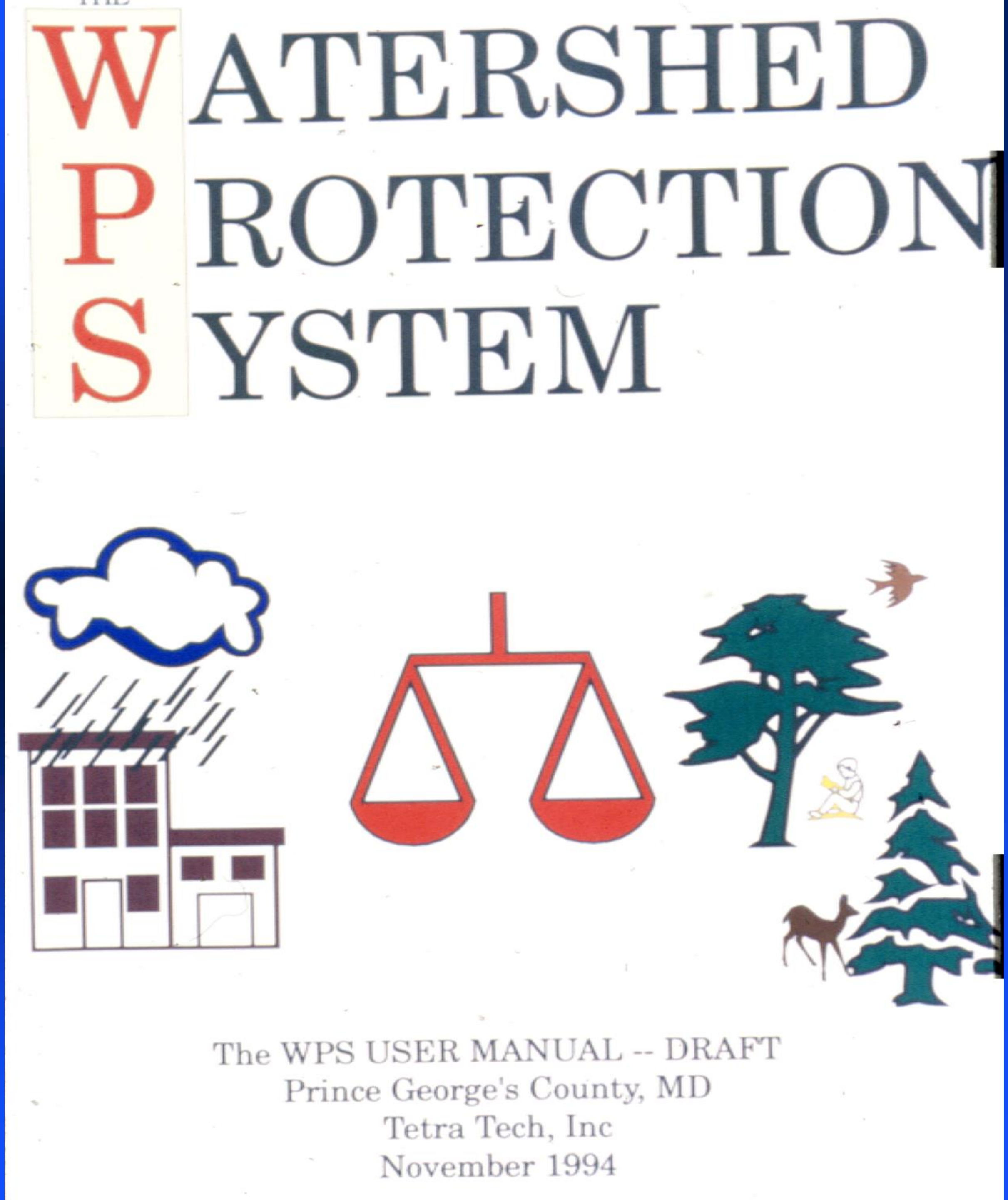
  (Planning level model)

- GIS-Based HSPF Models

  (Detailed Watershed Simulation)

- BASINS

- Case Study using BASINS


WATERSHED
PROTECTION
SYSTEM

The WPS USER MANUAL -- DRAFT
Prince George's County, MD
Tetra Tech, Inc
November 1994

(1) Planning Level Model

Watershed Protection System

- Watershed simulation model for Planning-level analysis
- Watershed management methods
- Watershed characteristics and Data overlays
- Stormwater management practices module
- Industrial and commercial facility module
- Priority pollutant characteristics

WATERSHED PROTECTION SYSTEM

- **WATERSHED SIMULATION MODEL**
  - SIMULATION RUN
  - WATERSHED NAME & ABBREV.
  - RESULTS WINDOW
  - FILE MANAGER
  - SESSION MANAGER
  - PRINT MANAGER
- **WATERSHED MANAGEMENT METHODS**
  - GOAL SETTING
  - PRIORITIZATION & RANKING
  - LANDUSE TARGETTING
  - POTENTIAL BMP'S
- **WATERSHED CHARACTERISTICS**
  - LAND USE
  - SOIL
  - SLOPE
  - RIVER
  - ROAD
  - WELLS
  - NPDES FACILITIES
  - USGS GAGES
  - GNIS DATA
  - WQ STATIONS
- **BUSINESS AND INDUSTRY**
  - POLLUTANT SOURCE I.D..
  - INDUSTRIAL FACILITY I.D..
  - FACILITY RETRIEVAL
  - POLLUTANT ↓↑ FACILITY
- **STORMWATER CONTROL FACILITIES**
  - COUNTYWIDE
  - WATERSHED
  - GEOGRAPHIC AND TABULAR FORMATS
- **PRIORITY POLLUTANTS**
  - CHEMICAL CHARACTER-ISTICS
  - FATE & TRANSPORT
  - INDUSTRIAL USES
  - ANALYTICAL METHODS
  - REGULATORY ISSUES
  - TOXICOLOGICAL CHARACTERIS-TICS

Simulation Methodology

- Run SWMM for small individual land use watershed
- Adjust model parameters to monitoring data
- Run SWMM 9 land uses for 12 pollutants
- 8 years of continuous simulation using hourly time step

Land Use Types Simulated

- Low density residential: >1/2 ac/lot
- Medium density residential: 1/2 - 1/8 ac/lot
- High density residential: < 1/8 ac/lot
- Commercial
- Industrial
- Open space
- Forest
- Agriculture
- Bare land

Constituents Simulated

Flows

Biological Oxygen Demand

Chemical oxygen demand

Total suspended solids

Dissolved suspended solids

Total phosphorous

Dissolved phosphorus

Total nitrogen

Ammonia & Organic nitrogen

Copper

Cadmium

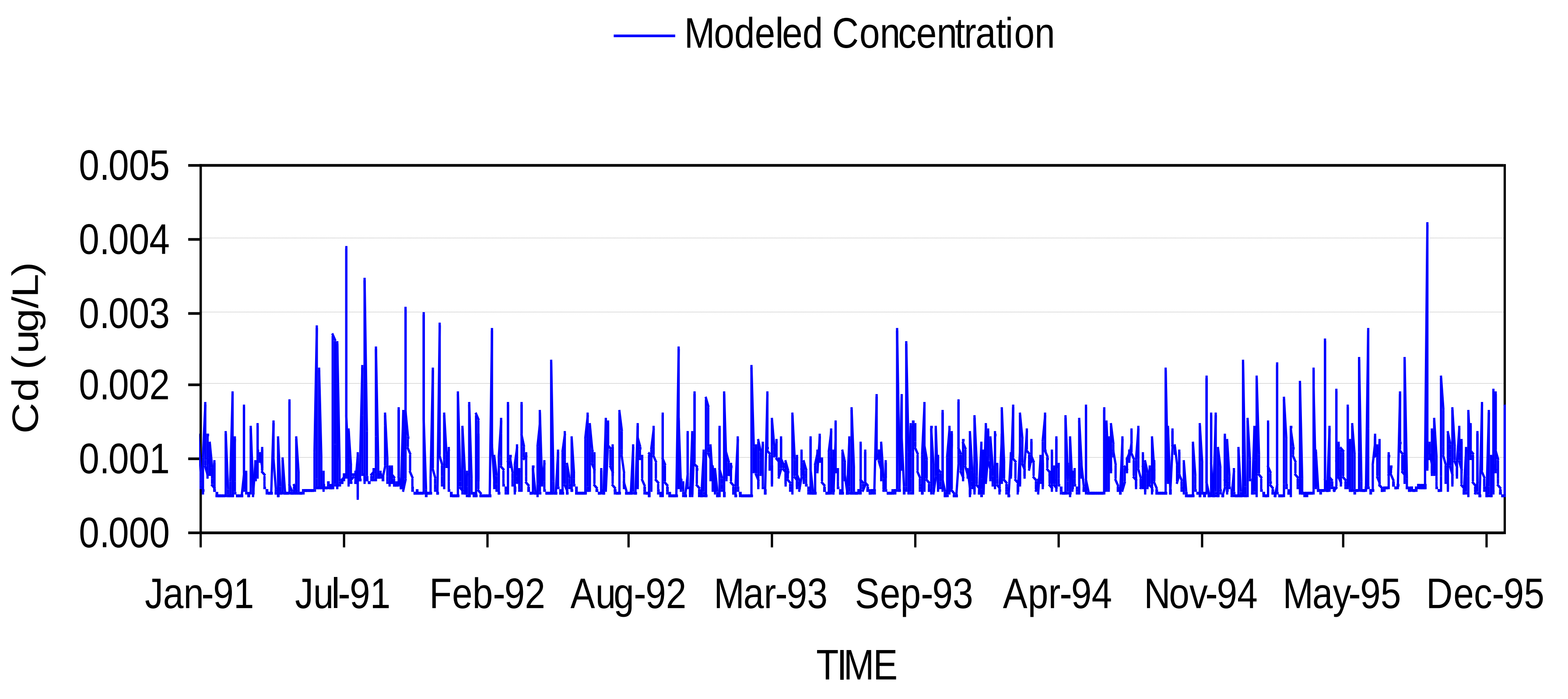
Zinc

Lead

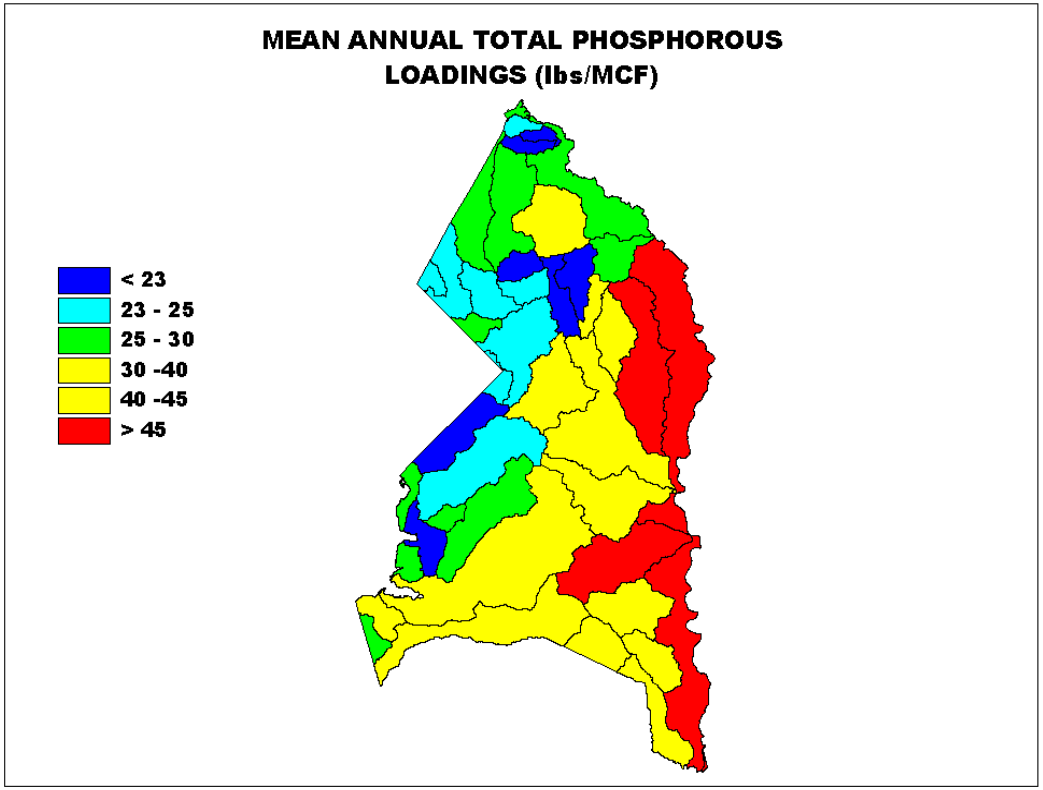
Flow / Pollutant Hourly Time Series

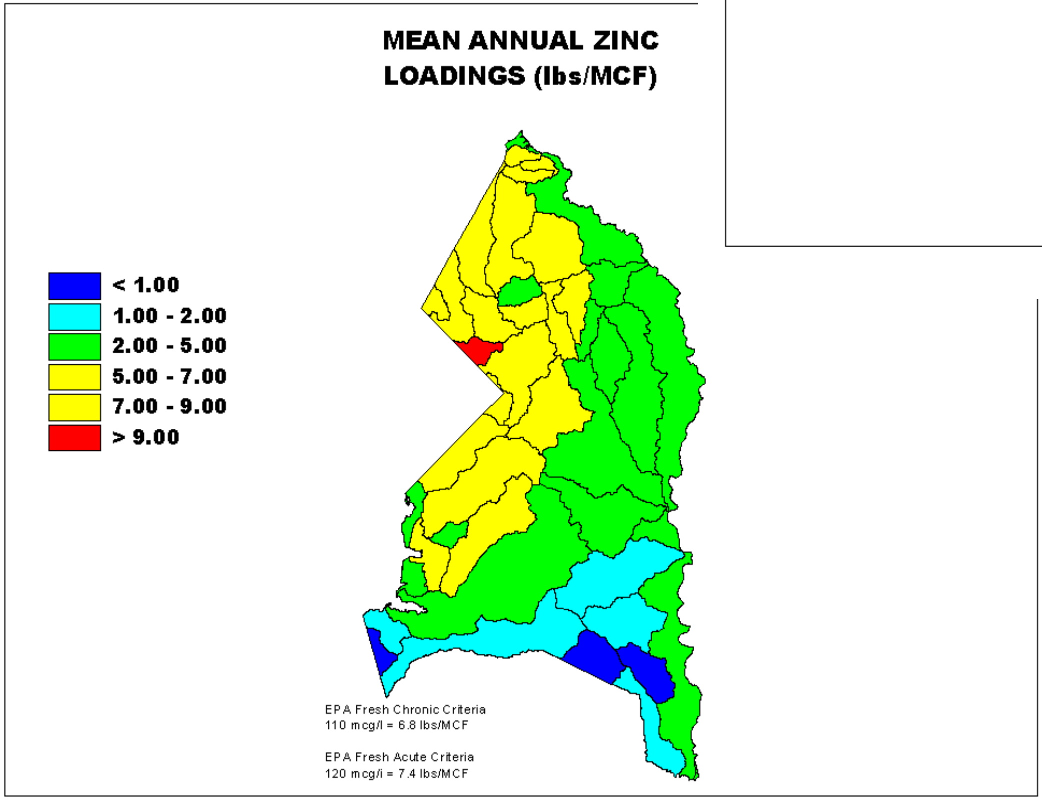
Heavy Metal

Residential Land Use

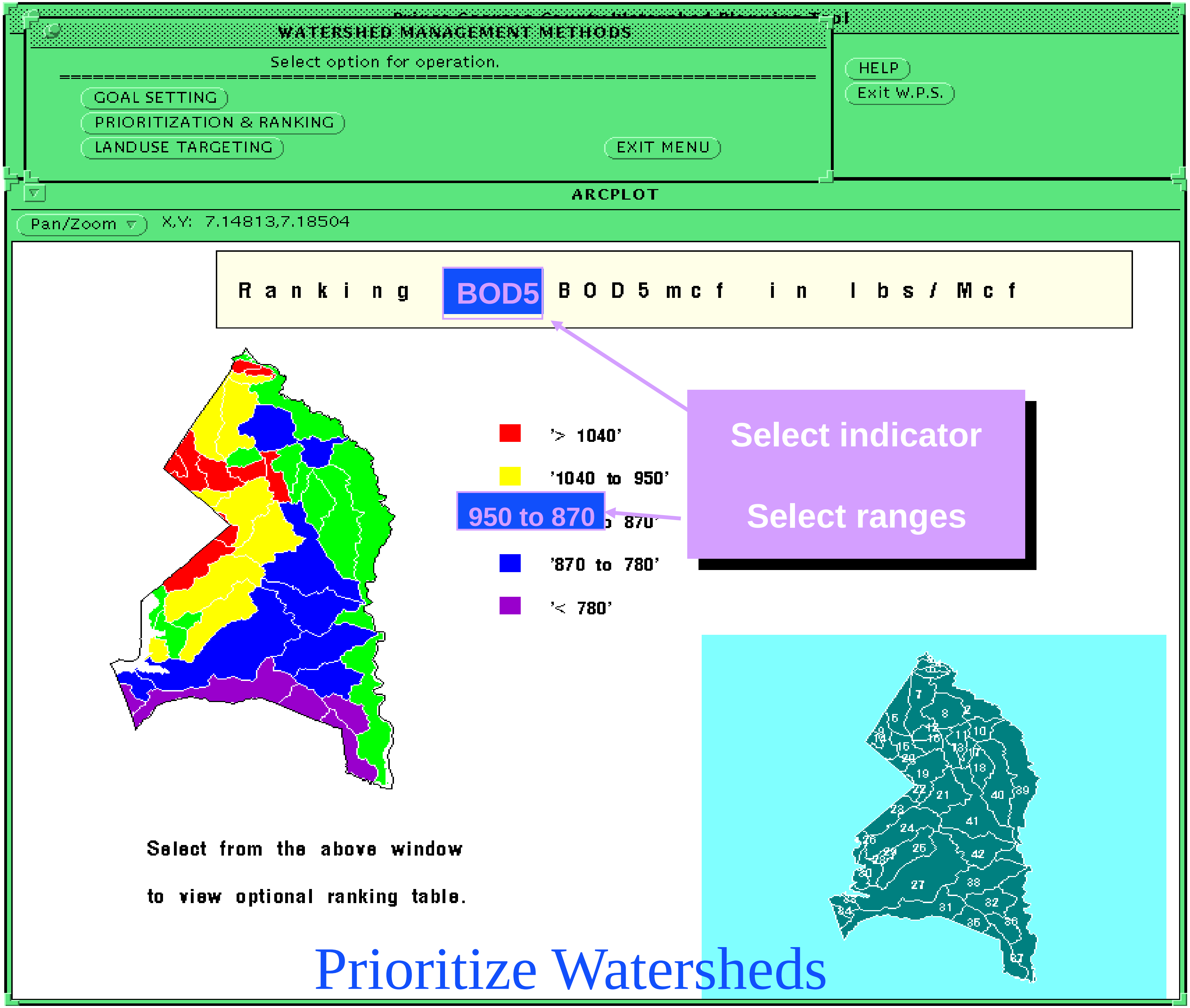


Pollutant Loadings Distribution



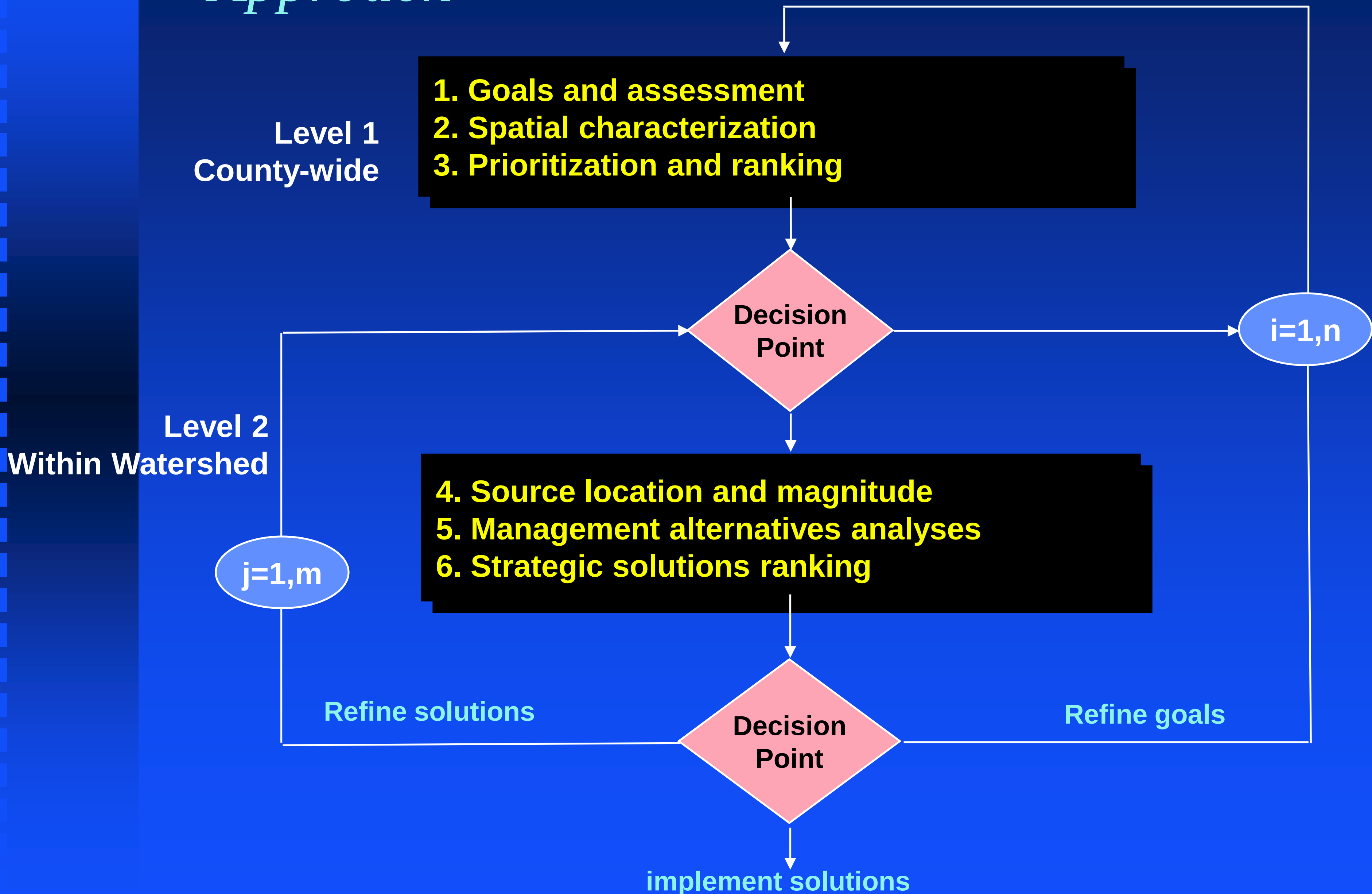


To Prioritize Watersheds based on Pollutant Loadings



Prioritize Watersheds

Structured Watershed Management Approach



(2) Application of GIS-Based HSPF Model

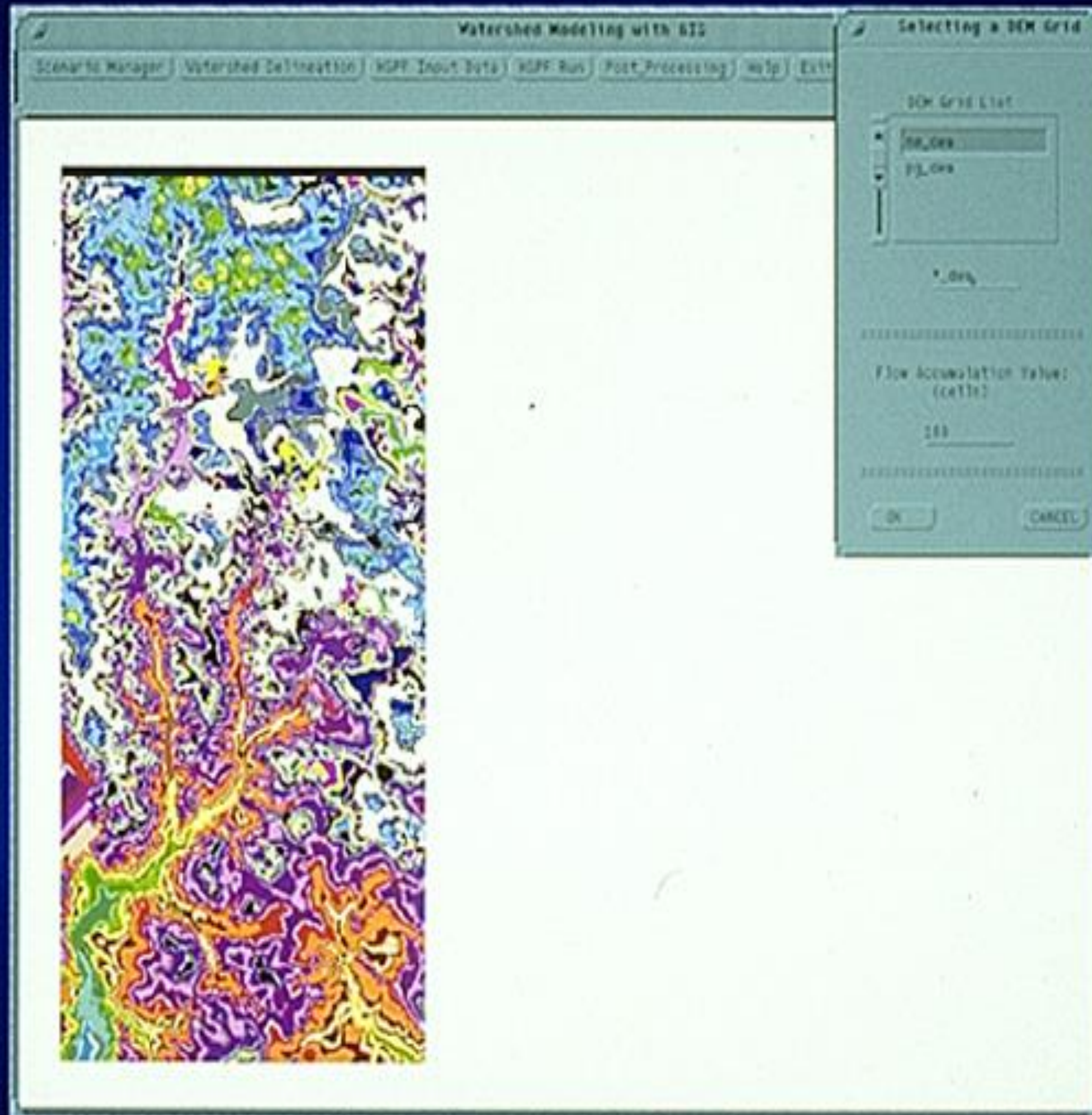
Hydrological Simulation Program

- FORTRAN

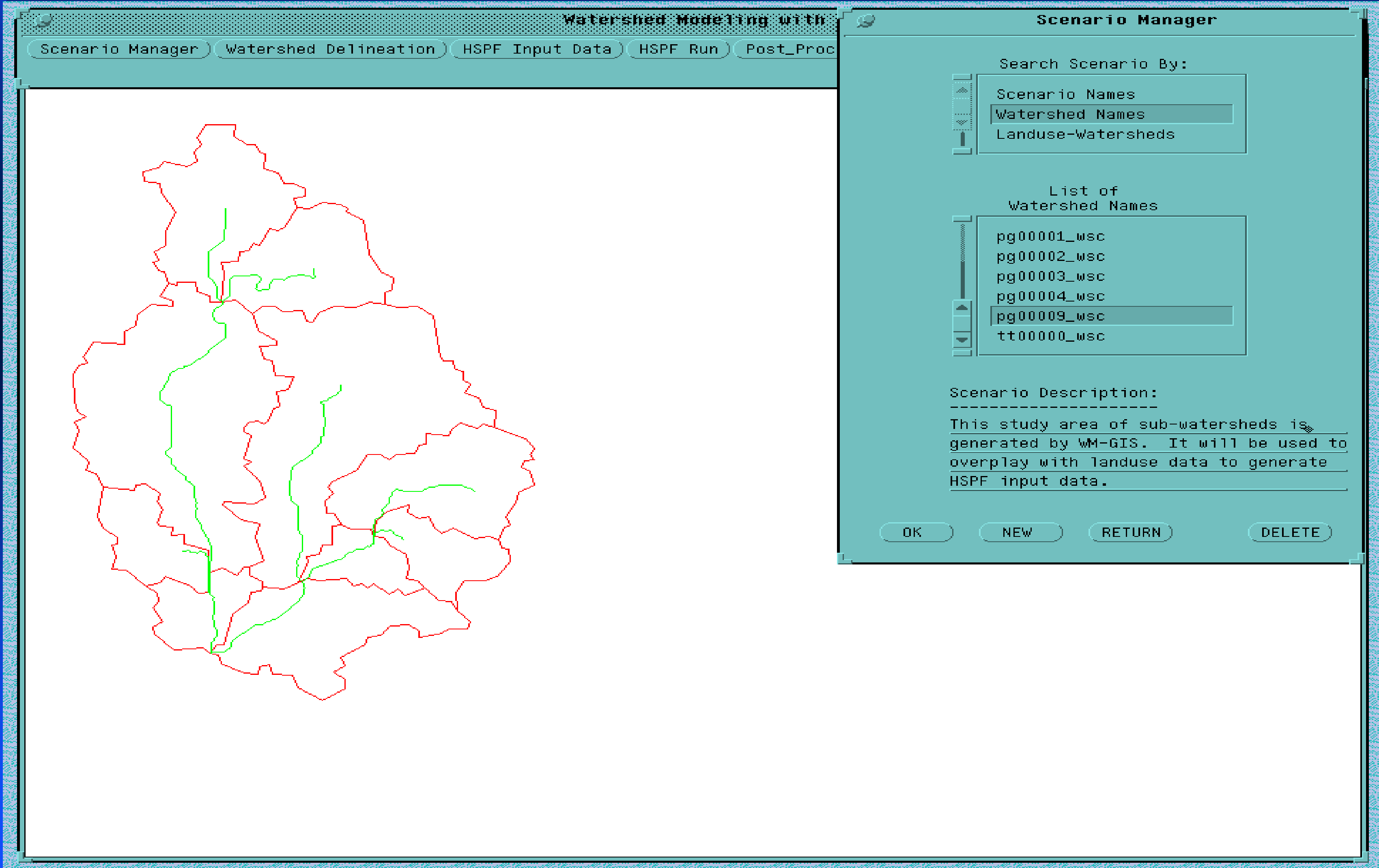
Detailed Watershed Management Model

- Continuous simulation of hydrology and water quality in a watershed
- Spatial and temporal variability of flow and pollutant loadings
  - location, duration and frequency of wet and dry conditions
- simulation of alternative management scenarios
- Prediction of future condition

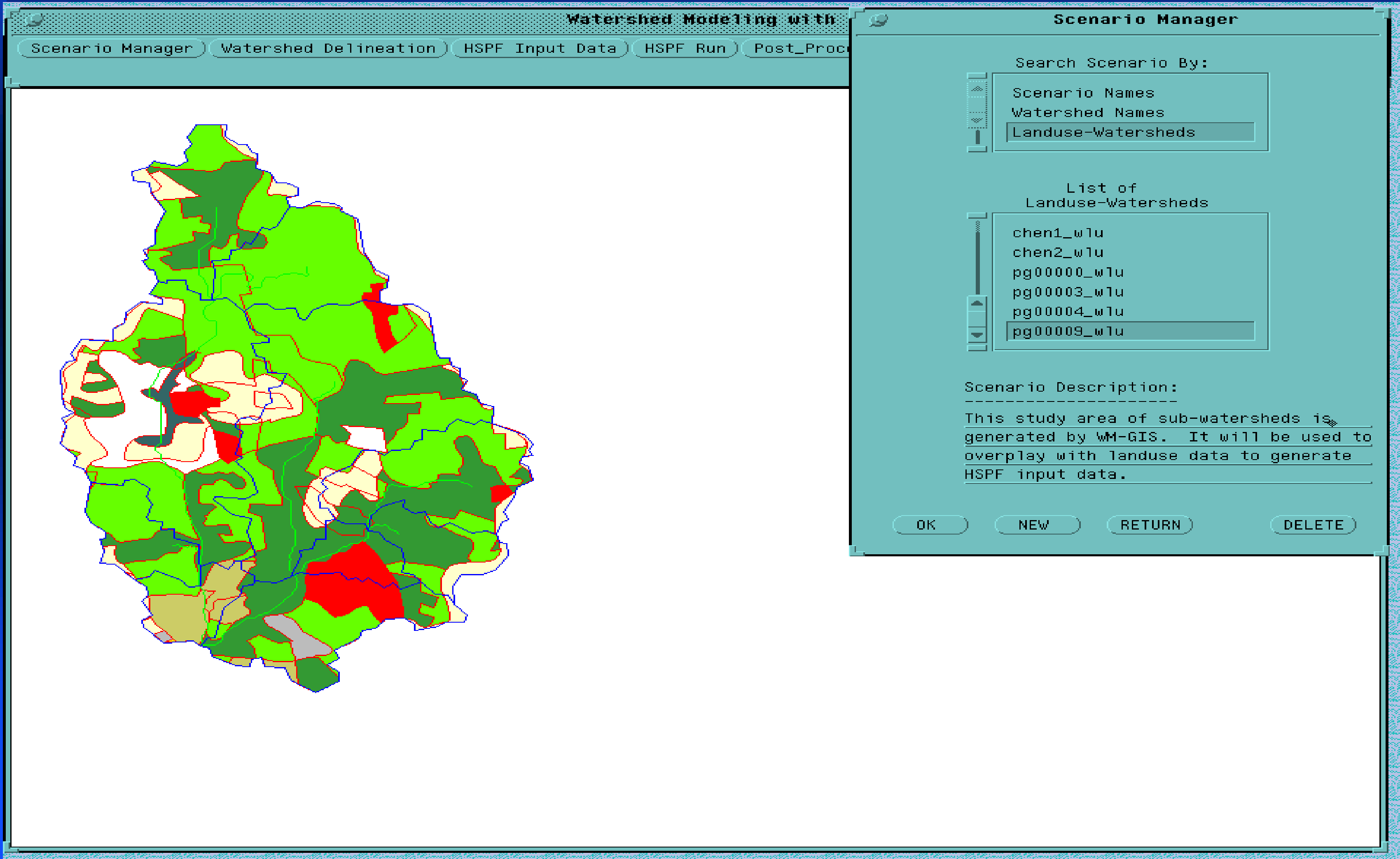
Select DEM for subbasin analysis and delineation



Automatically Delineate Sub-Watershed Boundary

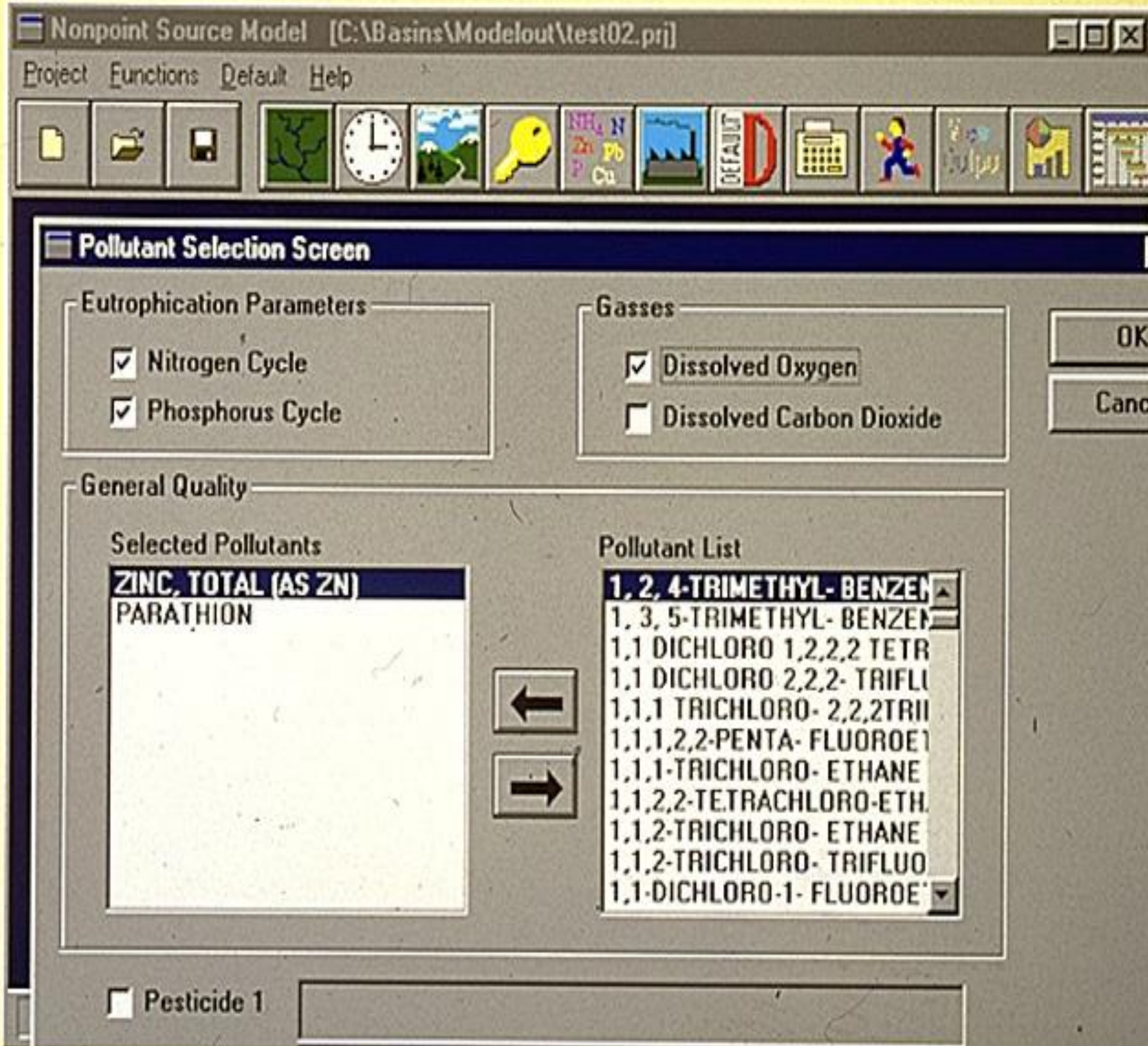


Automatically Determine Land Use Distribution for each Sub-Watershed



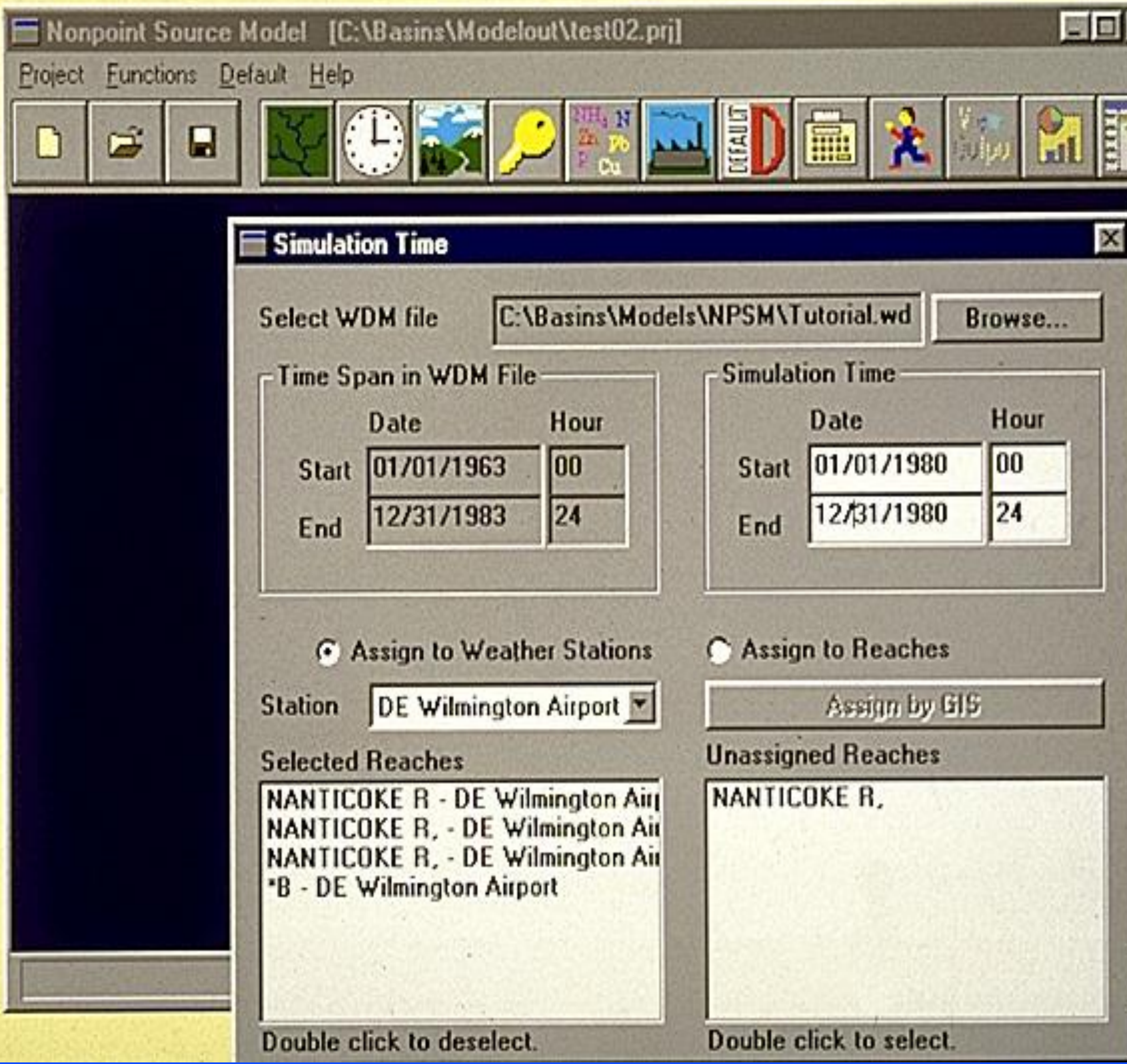
HSPF Interface

Pollutant selection for HSPF simulation

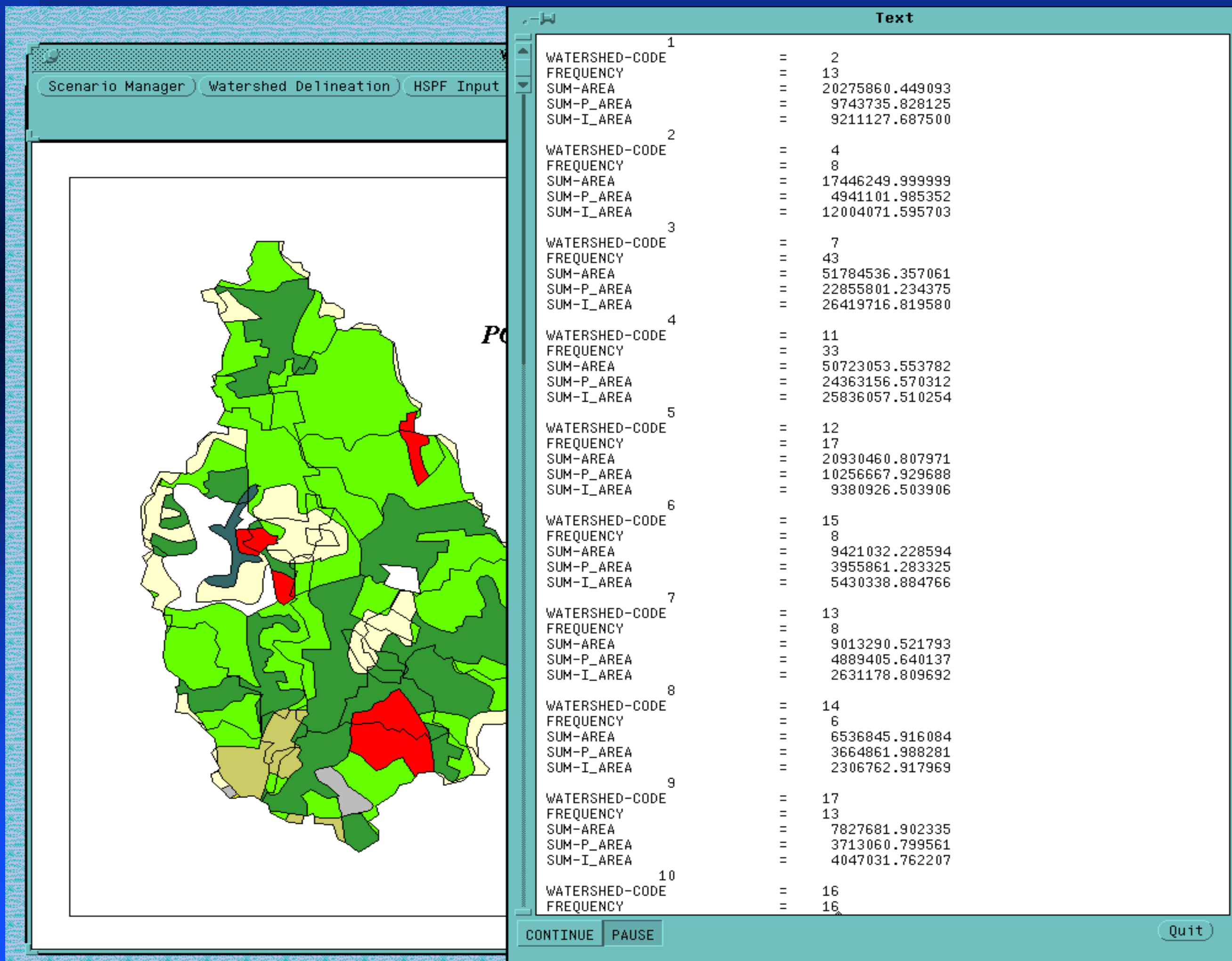


HSPF Interface

Weather data assignement screen

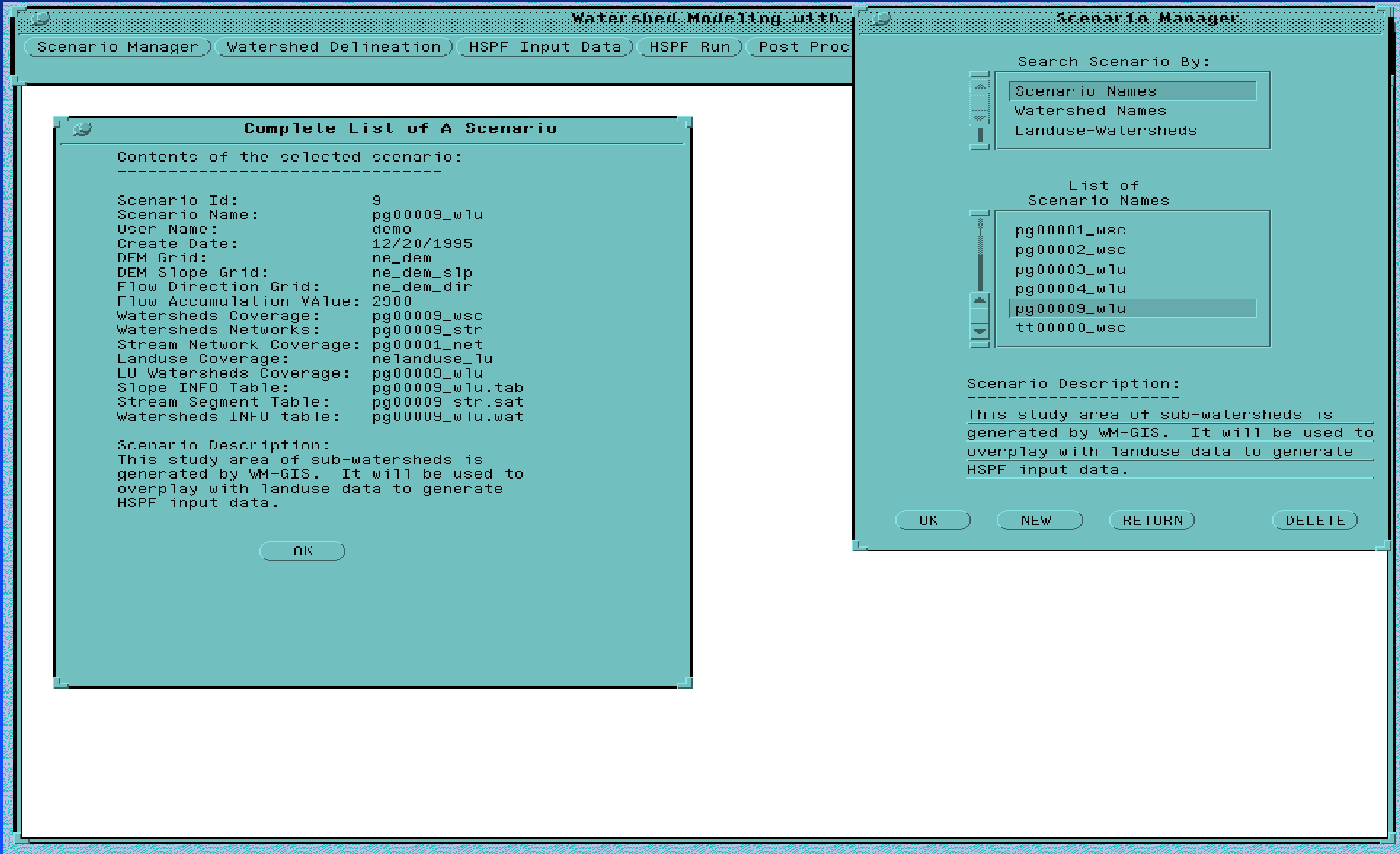


Automatically Assign Hydrologic & Water Quality Parameters (each Land Use in each Sub-Watershed)



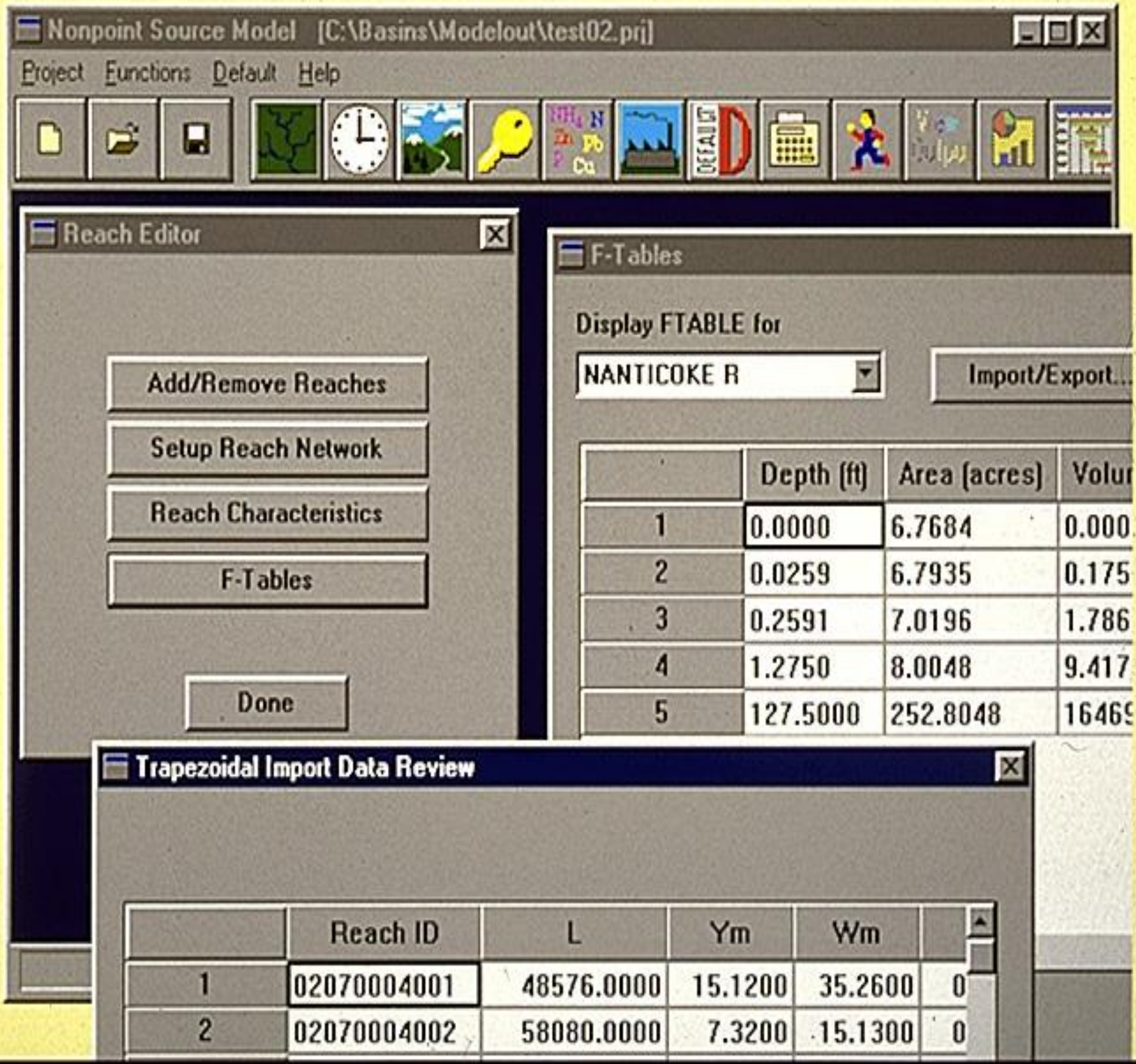
For Both Pervious and Impervious areas

Provide Point Sources Data, if Any

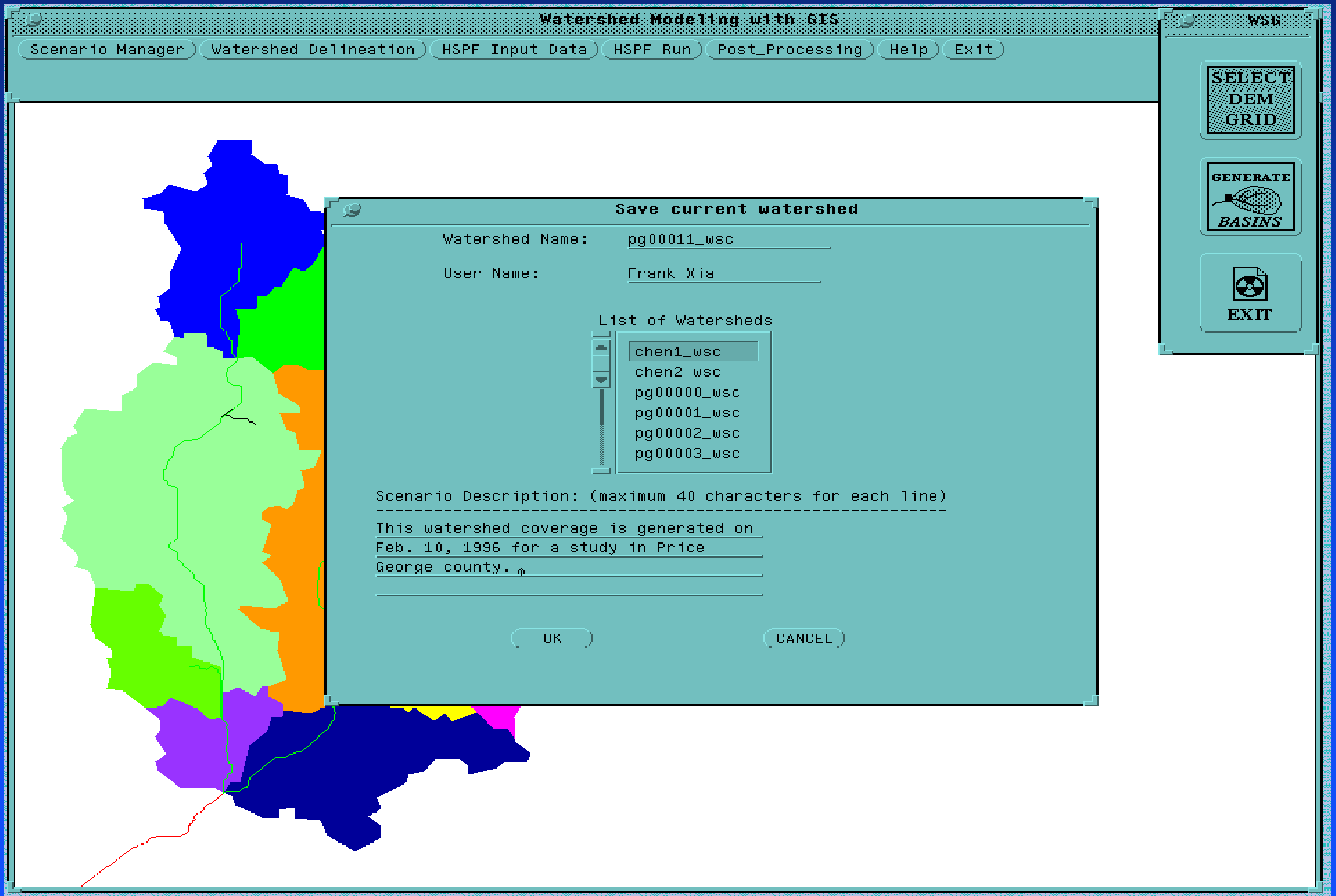


HSPF Interface

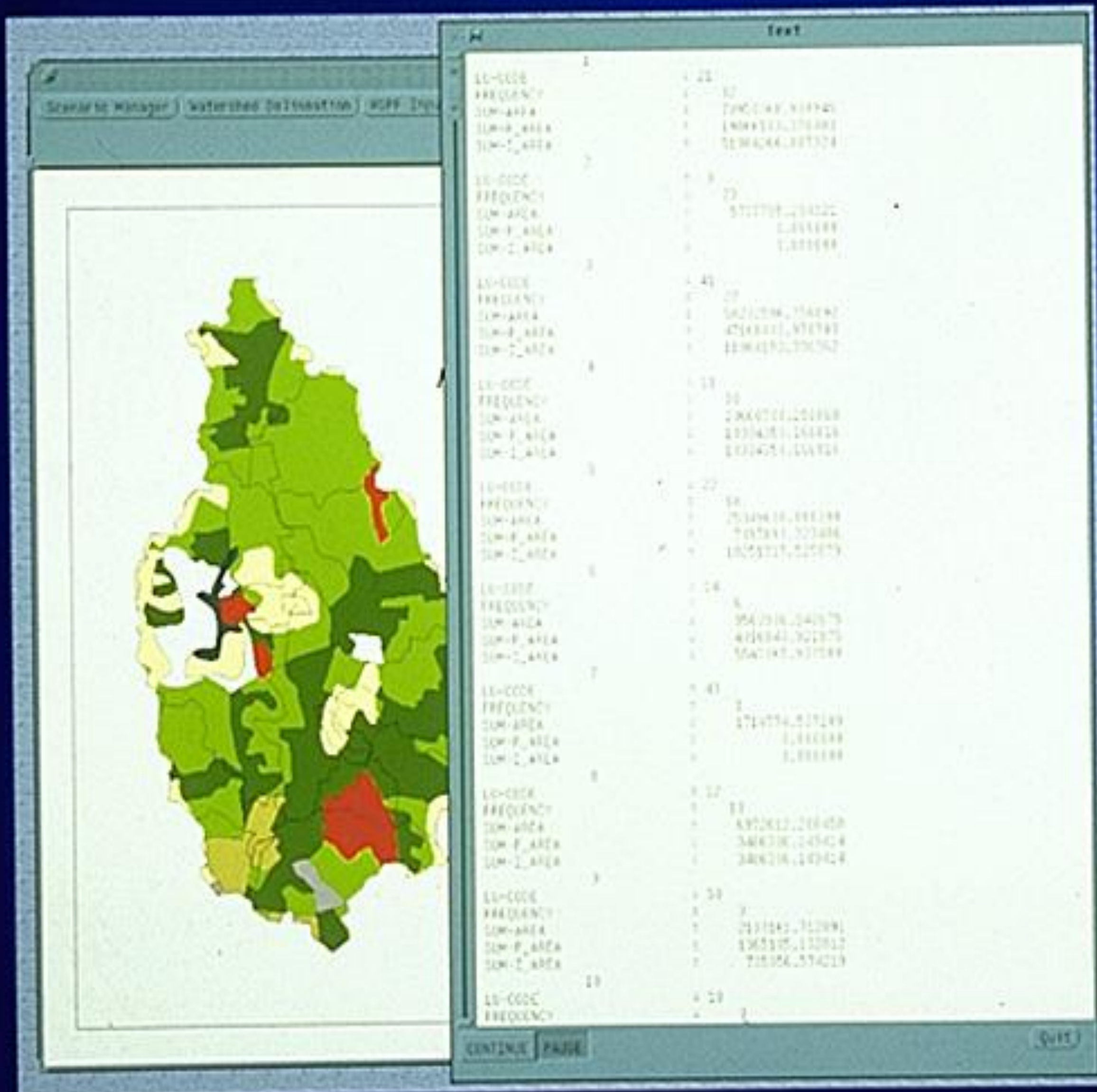
Reach data screens including F-tables and F-tables generator.



Automatically Generate REACH Data, Network and F-Tables

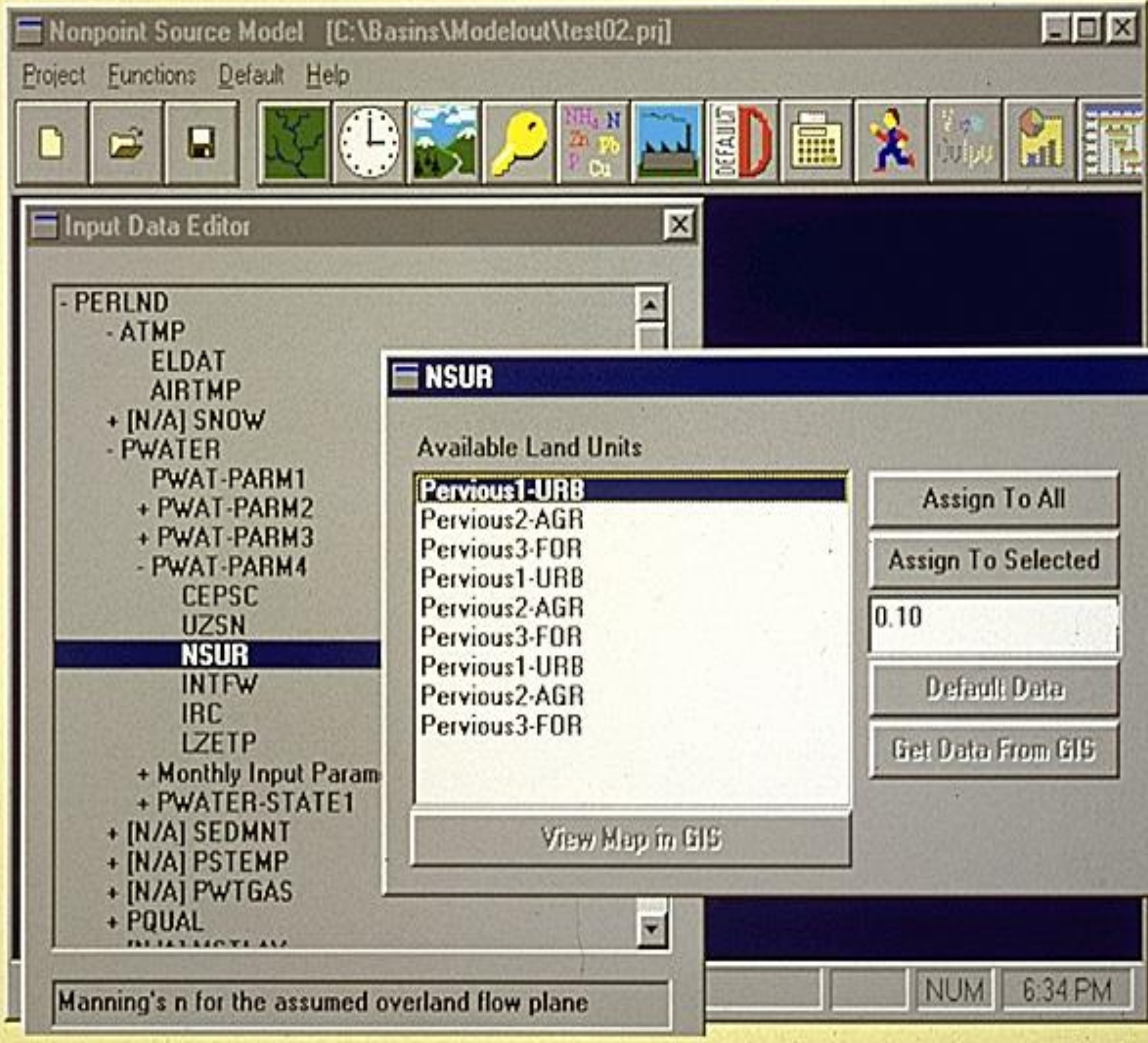


Generate summary information by land use category and automatically derive input data for watershed modeling with HSPF

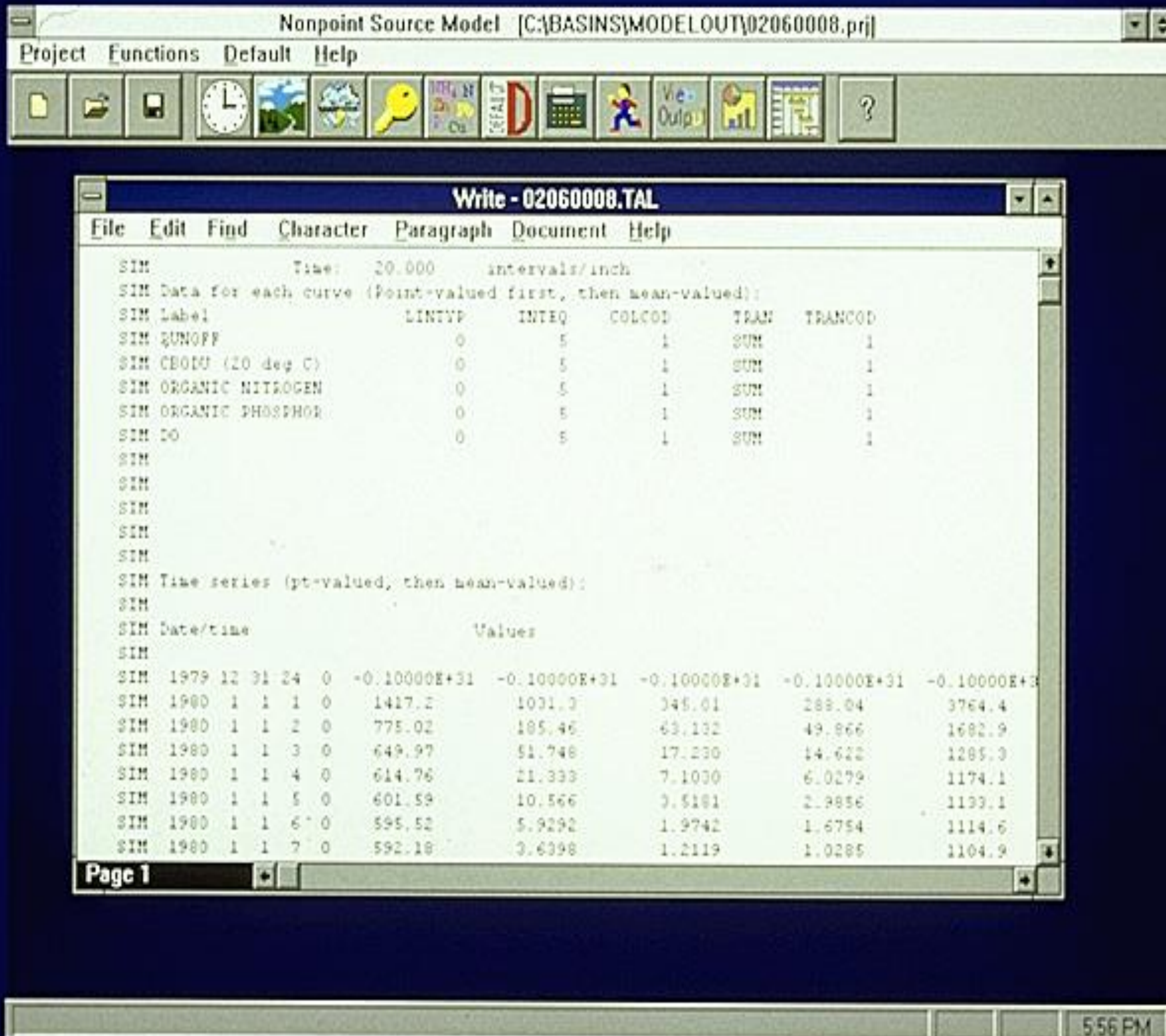


HSPF Interface

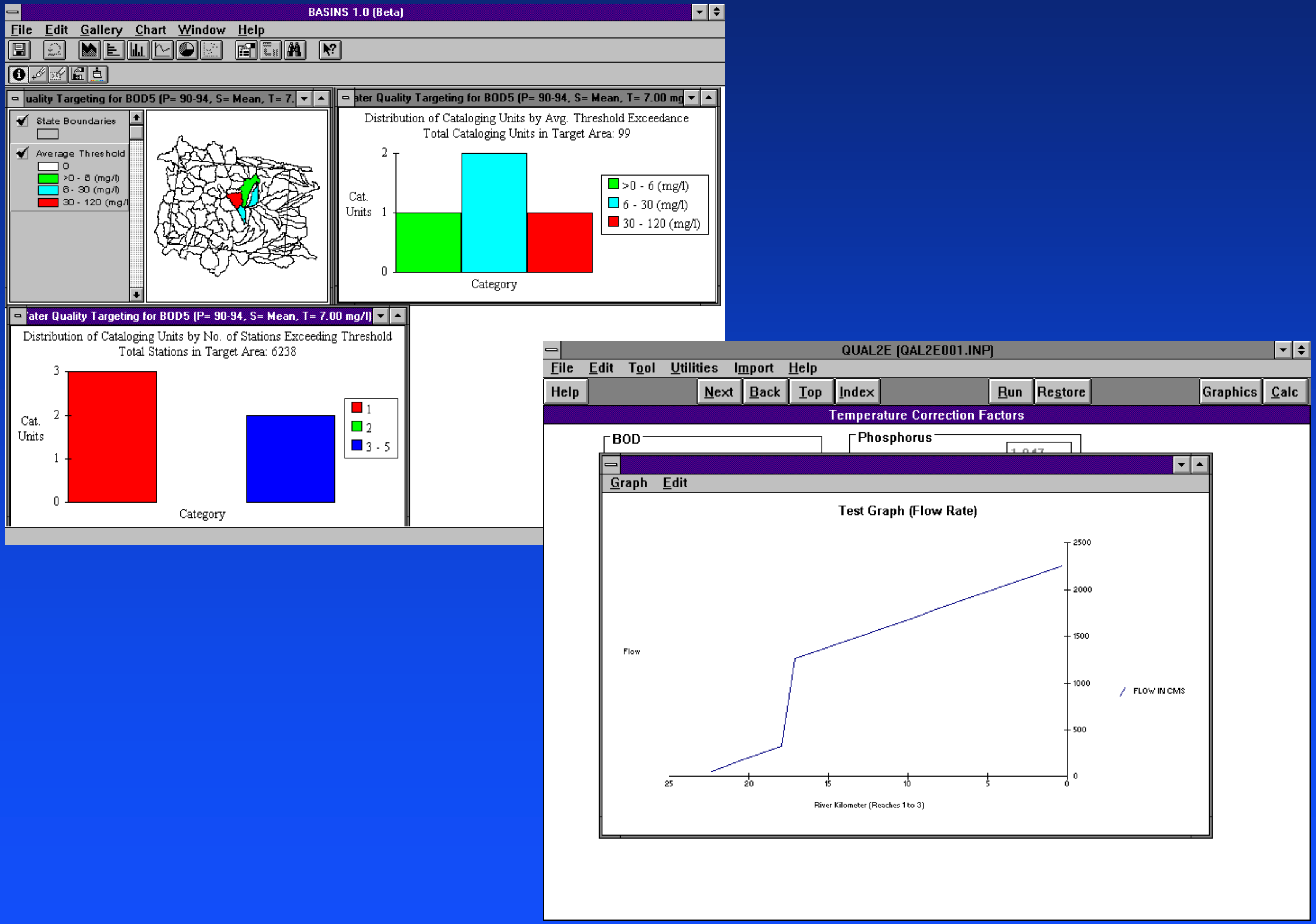
View and/or edit parameter values and options



Sample Output



HSPF Outputs



Why Use GIS As a Modeling Platform

- Save time and cost
- Offer a wide range of modeling options
- Allow a wide range of analysis
  - * Various scale, complexity and application domain
- Replicable results … defensible analysis
- Flexibility and iterations
  - * Evaluation of a wide range of alternatives
- Communicate to public and decision makers
- Ease of Integration of complex models

Cost and Time Savings with GIS
(Conduct 3 Watershed Studies)

	Cost	Time	Alt.
1970's W/o GIS	84 FTE	6+yr.	3
Today W/ GIS	2.7 FTE	10 mo.	15

(3) BASINS

BETTER ASSESSMENT SCIENCE INTEGRATING POINT AND NONPOINT SOURCES

What Is BASINS?

Better Assessment Science
Integrating
Point and Nonpoint Sources

Integrated GIS, data analysis and modeling system designed to support watershed-based analysis and TMDL development

- ***Data:*** **national data sets with options to import local data**
- ***Tools:*** **provide quick access to analysis techniques for watershed assessment**
- ***Models:*** **provide more detailed analysis and predictive evaluations to support studies**

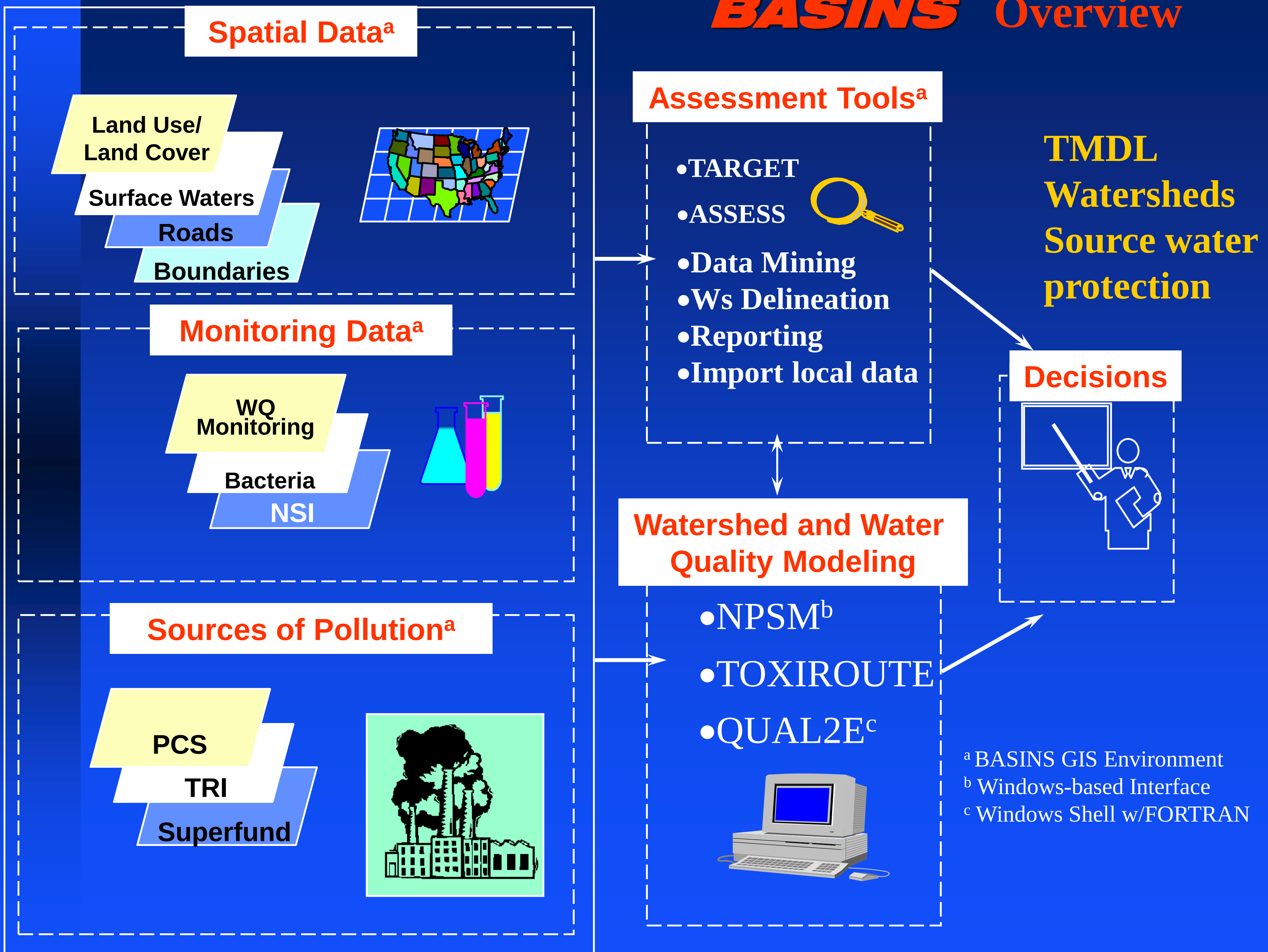
BASINS Facts and Requirements for Use

- U.S. EPA Product - Office of Science and Technology (OST)
- Available for every state in the continental U.S.
- Hardware and Software Requirements:
  - ArcView GIS Version 3.0a or 3.1
  - Windows 95, 98, or NT
  - 133-MHz Pentium processor (at minimum)
  - 250 mb hard disk space (at minimum)
  - 32 mb of RAM
  - CD-ROM and color monitor

BASINS Applicability

- Multi-purpose support system
  - Watershed management and basin planning
  - TMDL program
  - Source water protection
  - Pollutant trading
- Multiple users
  - National assessment
  - Regional assessment
  - States
  - Local governments
  - Private

BASINS Overview



[a] BASINS GIS Environment
[b] Windows-based Interface
[c] Windows Shell w/FORTRAN

BASINS Data Products

Spatial Data

Land use and land cover

Urbanized areas

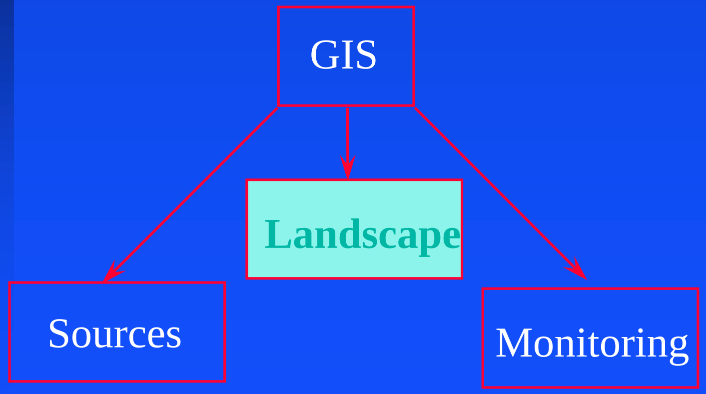
Populated place locations

Reach file 1

Reach file 3

Major roads

USGS hydrologic unit boundaries (accounting and catalog units)



Drinking water supply sites

Dam sites

EPA region boundaries

State boundaries

County boundaries

DEM

Ecoregions

NAQWA study unit boundaries

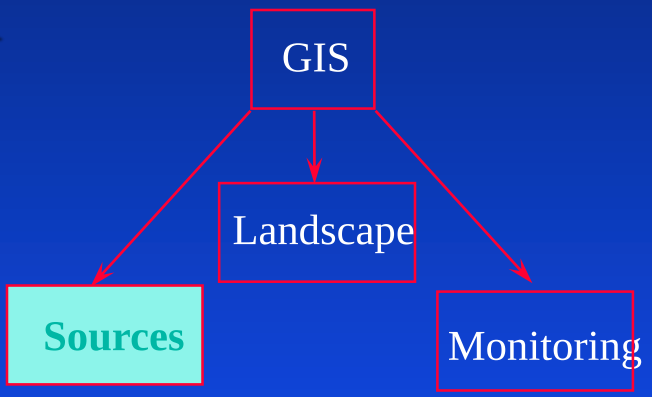
Managed area database (Federal and Indian Lands)

Soil (STATSGO)

BASINS Data Products

Sources of Pollution

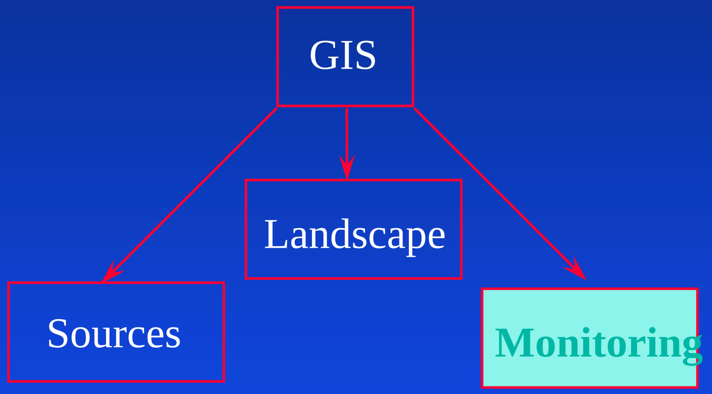
- Permit Compliance System (PCS) sites and computed annual loadings
- Industrial facility sites
- Toxic Release Inventory (TRI) sites (annual releases)
- Superfund national priority list sites
- Hazardous and solid waste sites



BASINS Data Products

Environmental Monitoring Data

- Weather station sites
- USGS gauging stations
- Dam sites
- Classified shellfish area
- 1996 Clean water needs survey



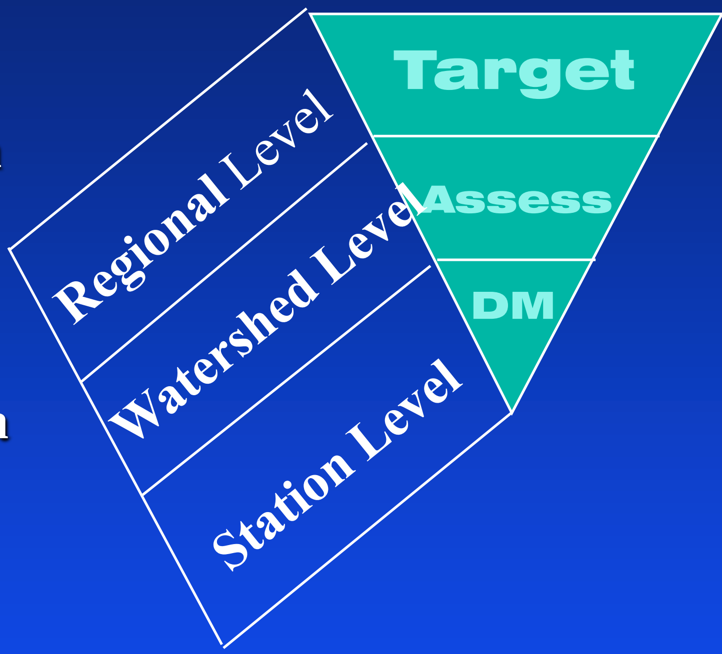
Assessment Tools included with ***BASINS***

Target: Broad-based evaluation of watershed water quality and point source loadings.

Assess: Watershed-based evaluation of specific water quality stations and/or dischargers and their proximity to waterbodies.

Data Mining: Dynamic link of data elements using a combination of tables and maps. Allows for visual interpretation of geographic and historical data.

Watershed Reporting:
Automated summary report system. Allows users to select types of information to be included. Automated generation of associated graphics and tables.



BASINS

Modeling Capabilities

- Models to address multiple objectives
  - Source assessment
  - Receiving water evaluation
- Models which operate on various scales
  - Local scale
  - Watersheds
  - Basins
- Models which can be applied at various levels of complexity
  - Screening
  - Detailed

What Constitutes a Model?

Data — **Algorithms** — **Output**

Time series
Rainfall
Streamflow
WQ sampling

Spatial/Landscape
Soils
Topo
Cover
streams
Lakes

Kinetics data
Pollutant charact.
Fate & transport

Watershed Models
Hydrology
Buildup
Washoff
Erosion
Overland transport.
Fate & transport

Waterbody Models
Hydraulics
Hydrodynamic
Fate & transport
Scour & deposition
Algal growth

Time series
Summary statistics
% change/Improvement
Violations
Classification maps
Impact maps

BASINS Nonpoint Source Model (NPSM)

HSPF (Hydrologic Simulation Program-FORTRAN)

- Variable time step continuous simulation model
- Predicts loadings in mixed land use settings for:
  - Nutrients
  - Toxics
  - Bacteria
  - Sediment
- Considers point source and nonpoint source loadings

Watershed Model

Waterbody Model

How NPSM fits into BASINS

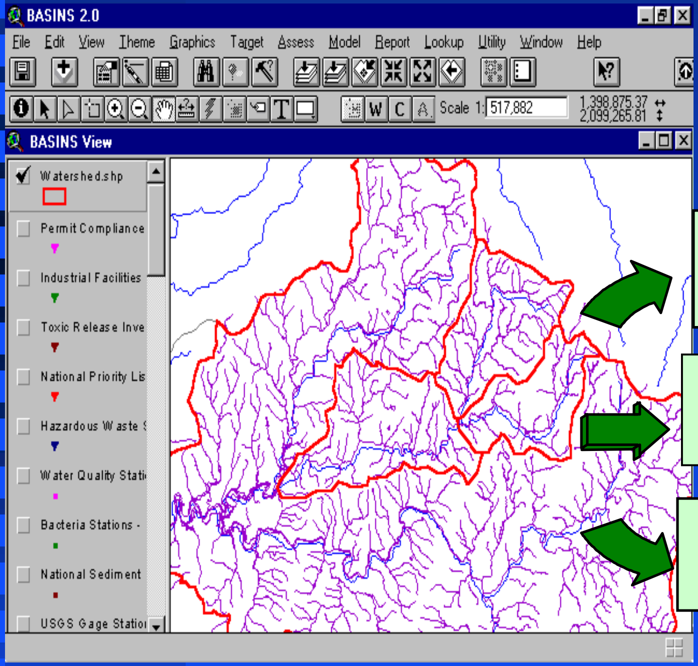
C

Meteorological Data

D

Landuse and pollutant specific Data

A *BASINS - GIS*

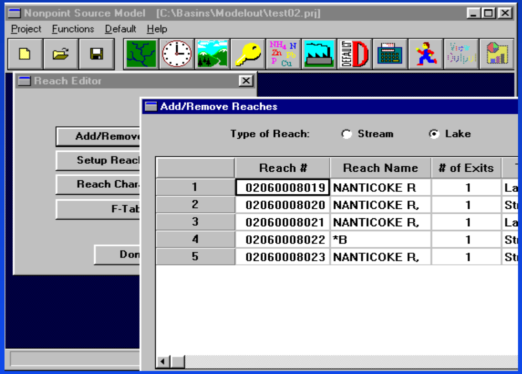


Point Sources

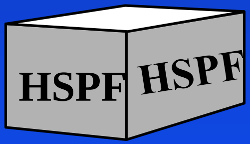
Land Use Data

Stream Data

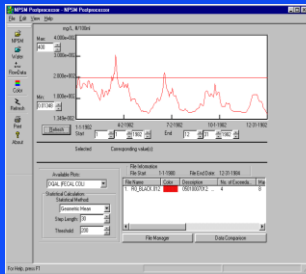
B *NPSM Windows interface*



E *Core Model*



F *Post Processing*



BASINS Stream Water Quality Models

Qual2e

- Steady state, one-dimensional river model
- Provides more detailed, process oriented river modeling
- Models up to 15 constituents
- Uses streeter-phelps for D.O. Modeling
- Eutrophication and nutrient processes

Watershed Model

Waterbody Model

BASINS Water Quality Models

Toxiroute

- Steady state, design flow
- Evaluates instream concentrations for stream networks with multiple discharges
- Incorporates nonpoint source loadings
- Chemical fate is estimated by first order decay rate (half life)

Watershed Model

Waterbody Model

GIS Modeling Limitations

Data Data Data Data

* **Availability**
* **Scale**
* **Accuracy**

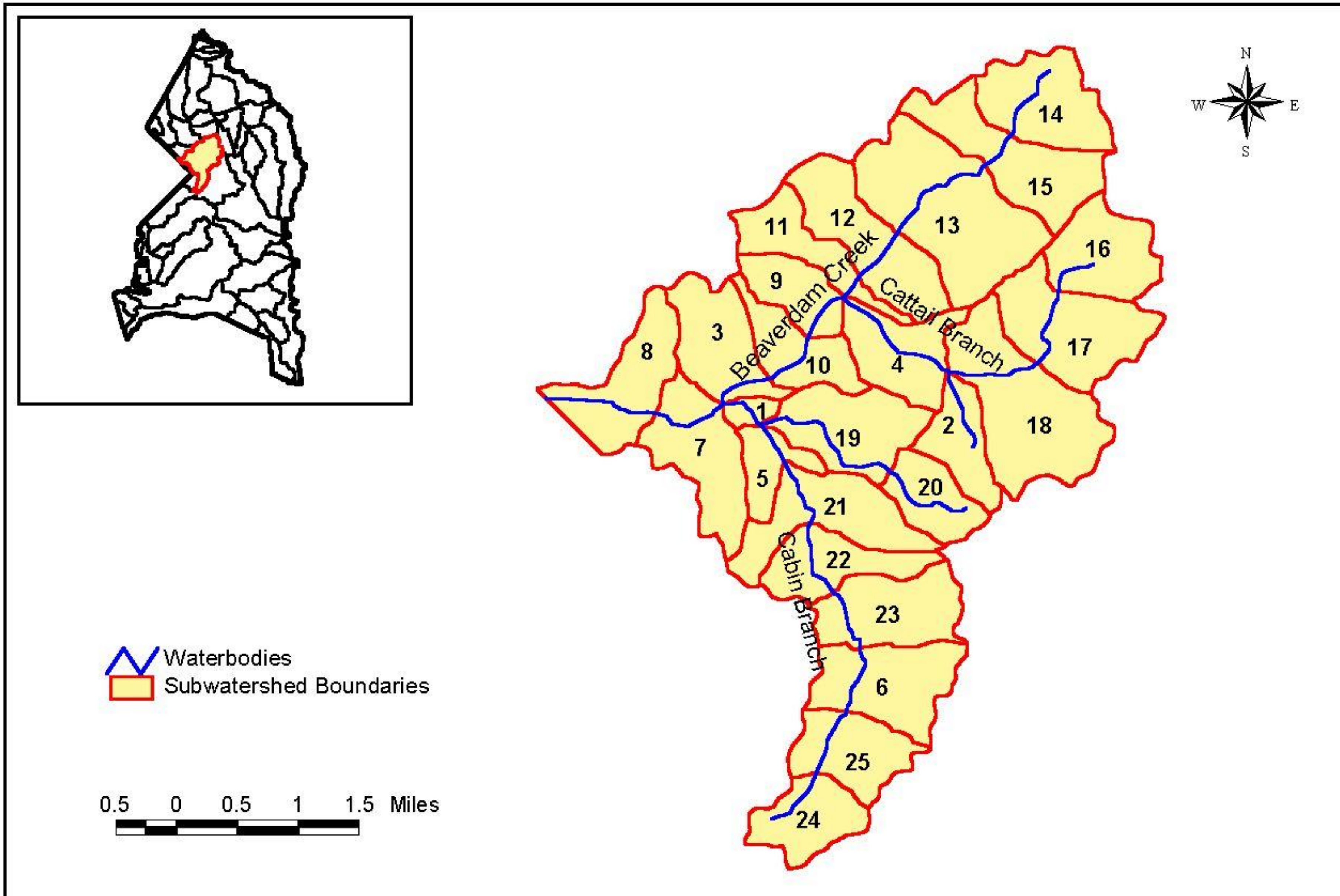
Modeling the Lower Beaverdam Creek

Using

BASINS

Lower Beaverdam Creek Watershed

- Watershed area: 9,753 acres   (15.24 Sq. Miles)
- 16.0 miles of EPA Reach File
- Predominantly residential and industrial. Also contains some commercial, forested, and open areas.
- Primarily soil type:
  - deep, well drained, highly erodible soils
  - low permeability
  - primarily clay with a thin mantle of silt, sand, or loam
- Significant impervious area results in high runoff potential



Lower Beaverdam Creek Subwatersheds

Map Projection: State Plane - 1983
Maryland

Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0

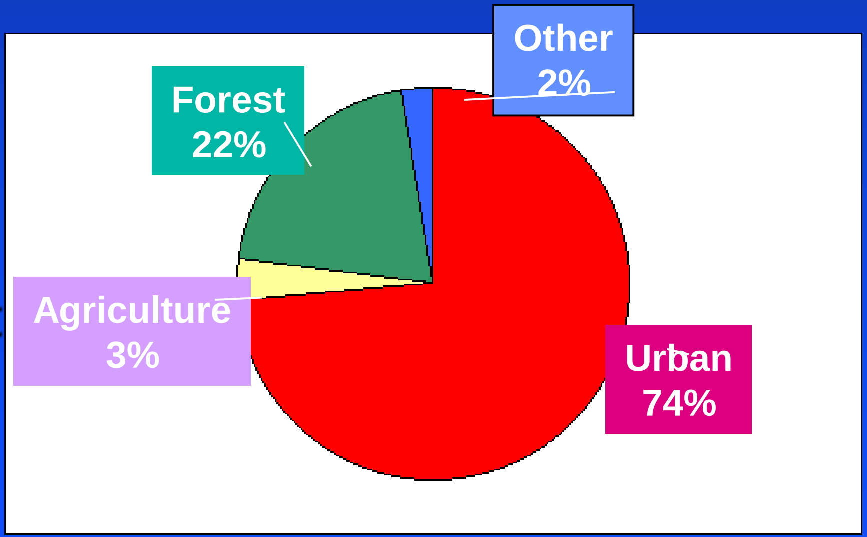
Landuse

Grouped the County landuses into 8 categories:

- Low-density Residential (urban)
- Medium-density Residential (urban)
- High-density Residential (urban)
- Commercial (urban)
- Industrial (urban)
- Other Urban (urban)
- Agricultural (rural)
- Forested (rural)

Rationale for grouping:

- Primarily urban and forested land
- Calibration sites used to develop the County Default Dataset represent residential, commercial, industrial, agricultural, and forested landuse-specific areas



Modeling Tasks and Requirements

- Data processing and model setup
- Calibration of the model for flow and water quality
- Model execution and development of flow and pollutant loads

Key Data Used

BASINS data

- Weather station data
- Reach File, version 3.0 stream networks
- Digital Elevation Model (DEM)

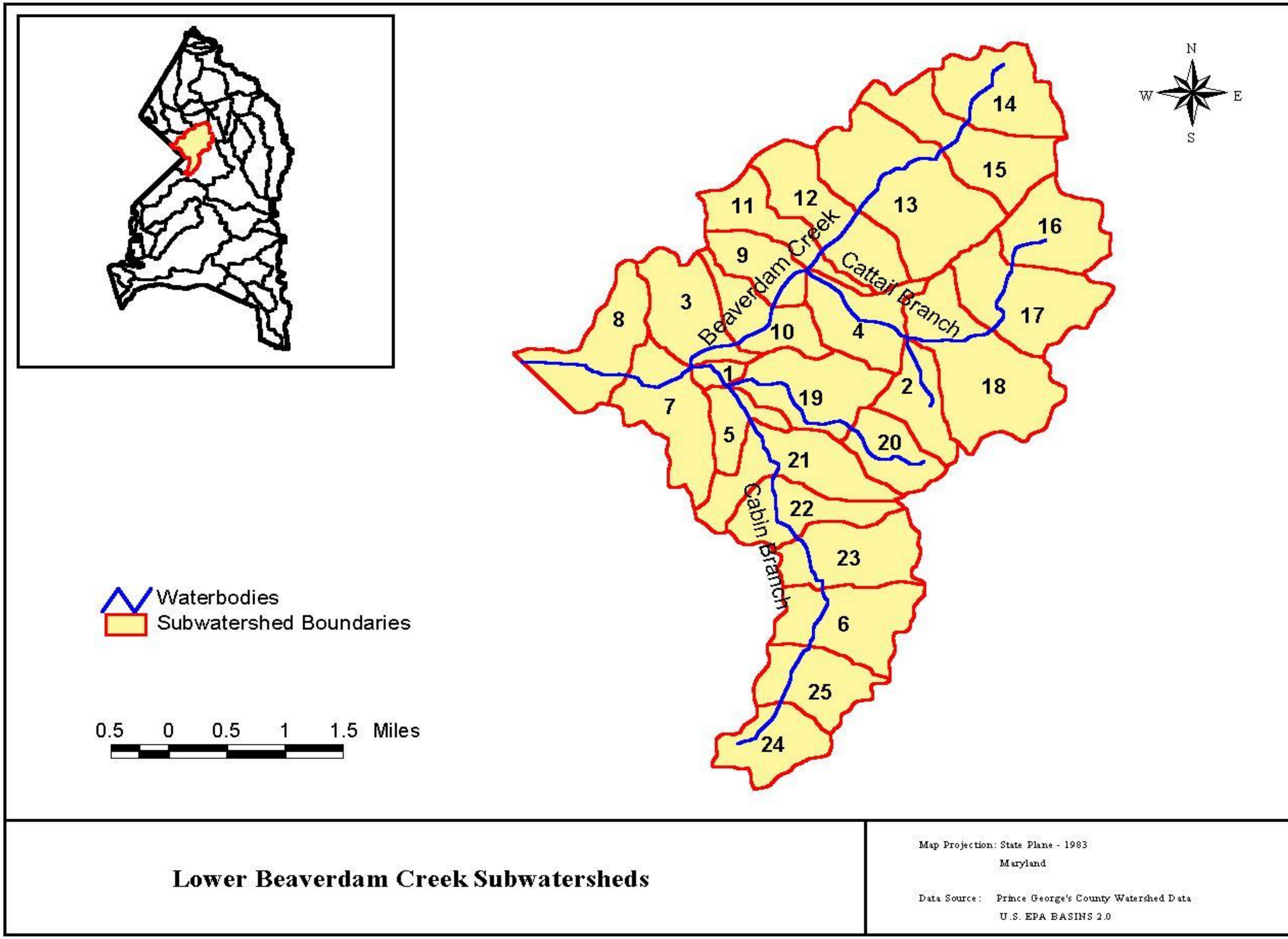
Prince George's County data

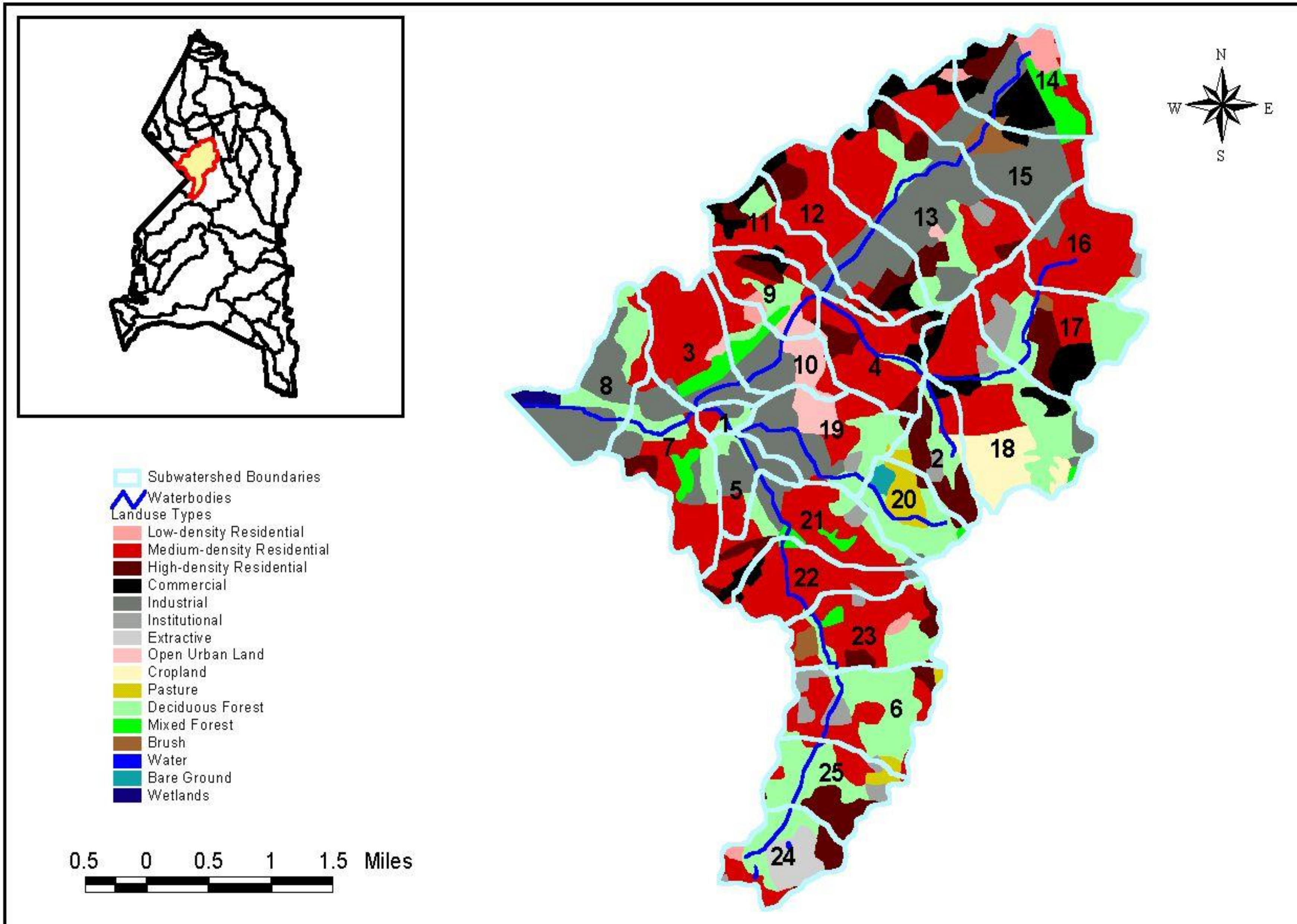
- Landuse/land cover
- Contours
- Stream networks
- Transportation/urban data
- Watershed boundaries
- Soil data

Model Setup

- The Lower Beaverdam Creek watershed was segmented into 11 subwatersheds.
  - Delineations were based on County contour and stream network data
- County landuse data were used to represent the subwatersheds.
- A WDM file containing meteorological data representative of the watershed was developed.
- Stream data were compiled and F-Tables (rating curves) developed.

Twenty Five (25) Sub-Basins





Landuse Data
Lower Beaverdam Creek

Map Projection: State Plane - 1983

Maryland

Data Source: Prince George's County Watershed Data

U.S. EPA BASINS 2.0

Lower Beaverdam Creek Watershed

Table 2. Landuse distribution by modeled landuse categories.

Landuse Categories	Area (ac)	Percentage of Total (%)
Low-density Residential	306.03	3.14
Medium-density Residential	3597.28	36.89
High-density Residential	772.90	7.93
Commercial	541.70	5.56
Industrial	2068.98	21.22
Agricultural	326.27	3.35
Forested	2137.57	21.92
Total	**9750.73**	**100.00**

Landuse Representation in the Model

Assigned impervious percentages to individual County landuse types

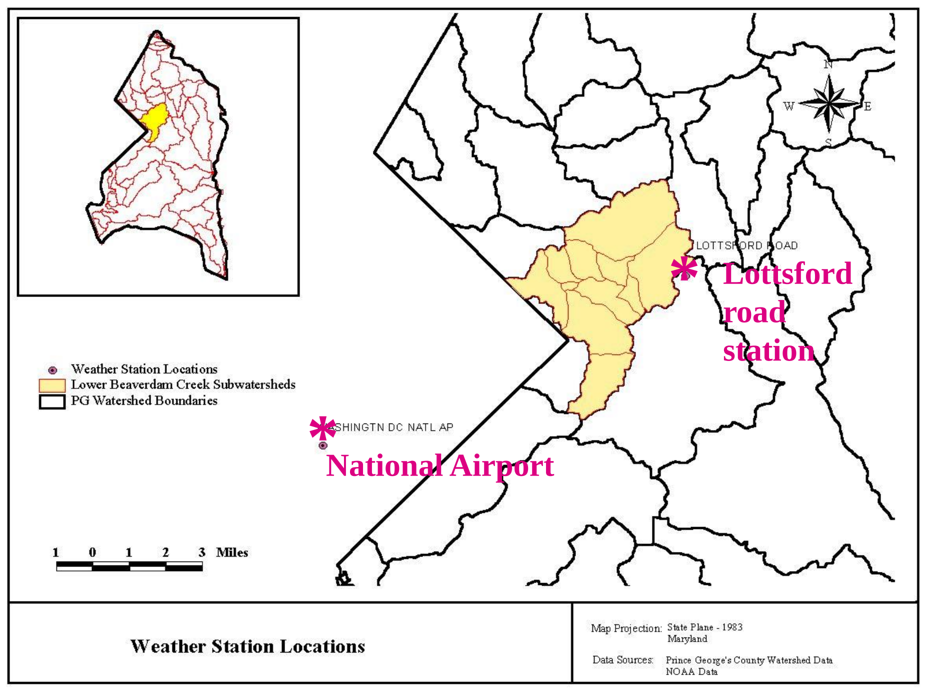
Used these percentages to divide landuse areas into separate <u>pervious</u> and <u>impervious</u> units

Development of a WDM File for Meteorological Data

(1) NOAA Data

from Reagan National Airport:

- **Air temperature**
- **Dew point**
- **Wind movement**
- **Solar radiation**
- **Cloud cover**
- **Evapotranspiration**



(2) County data

Hourly precipitation data from the Lottsford Road weather station

Compilation of Stream Data and Development of F-Tables

Compiled stream dimensions and characteristics for development of HSPF F-tables. Used the following data and methods to represent each stream segment:

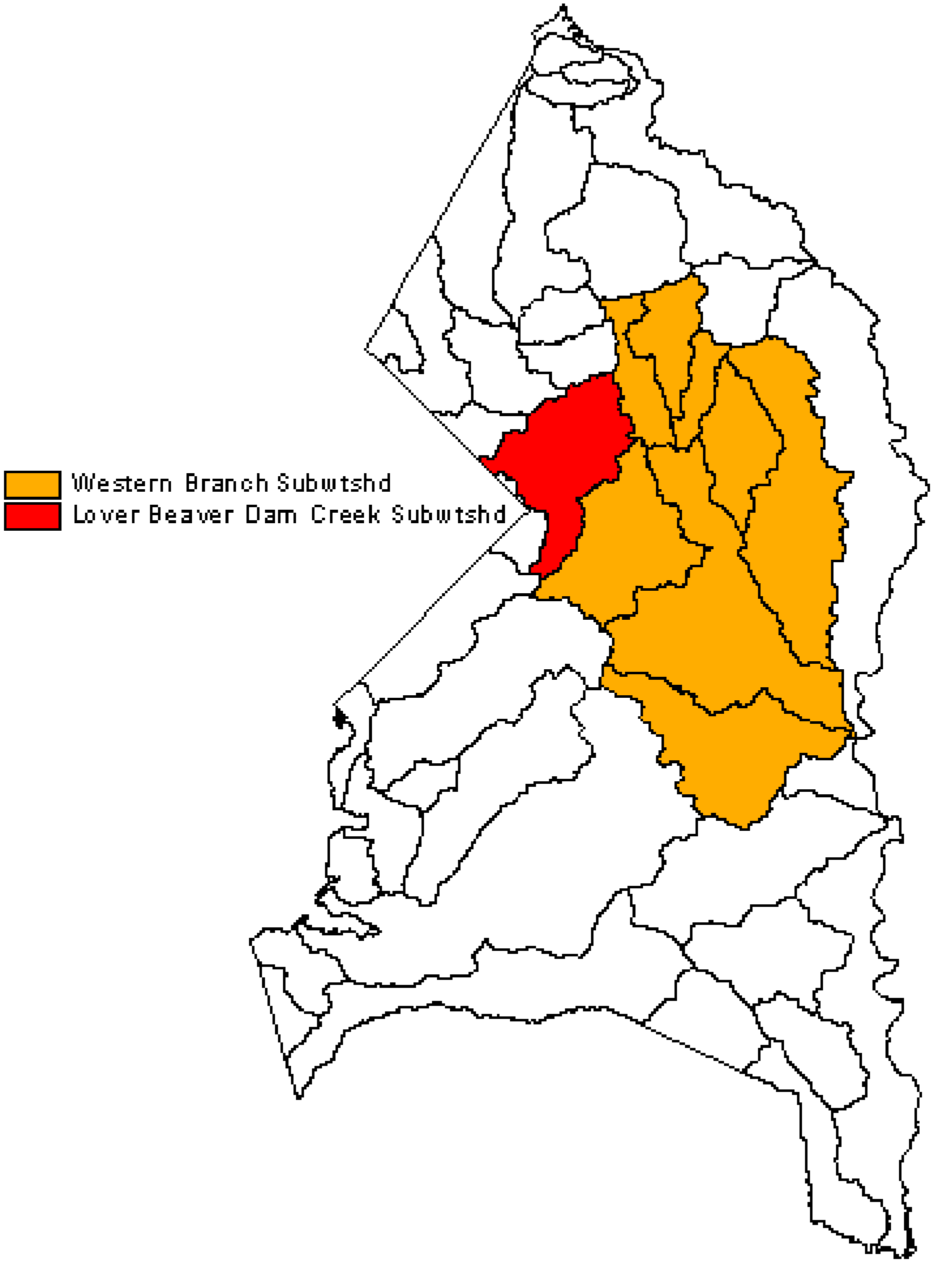
- **Field observations**
- **Detailed county topography data**
- **HEC-2 & TR-20 outputs**

Sampling Program

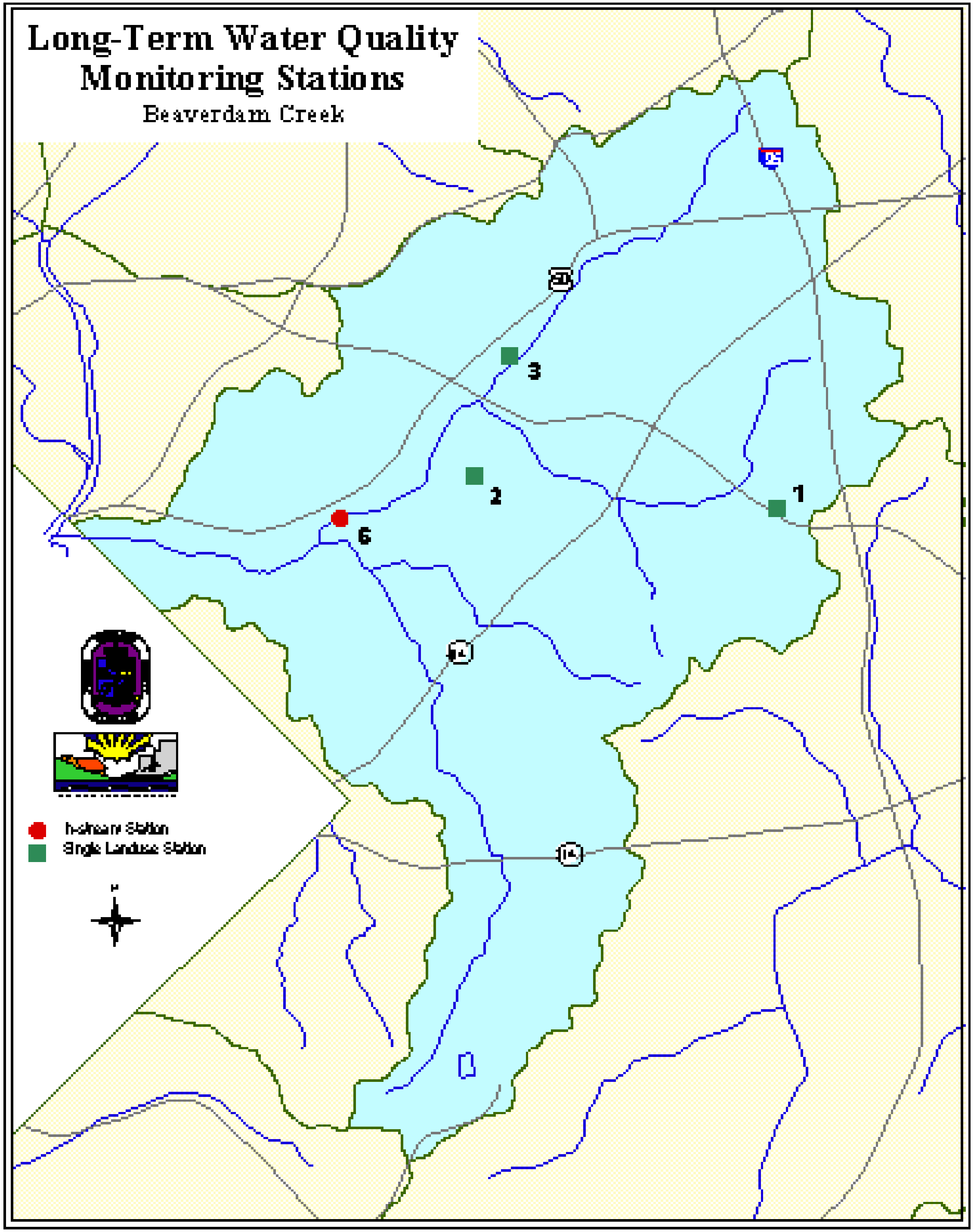
- Four years sampling data
- Sample at 8 stations
  - 5 land-use specific sites
  - 3 in-stream stations
- Dry weather monitoring
  - Four baseflow samplings at 8 stations
- Wet weather monitoring
  - Eight or more storm samplings every year at 8 stations

Monitoring Parameters

- Flow measurements
- pH and temperature
- Four trace metals
- Nutrients (Nitrogen and Phosphorus)
- Conventional pollutants (BOD, TSS)
- Oil and Grease
- Fecal coliform



Sampling Watersheds



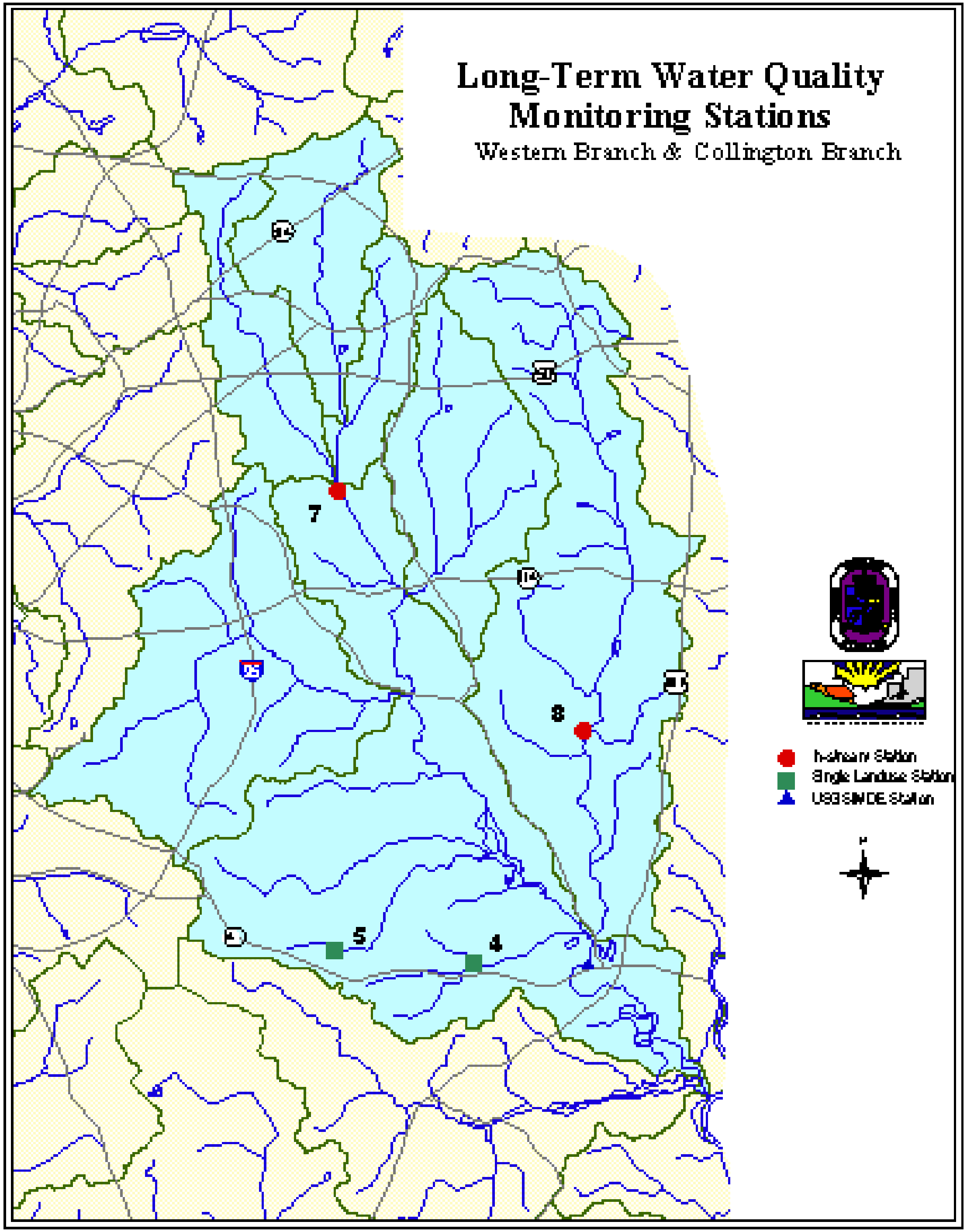
Beaverdam Creek

Land use specific basins

- Residential
- Commercial
- Industrial

In-stream stations

- Beaverdam Creek



Western Branch

Land use specific basins

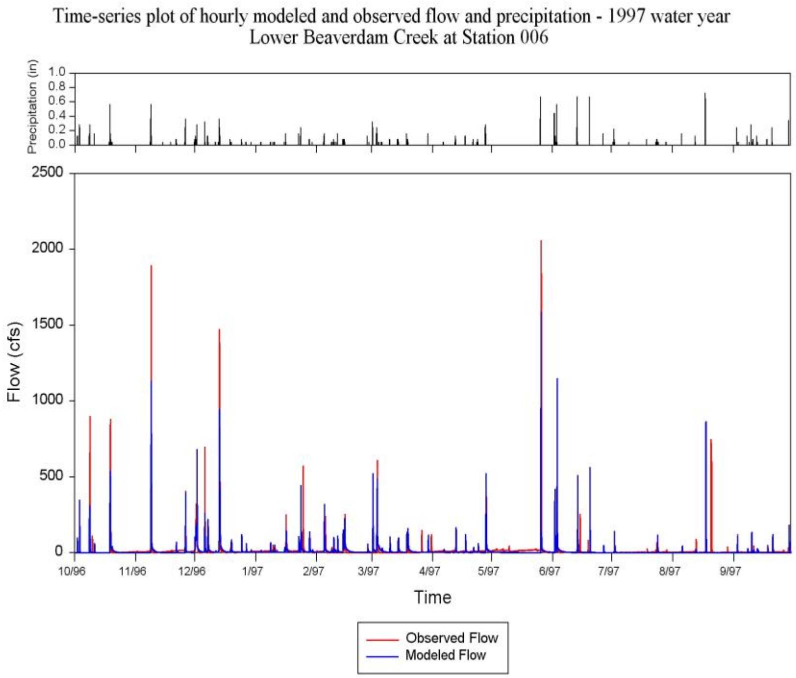
- Forest
- Agriculture

In-stream stations

- Western Branch
- Collington Branch

Hydrology Calibration

- **Overall water balance**
  - Compared annual modeled flow to observed flow at basin and subbasin outlets
  - Calculated watershed runoff coefficients as a ratio of flow to precipitation
- **High-flow low-flow distribution**
  - Compared observed and modeled peak flows and baseflows
- **Storm flows**
  - Analyzed storm flow volumes and hydrograph shapes
  - Considered distribution between surface runoff and interflow
- **Seasonal variations**
  - Analyzed seasonal variations in the flow regime



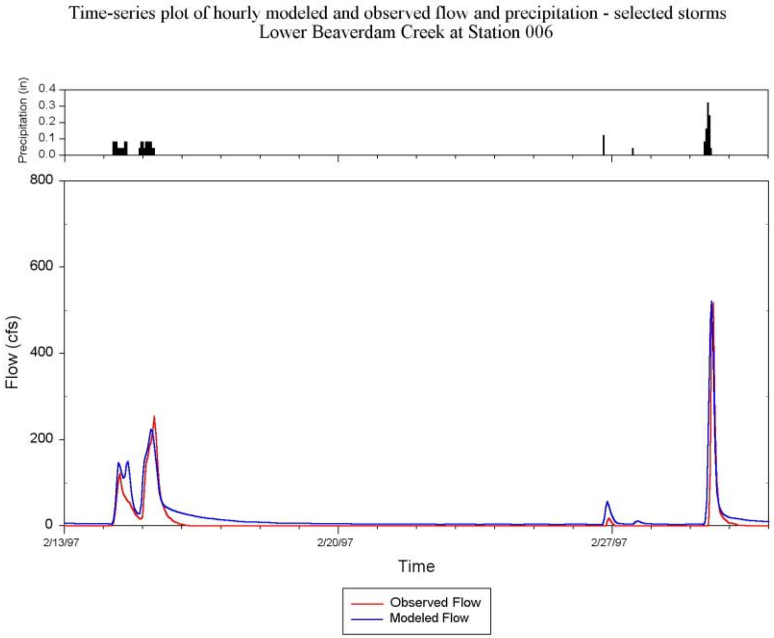
Annual water budget error: 11.6 %

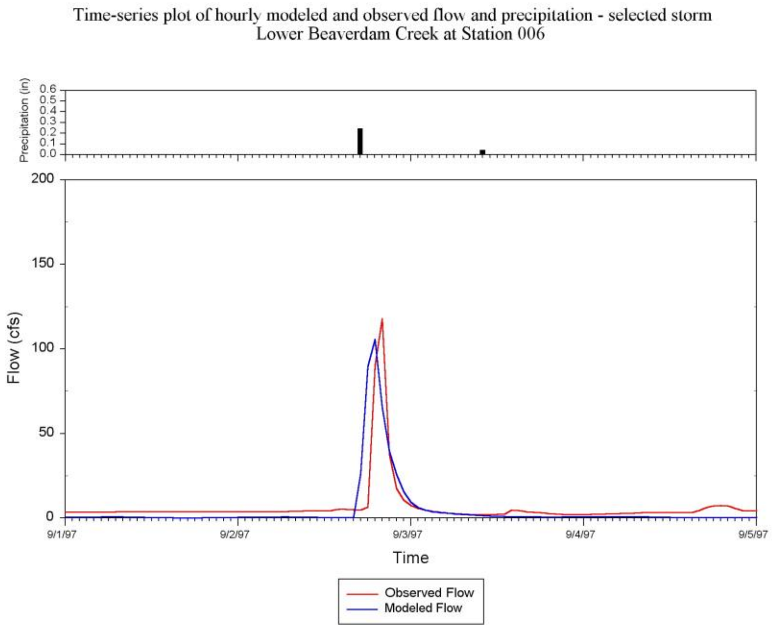
Error in peak flows (highest 10 % of flows): 1.5 %

Hydrology Calibration Results

Annual Budget

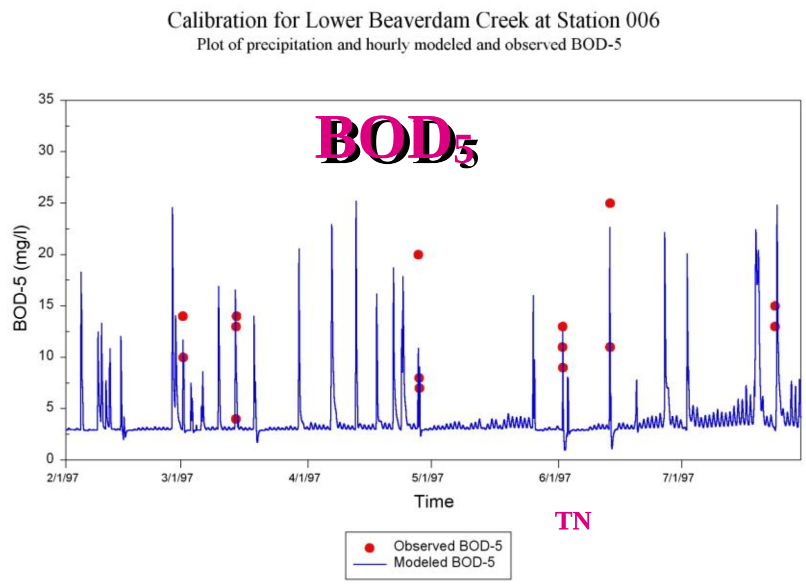
Selected Storms

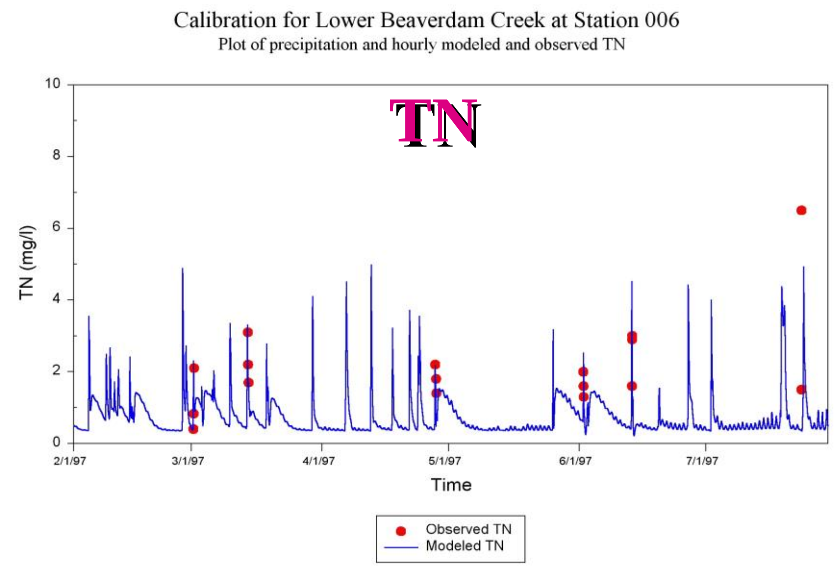


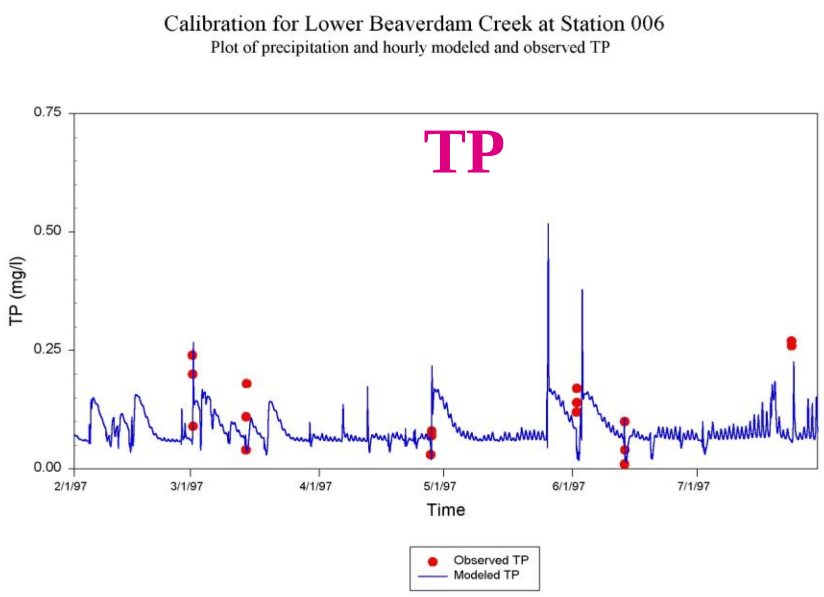


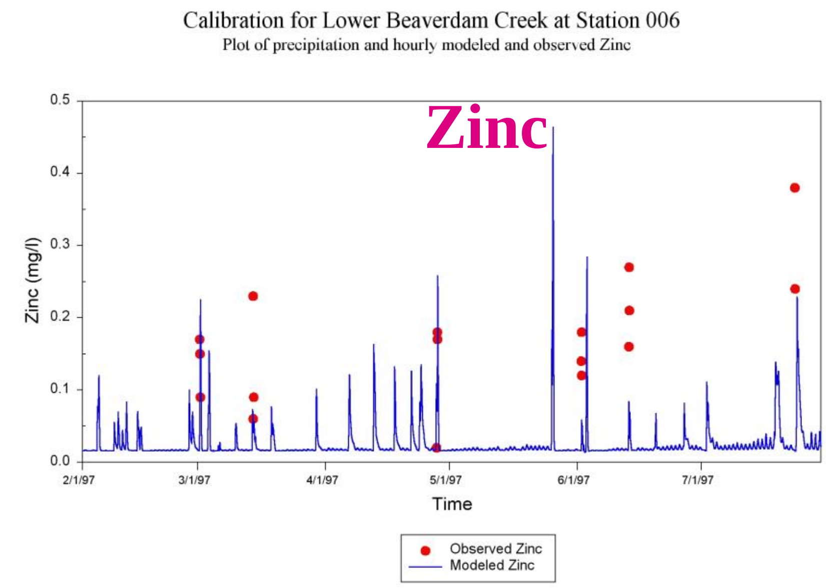
Water Quality Calibration

- Performed for the following pollutants:
  - BOD-5
  - Total Nitrogen (TN)
  - Total Phosphorus (TP)
  - Zinc
- Compared hourly concentrations to observed concentrations (from monitoring data)
- Adjusted key HSPF model parameters within a reasonable range to achieve an acceptable calibration
- Assessed annual pollutant loads


Calibration for Lower Beaverdam Creek at Station 006
Plot of precipitation and hourly modeled and observed BOD-5
BOD5
BOD-5 (mg/l)
Time
TN
Observed BOD-5
Modeled BOD-5

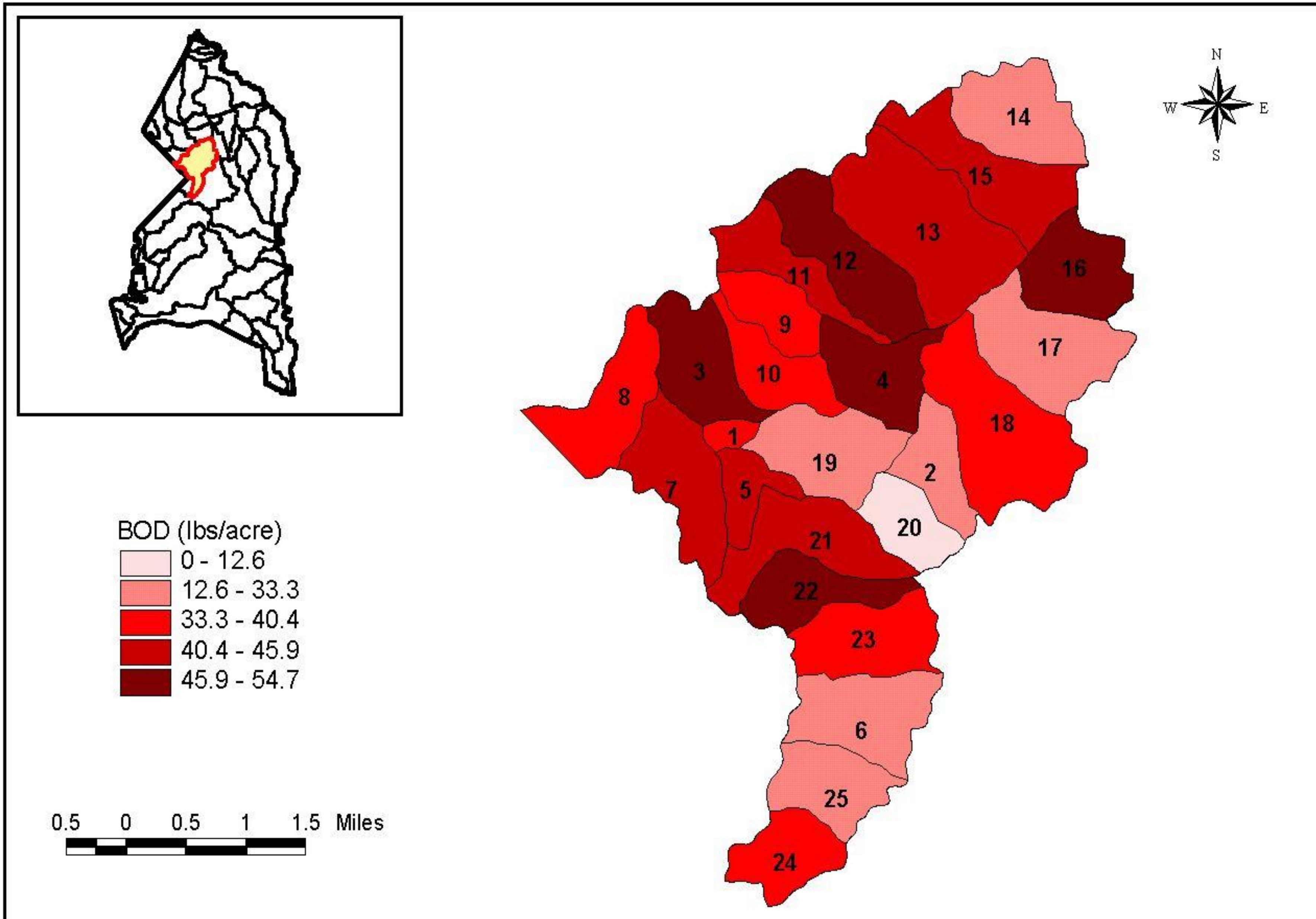

Calibration for Lower Beaverdam Creek at Station 006
Plot of precipitation and hourly modeled and observed TN
TN
TN (mg/l)
Time
Observed TN
Modeled TN


Calibration for Lower Beaverdam Creek at Station 006
Plot of precipitation and hourly modeled and observed TP
TP
TP (mg/l)
Time
Observed TP
Modeled TP


Calibration for Lower Beaverdam Creek at Station 006
Plot of precipitation and hourly modeled and observed Zinc
Zinc
Zinc (mg/l)
Time
Observed Zinc
Modeled Zinc

Simulated Pollutant Loadings

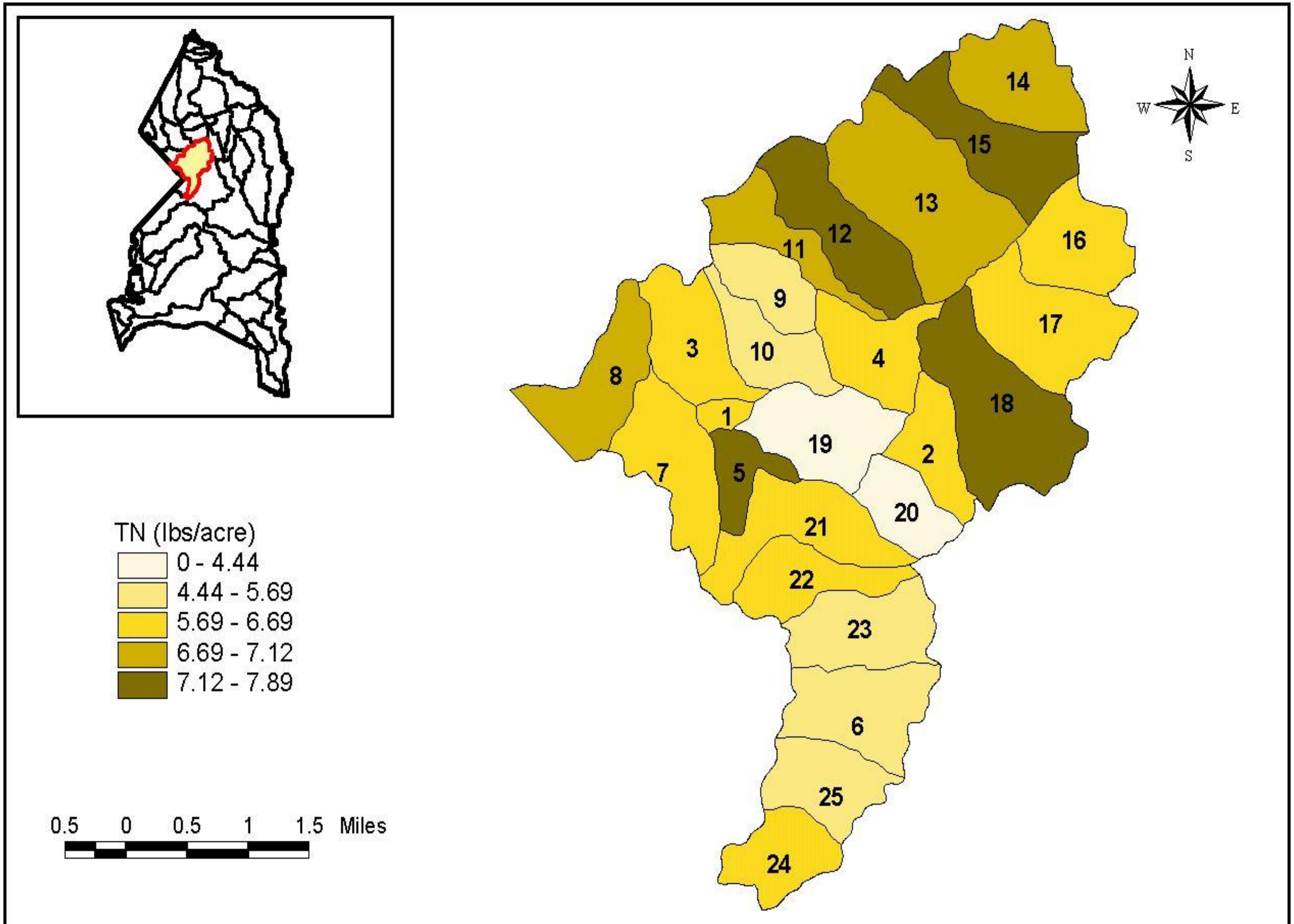
Subwatershed	Annual Nonpoint Source Load (lbs)						
	BOD	TN	TP	CD	CU	PB	ZN
1	2153	363	37	0.44	2.0	3.5	22
2	7920	1601	227	2.54	11.0	25.7	155
3	19806	2567	323	3.80	17.1	35.6	210
4	17205	2325	329	3.92	17.4	40.3	233
5	7837	1337	114	1.44	7.1	10.8	75
6	13613	2453	291	3.20	13.5	26.3	161
7	18889	2916	331	3.97	17.8	35.4	216
8	14964	2957	229	2.91	14.2	18.9	142
9	8907	1290	171	2.09	9.2	18.9	113
10	11120	1619	161	2.13	10.2	15.4	102
11	12992	1984	242	2.83	13.0	26.4	162
12	23673	3627	421	5.16	24.1	49.0	302
13	37852	6051	641	7.93	37.0	70.0	442
14	13932	2930	287	3.45	16.7	25.9	183
15	22063	3886	343	4.21	21.0	31.5	222
16	20318	2487	333	3.87	17.3	37.9	219
17	17407	3226	374	4.41	19.7	39.0	244
18	21859	4211	617	4.98	21.5	38.7	248
19	16546	2741	255	3.26	15.5	23.6	160
20	3166	1029	164	1.10	4.0	6.1	41
21	20143	2992	365	4.31	19.3	40.0	240
22	17104	2065	292	3.34	14.9	33.4	191
23	15625	2322	313	3.68	15.7	35.3	205
24	10044	1876	185	2.35	10.7	19.5	127
25	8776	1836	233	2.71	11.4	25.2	152



Annual BOD Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

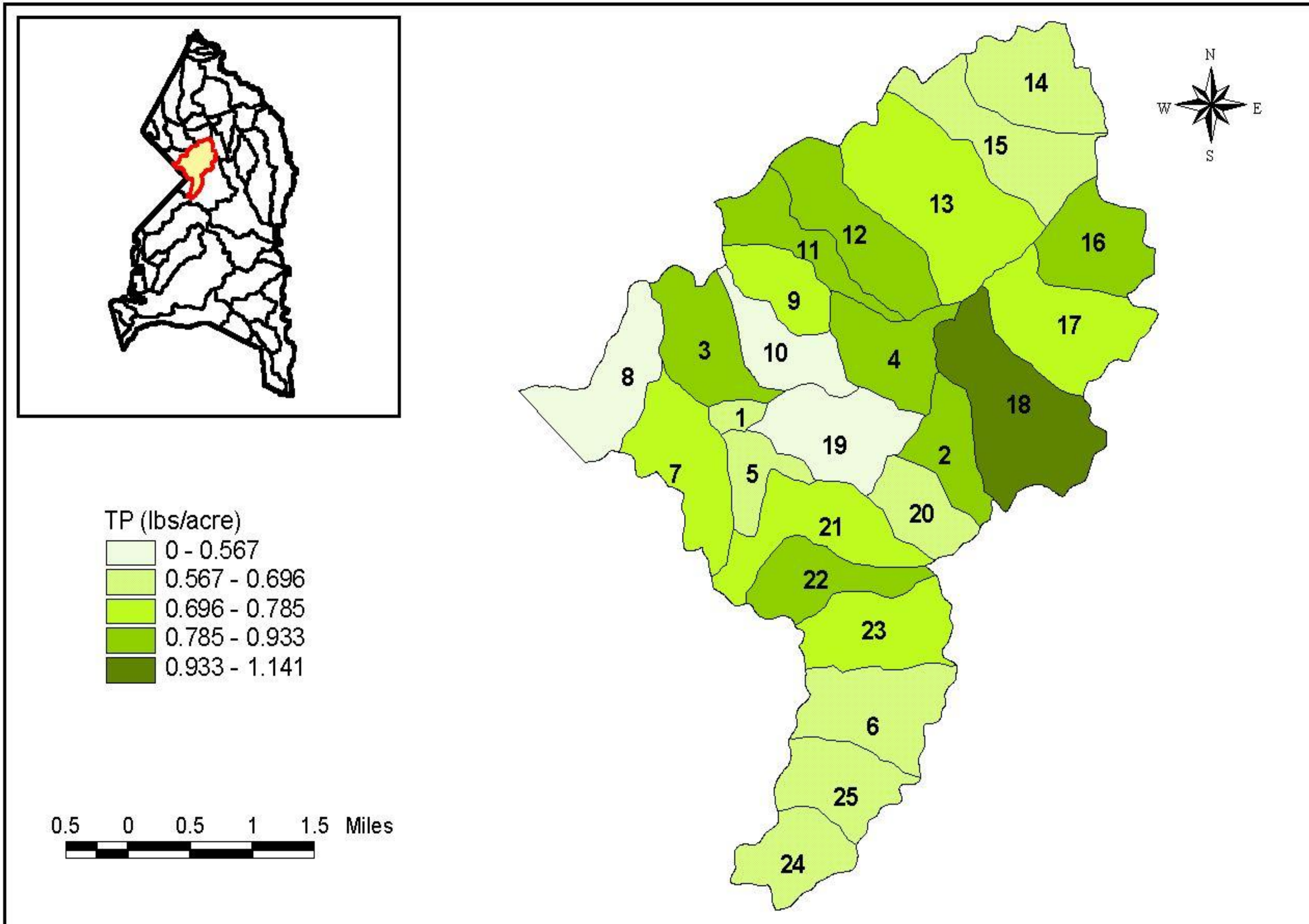
Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0



Annual Total Nitrogen Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

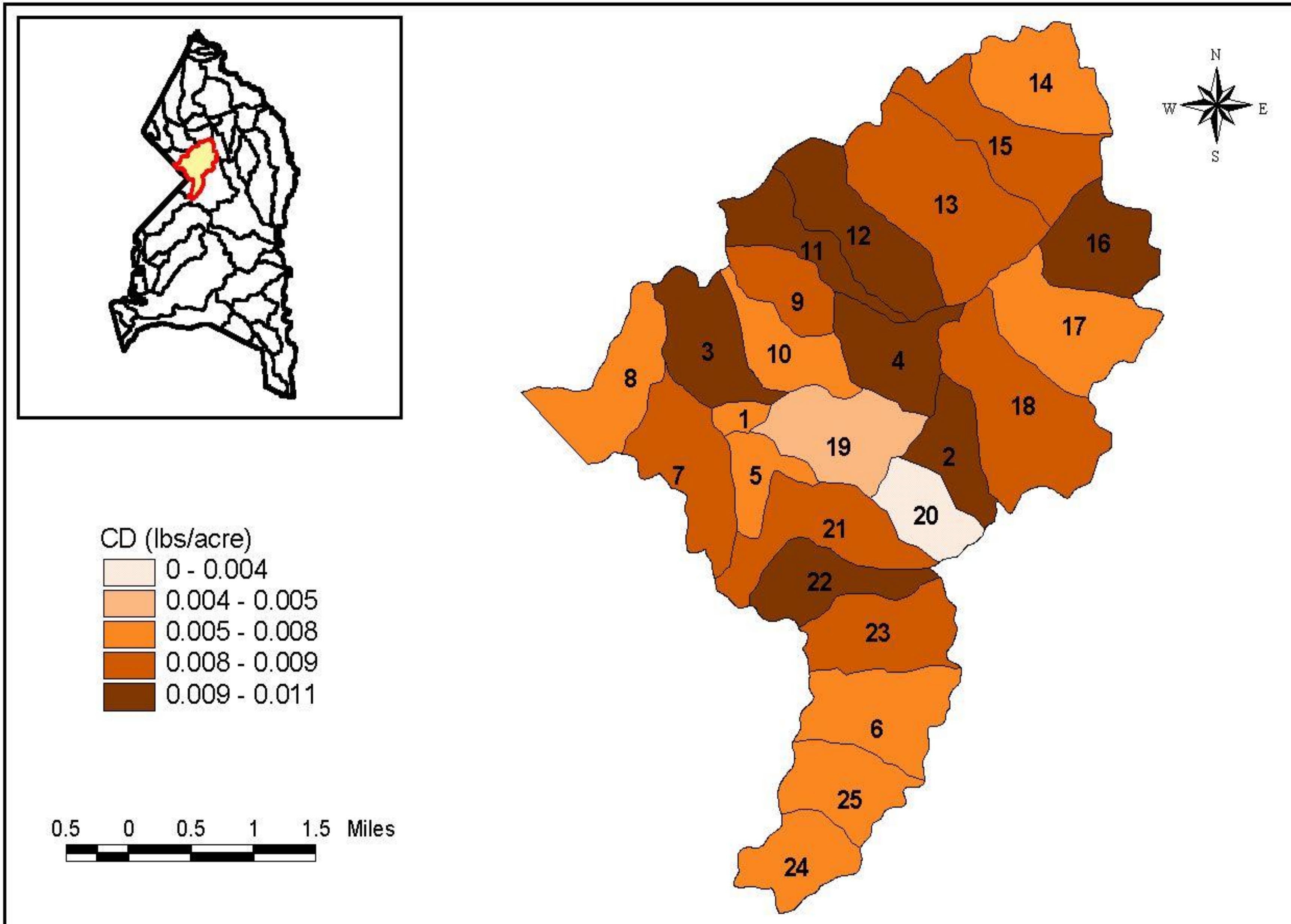
Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0



Annual Total Phosphorus Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

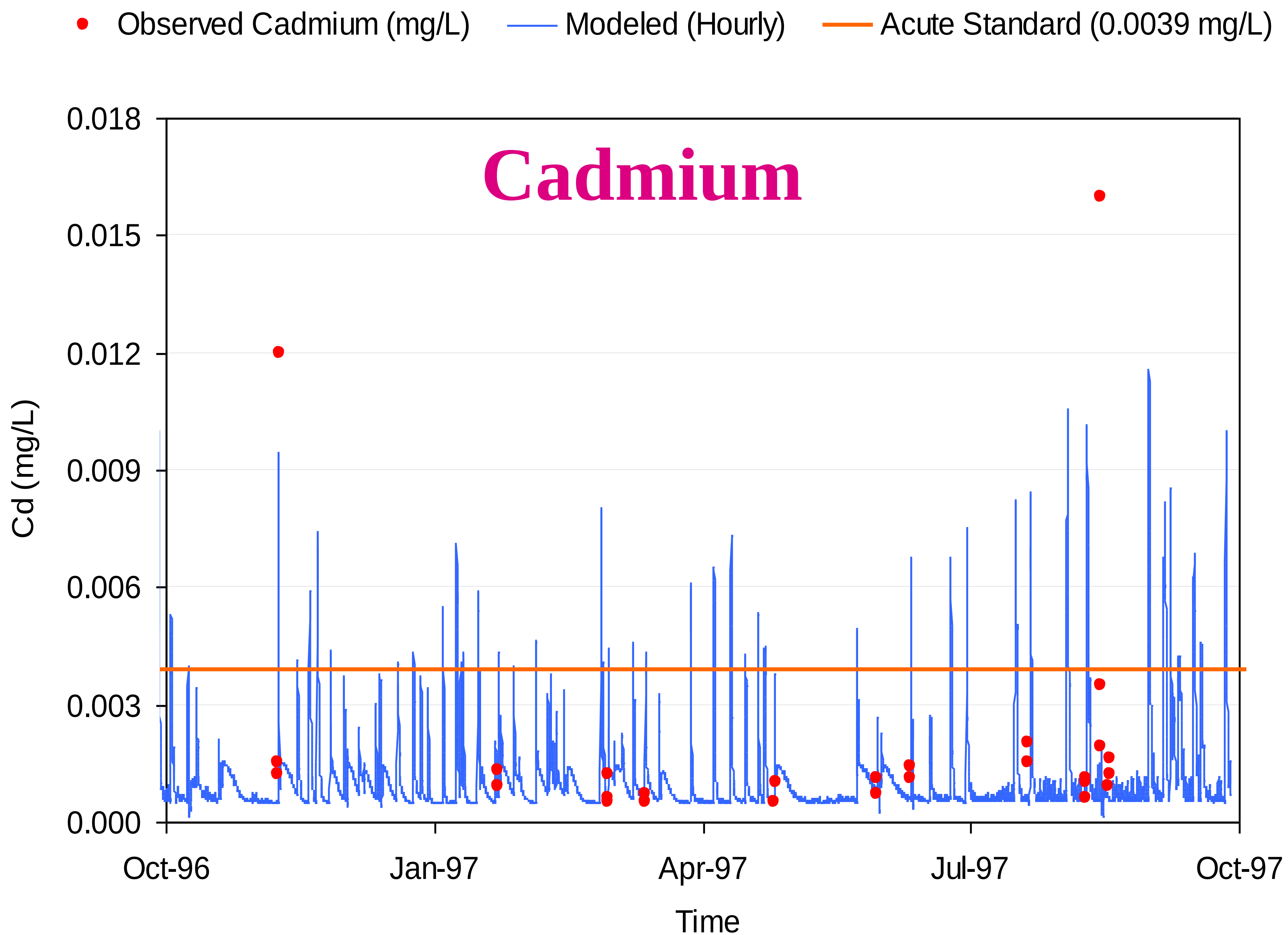
Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0

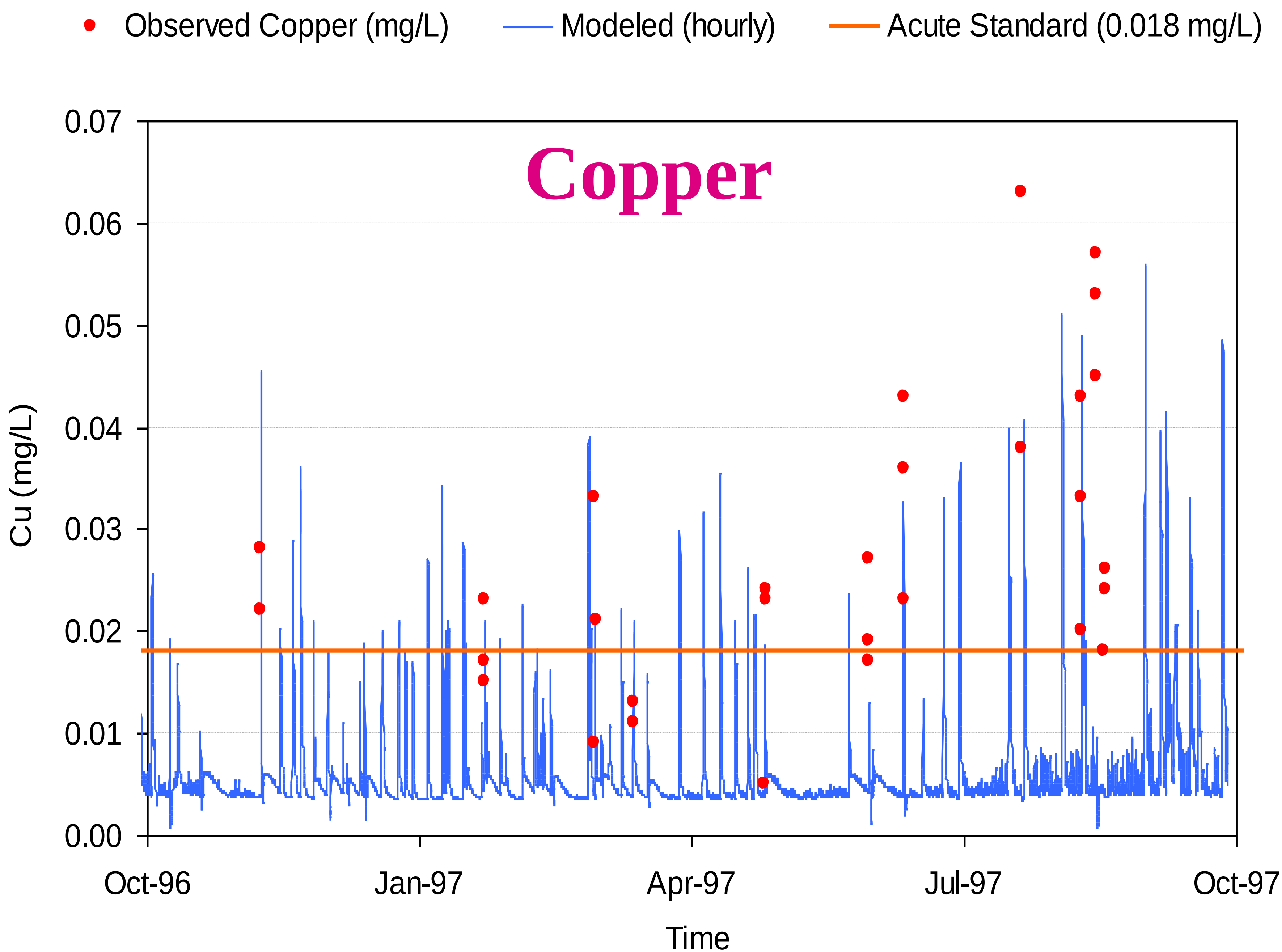


Annual Cadmium Unit Area Loads
Lower Beaverdam Creek

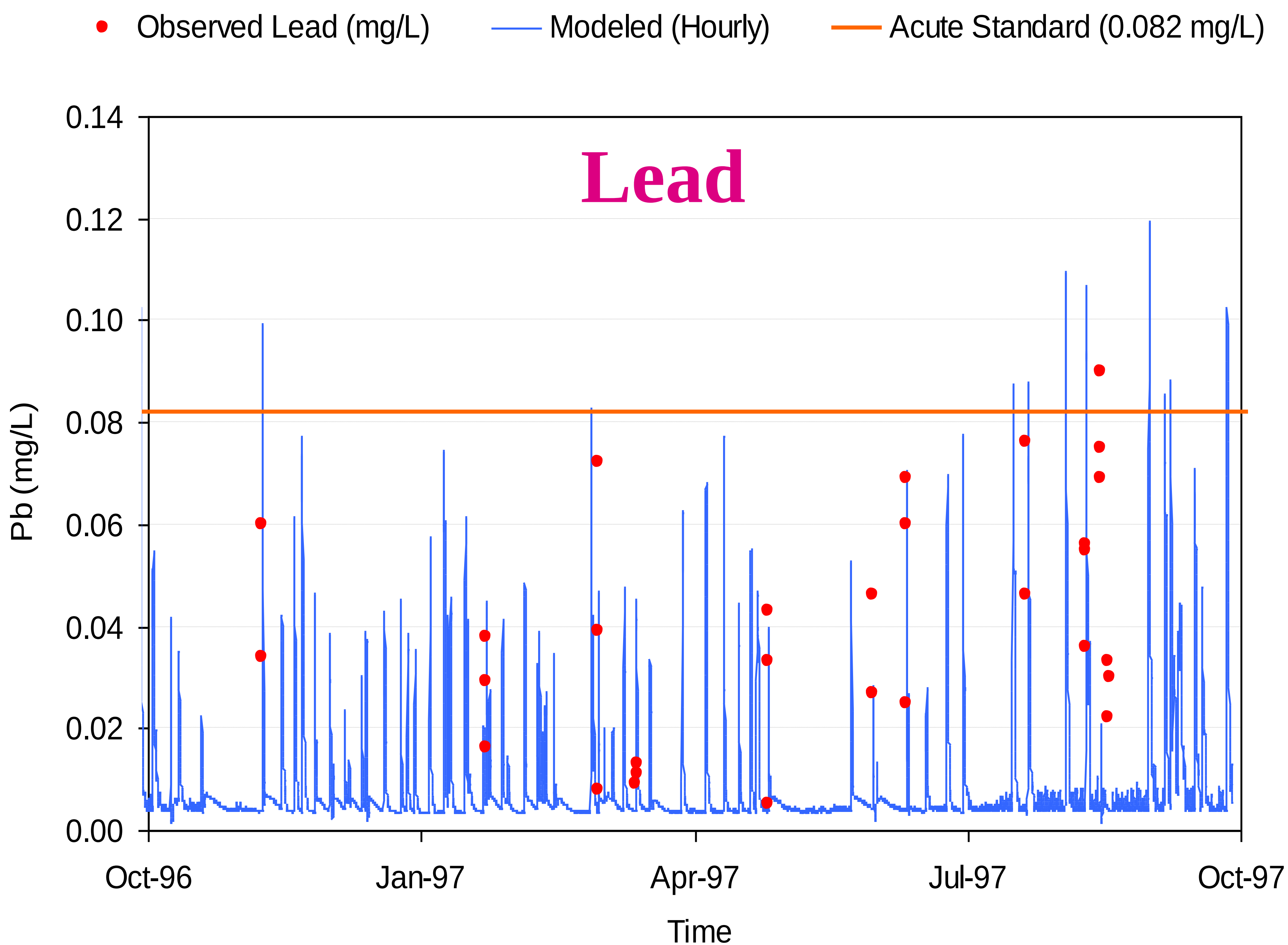
Map Projection: State Plane - 1983
Maryland

Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0

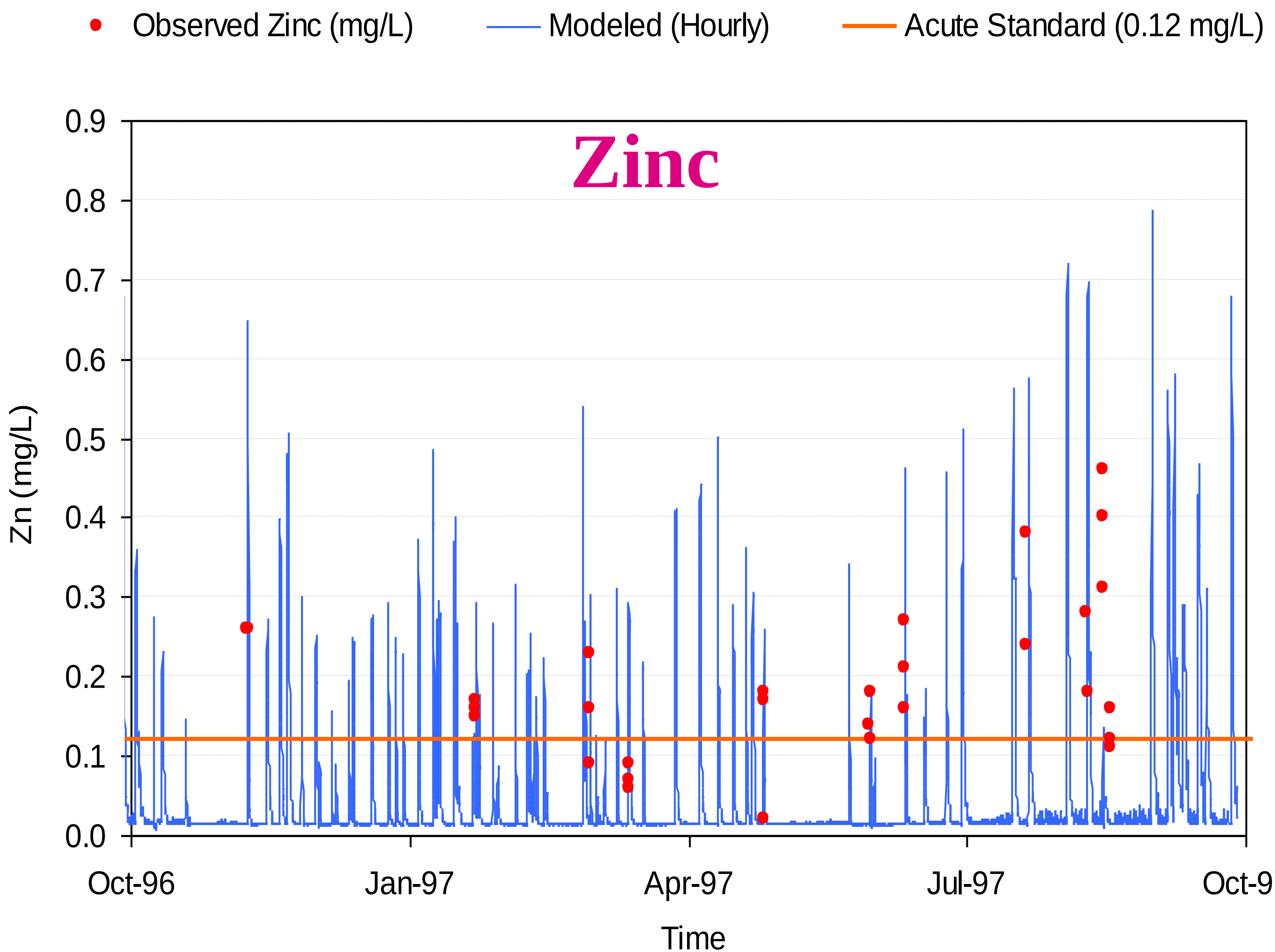

Observed Cadmium (mg/L)
Modeled (Hourly)
Acute Standard (0.0039 mg/L)
Cadmium
Cd (mg/L)
0.018
0.015
0.012
0.009
0.006
0.003
0.000
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Time



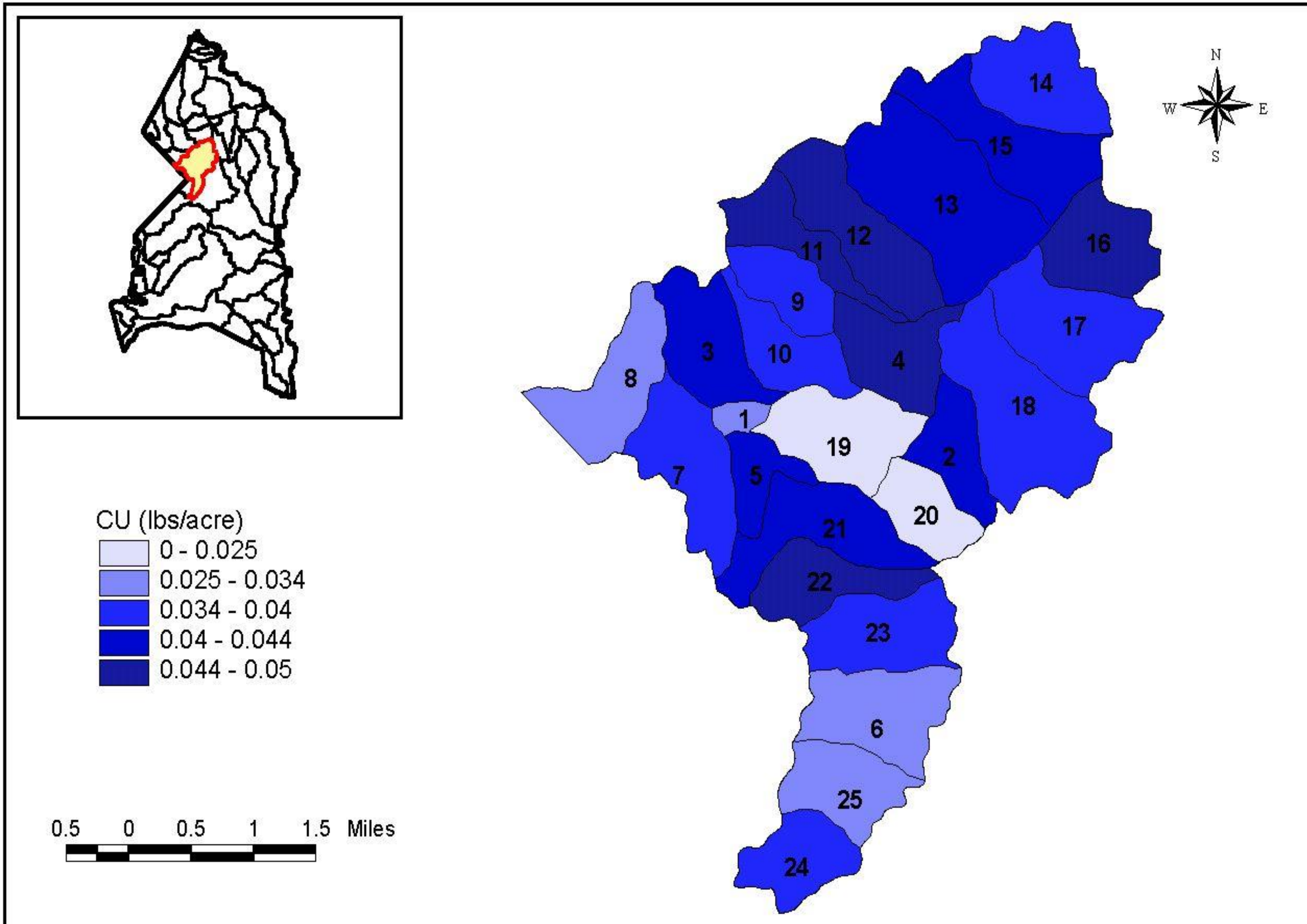
Observed Copper (mg/L)
Modeled (hourly)
Acute Standard (0.018 mg/L)
Copper
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Cu (mg/L)
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Time



Observed Lead (mg/L)
Modeled (Hourly)
Acute Standard (0.082 mg/L)
Lead
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Pb (mg/L)
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Time



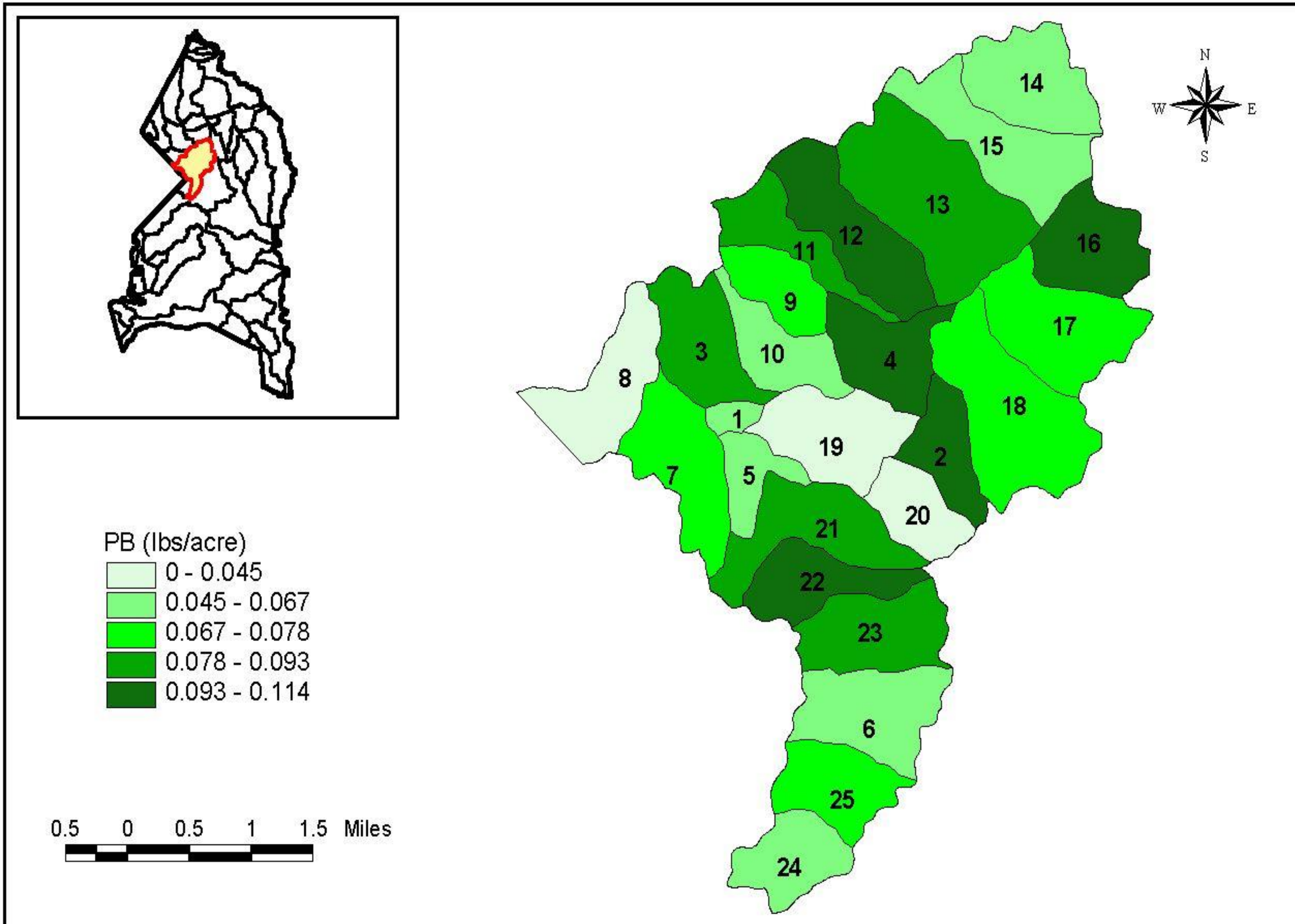
Observed Zinc (mg/L)
Modeled (Hourly)
Acute Standard (0.12 mg/L)
Zinc
Zn (mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Time



Annual Copper Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

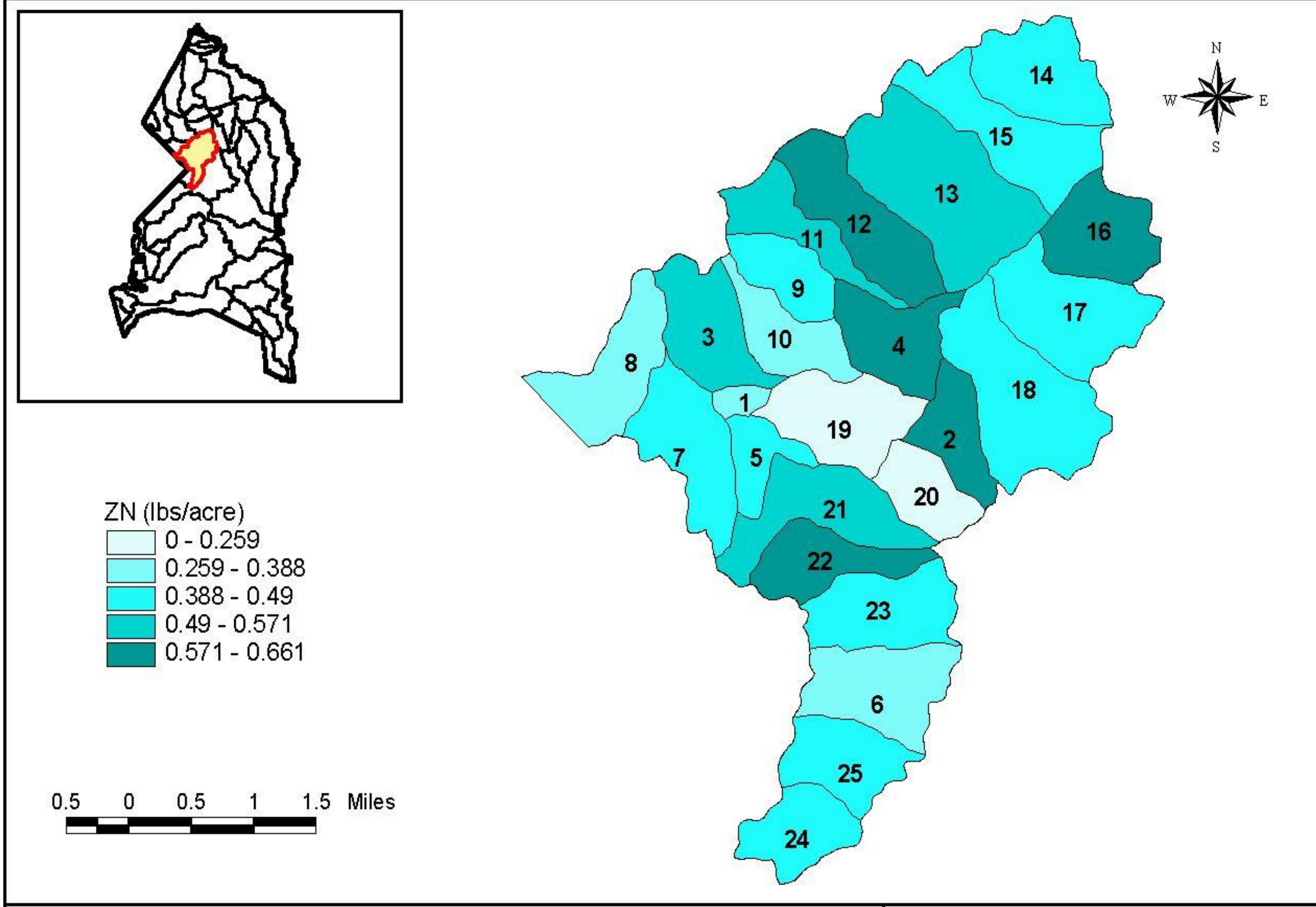
Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0



Annual Lead Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0



Annual Zinc Unit Area Loads
Lower Beaverdam Creek

Map Projection: State Plane - 1983
Maryland

Data Source: Prince George's County Watershed Data
U.S. EPA BASINS 2.0