Basin-Scale Modeling of Nutrient Impacts in the Eel River Watershed, Plymouth, Massachusetts

by

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B.A. Economics / Geology
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SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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ABSTRACT

A surface water hydrologic model was developed to assess nutrient impacts in the Eel River Watershed. The study was performed on behalf of the Eel River Watershed Association, in response to specific concerns regarding eutrophication of the watershed. These concerns are focused on increased nutrient loading caused by a recently constructed Waste Water Treatment Facility, as well as increased development (i.e., golf courses and residential).

The surface water model HSPF was chosen for its comprehensive hydrologic simulation capabilities, deemed necessary for the heterogeneous, baseflow-dominated nature of the watershed. Additionally, multiple levels of nutrient transport modeling are possible with HSPF, including build-up / wash-off algorithms. Finally, recent versions of HSPF (i.e., WinHSPF) are integrated with GIS, allowing for rapid characterization, delineation, and discretization of the watershed.

Hydrologic calibration of the model was successful in replicating observed stream flow to the resolution of the daily storm hydrograph. Detailed total nitrogen and total phosphorous loading estimates were then calculated to provide a screening tool for the extent of nutrient impacts. The results indicate increased loads of 167% and 171% for total nitrogen and total phosphorous, respectively, in the watershed.

These loading estimates were integrated within the HSPF hydrologic model via the build-up / wash-off algorithms. Nitrate transport was simulated under baseline conditions, with modeled results indicating a strong correlation to measured concentrations. Forecasting of the impacts from WWTF effluent discharge was then performed. A significant localized increase in nitrate concentrations on the order of 15-20% was modeled, indicating the potential for increased eutrophication in associated water bodies.

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Dedication

To Kerri, for her inspiration and support.

Acknowledgements

First of all, I would like to thank the Eel River Watershed Association for providing me with the opportunity to work on this study, as well as setting an example for environmental activism. Their efforts should be commended.

My gratitude goes to those who assisted in performing this research, including my thesis and group project advisors, as well as the MIT Eel River Investigation Team (MERIT). Dr. E.E. Adams and Dr. Peter Shanahan provided insightful guidance for my research, particularly during portions of the modeling when it was difficult to see the "big picture". Special thanks go to the MERIT team for all of the long hours spent in making this study successful.

Finally, I would like to thank my family for their never-ending support through the years.

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1.0 INTRODUCTION

The Eel River Watershed (ERW) is a relatively small watershed located in southeastern Massachusetts between Boston and Cape Cod. It encompasses approximately 13.3 square miles (8,510 ac.) and ultimately discharges into the Plymouth Harbor. The watershed flow regime is groundwater-dominated, due to the high hydraulic conductivity of the underlying Plymouth-Carver Aquifer, which is largely comprised of sand and gravel. The Plymouth-Carver has been designated as a "sole source" aquifer by the U.S. Environmental Protection Agency (U.S. EPA) (Hansen and Lapham, 1992). The surface water system is variable, and consists of a network of kettle ponds, streams, and ultimately the Eel River, which flows in two branches prior to its convergence near the mouth.

Due to its largely undeveloped nature (>75%), the watershed health is good in terms of both conventional pollutants and trophic state. The east branch of the Eel River is in an oligotrophic state, while the western branch has indications of mesotrophic conditions, believed to be caused by relatively greater development in this area (TAC, 2000).

Currently, however, developmental pressures have threatened the health of the watershed via increased nutrient loading. The nutrients of greatest concern are nitrogen and phosphorus, with the recently constructed wastewater treatment facility (WWTF) for the town of Plymouth, as well as residential and golf course development (i.e., the Pinehills community), posing the greatest threats. In order to assess the magnitude of the potential nutrient impacts, the MIT Eel River Investigation Team (MERIT) performed a multi-scale integrated assessment, and recommended a mitigation strategy based on the threat.

The research performed in this thesis documents the performance of one of the study components, consisting of a basin-scale surface water model of nutrient loading and transport, which was prepared using WinHSPF in conjunction with ArcView 3.2 and BASINS 3.0.

The other components of the study which were performed include:

- A MODFLOW groundwater model of the Plymouth-Carver Aquifer which assessed the specific fate and transport of nitrogen in the subsurface (Ahanin, 2002);
- Development of an in-stream water quality model using software developed by MERIT within the U.S. EPA WASP framework (RWQMWASP) (Nair, 2002);
- Design of an effective and economical mitigation strategy for the wastewater treatment plant, consisting of a vertical flow mitigation wetland, which serves to dramatically reduce the nitrogen load of the WWTF (Johnson, 2002).

1.1 Scope

This thesis has been prepared pursuant to the requirements of the Master of Engineering degree in Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT). It was performed as a portion of an integrated study of the Eel River Watershed performed by MERIT. The integrated study, documented in a final report dated May 10, 2002, was performed on behalf of the Eel River Watershed Association (ERWA). The ERWA is a citizen-action group in Plymouth, MA dedicated to the preservation of the Eel River Watershed.

1.2 The Impacts of Excess Nutrient Loading

Concern for the ERW is focused on excess nutrient loading, due to its potential for triggering adverse effects in water quality. Nutrient supply is often noted to be the principal factor influencing biological growth in surface water bodies, with either nitrogen or phosphorous limitation being typical. A number of additional factors influence biological growth, including light intensity, turbidity, flow regime, dissolved oxygen, and temperature (UK Environmental Agency, 1998). Prior studies indicate uncertainty over the limiting nutrient in the ERW (TAC, 2000).

Eutrophication is the process by which a water body is enriched by excess nutrients (i.e., nitrogen and phosphorous), causing detrimental impacts to water quality. Surface water bodies may be classified as ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic or hypereutrophic, depending on the concentration of nutrients in the body of water and/or ecosystem characteristics (e.g., the presence of algal blooms). Oligotrophic water bodies typically have low nutrient concentrations and primary productivity, a high level of water clarity, and high biodiversity.

Eutrophic water bodies, on the other hand, are characterized by high nutrient concentrations and primary productivity, low water clarity, and less biodiversity (UN, 2000).

The western branch of the Eel River is currently characterized as mesotrophic, while the eastern branch is in an oligotrophic state (TAC, 2000). The increase of nitrogen and phosphorous loads to the watershed via the WWTF and increased development, however, threaten the watershed with a potentially higher degree of eutrophication.

Adverse impacts associated with eutrophication are numerous and include:

- **Increased Algal Growth**: A common result, with several associated negative effects, as discussed below.
- **Toxic Effects**: Algal blooms of certain species (i.e., cyanobacteria) may form toxins, including neurotoxins, hepatotoxins, cytotoxins, and endotoxins. Potential symptoms include gastroenteritis, renal malfunction, allergic reactions, and hepatitis.
- **Restricted Recreational Use**: Growth mats of aquatic plants may restrict recreational use of water bodies by choking off access.
- **Noxious Odors / Poor-Tasting Water**: Water may acquire a bad taste or noxious odors, typically caused by cyanobacteria and chlorophytes.
- **Fish Kills**: Anoxia may be triggered by decomposition of increased levels of organic matter, causing inhabitable conditions for fish and invertebrates.
- **Increase in Metals Concentrations:** Anoxic conditions may also trigger increases in dissolved concentrations of ammonia, iron, manganese, and hydrogen sulfide.
- **Methylhaemoglobinaemia ("Blue-Baby Syndrome")**: In infants, levels of nitrate in drinking water above 10 mg/L may interfere with the blood's capacity to carry oxygen, inducing life-threatening conditions.

Therefore, there are a wide range of impacts associated with eutrophication, which vary in severity from aesthetic impacts (i.e., noxious odor) to toxic effects and potentially death (UN 2000).

1.3 Materials and Methods

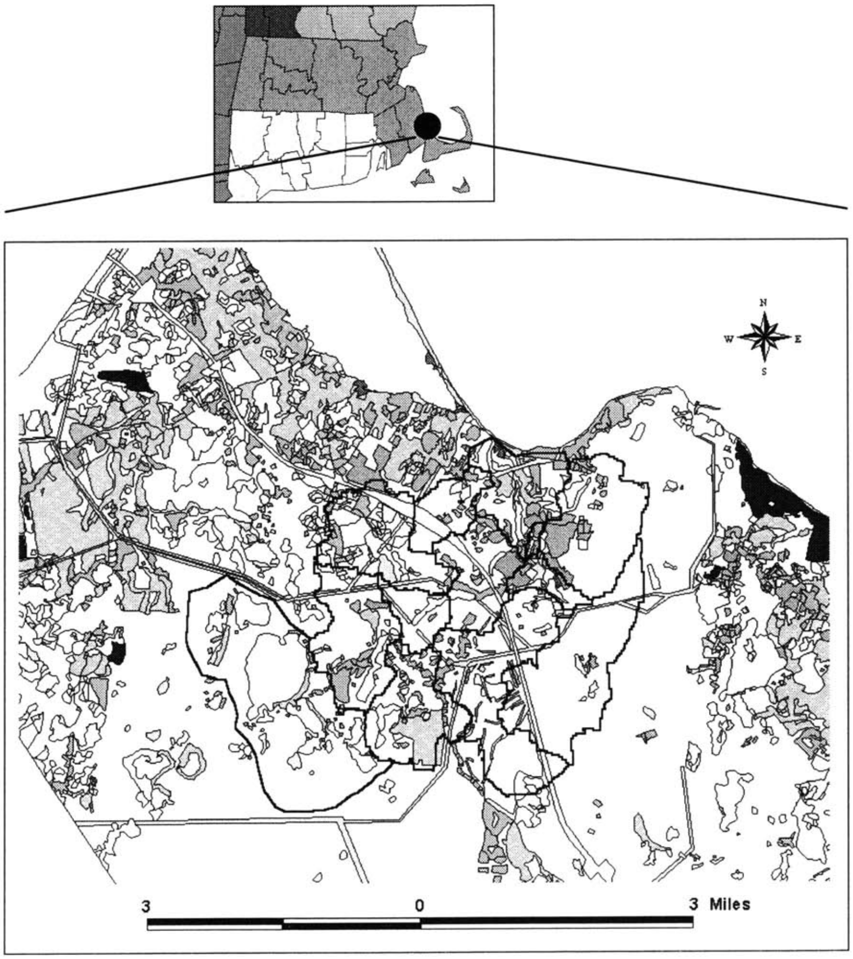
A modeling approach was deemed necessary to assess the complex nature of the surface water system. Several complementary programs and approaches were actually used to do so. The Geographic Information Systems (GIS) software ArcView 3.2a, with Spatial Analyst Version 1.1, was used for watershed characterization and delineation. BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) Version 3.0, a U.S. EPA-compiled suite of GIS extensions, was also used for this purpose, as well as to prepare a sequence of input files for HSPF (Hydrological Simulation Program-Fortran) Version 12, used in a windows-interface (WinHSPF). HSPF was used to simulate the surface water hydrology network of the ERW for nutrient transport via build-up and wash-of algorithms. Finally, GenScn Version 2.0 (A Tool for the Generation and Analysis of Model Simulation Scenarios for Watersheds) was used for time-series data viewing and analysis.

2.0 BACKGROUND AND PHYSICAL SETTING

2.1 Location

The Eel River Watershed is located in southeastern Massachusetts, between Boston and Cape Cod (see Figure 1 below). It is located within Plymouth County in the town of Plymouth, with central geographical coordinates of approximately 41°56' N latitude 70°37' W longitude (North American Datum 1927) (Hansen and Lapham, 1992). The watershed, as delineated, encompasses 8,512 acres, or 13.3 square miles, which drains into the Plymouth Harbor.

**Figure 1: Eel River Watershed (Plymouth, MA)
Location Map**



2.2 Meteorological Characteristics

The average annual temperature is approximately 50.6 °F, as reported for the period 1872-2001 for Boston, MA; substantial seasonal variation in temperature is noted (see Figure 2). The average annual precipitation for the same period is 41.7 inches and is well distributed, as can be seen in the following figures (see Figures 2 and 3) (NOAA).

Figure 2: Annual Climactic Trends

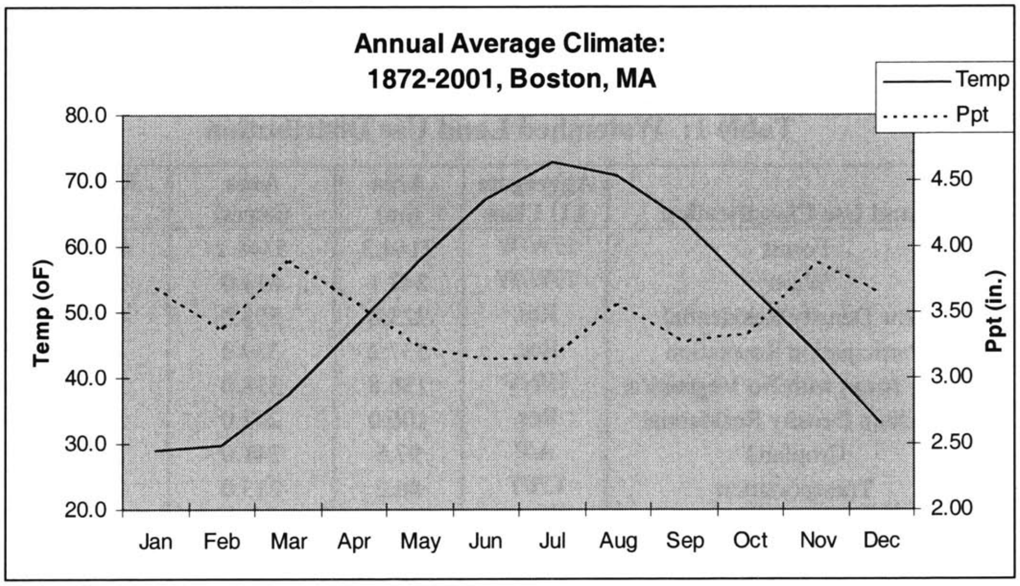
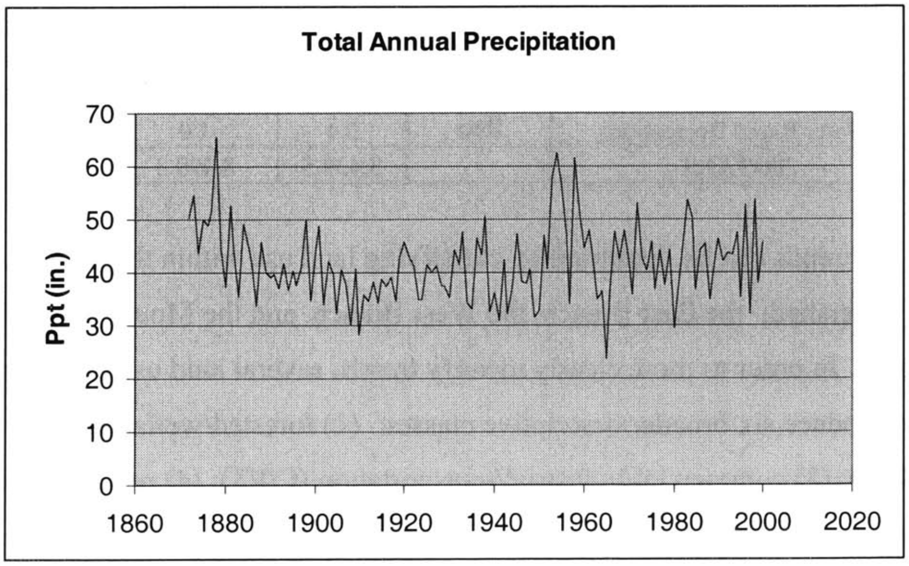


Figure 3: Annual Precipitation Values



The average rate of recharge to stratified deposits from precipitation is approximately 24 inches per year (Hansen and Lapham, 1992).

2.3 Land Use

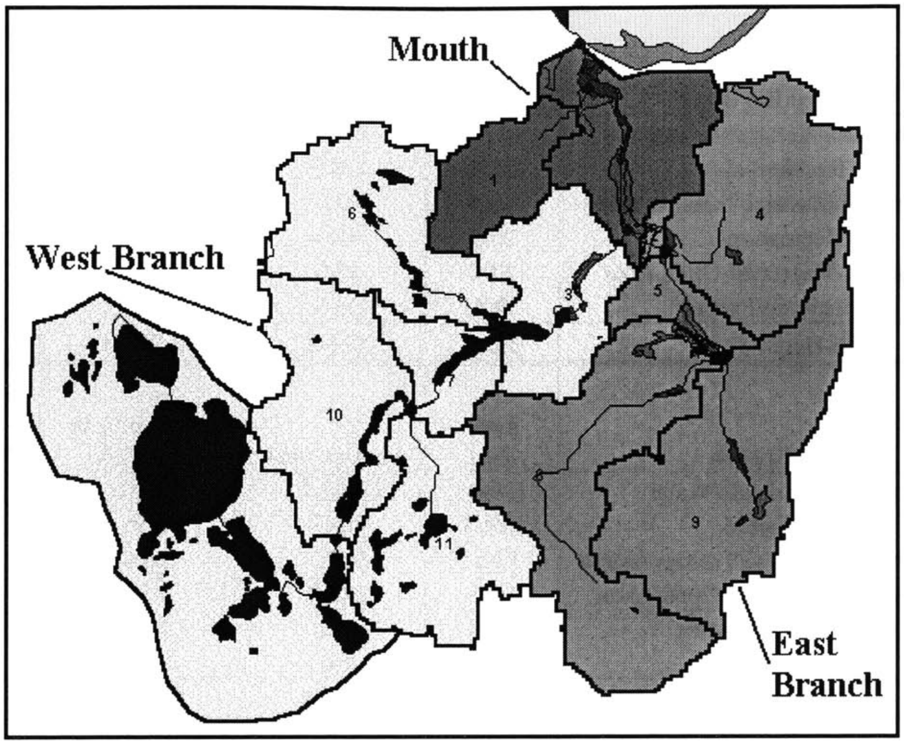
The land use distribution within the ERW was determined using ArcView GIS to interpret the MassGIS Land Use data layer, according to the 21 land use classification scheme (MassGIS). The results of the land use analysis confirm the undeveloped nature of the watershed, as indicated in Table 1 below.

Table 1: Watershed Land Use Distribution

Land Use Classification	Aggregate LU Class	Area (ha)	Area (acres)	Relative %
Forest	F/W/W	2164.3	5348.2	62.93%
Water	F/W/W	248.1	613.0	7.21%
Low Density Residential	Res.	225.8	558.0	6.57%
Participation Recreation	Rec.	137.2	339.0	3.99%
Open Areas with No Vegetation	U/NV	136.8	338.0	3.98%
Medium Density Residential	Res.	106.0	262.0	3.08%
Cropland	A/P	97.5	241.0	2.84%
Transportation	C/I/T	86.2	213.0	2.51%
Woody Perennial	F/W/W	58.7	145.0	1.71%
Mining	C/I/T	52.2	129.0	1.52%
Urban Open	U/NV	50.6	125.0	1.47%
Commercial	C/I/T	27.5	68.0	0.80%
Industrial	C/I/T	20.2	50.0	0.59%
Nonforested Wetland	F/W/W	19.4	48.0	0.56%
Pasture	A/P	5.7	14.0	0.16%
Saltwater Wetland	F/W/W	2.4	6.0	0.07%
Multifamily Residential	Res.	0.4	1.0	0.01%
Water Based Recreation	Rec.	0.4	1.0	0.01%
TOTALS		3,439.5	8,499.3	100.00%

Further land use trends can be discerned by classifying land use within the three major sub-basins in the watershed: the East Branch, the West Branch, and the Mouth of the Eel River (see Figure 4 below). In order to more clearly identify trends, several land use classifications were aggregated to produce six broader descriptive classes: (1) forested/wetlands/water (F/W/W); (2) residential (Res.); (3) commercial/industrial/transportation (C/I/T); (4) recreation (Rec.); (5) urban/non-vegetated open area (U/NV); and (6) agricultural/pasture (A/P).

Figure 4: Eel River Watershed Major Subbasins



The results of the subbasin analysis, as summarized in Table 2, indicate that the land use distribution is relatively even within the watershed, with forest/wetland/water dominating each of these areas. Residential development plays a larger role in the subbasin at the mouth of the Eel River, due to its proximity to the town of Plymouth. However, the West Branch has the higher amount of total residential development, with 505 acres, versus 179 acres at the Mouth and 137 acres in the East Branch. Recreational use, including the Forges Field Recreational Area, plays a larger role in the land use distribution in the East Branch, although it still encompasses only slightly more than 10% of the area covered by forest/wetlands/water in this subbasin.

Table 2: Land Use Distribution by Major Subbasin

Mouth of Eel River	**Area (ha)**	**Area (acres)**	**Relative % in Sub-Basin**	**Relative % in Watershed**
Forested/Wetlands/Water	172.0	425.0	51.6%	5.0%
Residential	72.4	179.0	21.7%	2.1%
Commercial/Industrial/Transportation	36.4	90.0	10.9%	1.1%
Recreation	25.5	63.0	7.6%	0.7%
Urban/Non-Vegetated Open Area	17.4	43.0	5.2%	0.5%
Agricultural/Pasture	9.7	24.0	2.9%	0.3%
Sub-Basin Total	**333.5**	**824.0**	**100.0%**	**9.7%**
West Branch	**Area (ha)**	**Area (acres)**	**Relative % in Sub-Basin**	**Relative % in Watershed**
Forested/Wetlands/Water	1394.2	3445.1	75.0%	40.5%
Residential	204.4	505.0	11.0%	5.9%
Commercial/Industrial/Transportation	126.7	313.0	6.8%	3.7%
Urban/Non-Vegetated Open Area	98.3	243.0	5.3%	2.9%
Agricultural/Pasture	32.0	79.0	1.7%	0.9%
Recreation	3.2	8.0	0.2%	0.1%
Sub-Basin Total	**1858.8**	**4593.1**	**100.0%**	**54.0%**
East Branch	**Area (ha)**	**Area (acres)**	**Relative % in Sub-Basin**	**Relative % in Watershed**
Forested/Wetlands/Water	926.8	2290.1	74.3%	26.9%
Recreation	108.9	269.0	8.7%	3.2%
Open Areas with no vegetation	64.3	159.0	5.2%	1.9%
Agricultural/Pasture	61.5	152.0	4.9%	1.8%
Residential	55.4	137.0	4.4%	1.6%
Commercial/Industrial/Transportation	23.1	57.0	1.8%	0.7%
Urban/Non-Vegetated Open Area	7.3	18.0	0.6%	0.2%
Sub-Basin Total	**1247**	**3082**	**100.0%**	**36.3%**
Watershed Total	**3440**	**8499**	**N/A**	**100.0%**

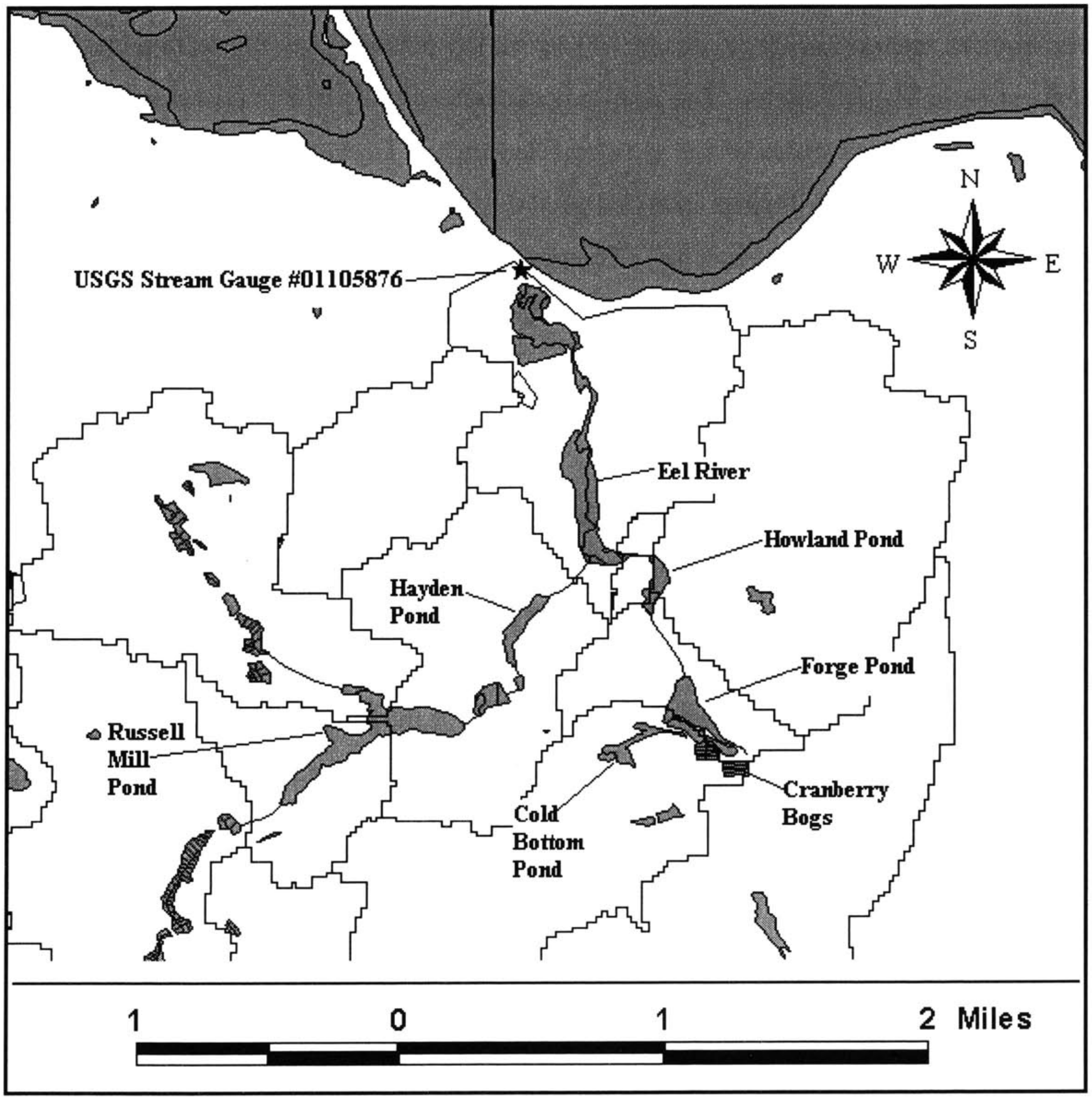
2.4 Surface Water Hydrology

The surface water hydrology network comprising the Eel River Watershed is heterogeneous, with only a small portion of the system consisting of a clearly defined channel, and the remainder consisting of kettle ponds, brooks and streams, several major ponds/man-made impoundments, cranberry bogs, and finally the Eel River itself, with its two branches.

The southwestern portion of the watershed is dominated by kettle ponds including Great and Little South Ponds, which were created during glacial retreat. Many of these ponds are isolated from other surface impoundments within the ERW and remain hydrologically connected through the groundwater flow regime only (Hansen and Lapham, 1992).

The two branches of the Eel River converge in the vicinity of the inlet to Eel River Pond. The western branch receives drainage from an area of 4,593 acres. Two major man-made ponds are located within this area: Russell Mill Pond and Hayden Pond. Also present are two major trout hatcheries, the Gilbert Fish Hatchery: upstream of Russell Mill Pond, and the Brewster Fish Hatchery, downstream of the outlet from Russell Mill Pond.

Figure 5: Major Water Bodies in the Eel River Watershed



The eastern branch drains an area approximately 2/3 the size of the western branch, encompassing a total of 3,082 acres. Several ponds link the eastern branch, starting with Cold Bottom Pond, which drains into Forge Pond and subsequently Howland Pond. Additionally, several large cranberry bogs are located between Cold Bottom Pond and Forge Pond.

The confluence of the Eel River is located downstream of Howland Pond and Hayden Pond. The river gains in size and discharge as it broadens into the Eel River pond, and eventually discharges at Plymouth Harbor (Hansen and Lapham, 1992; TAC, 2000).

2.5 Hydrogeology

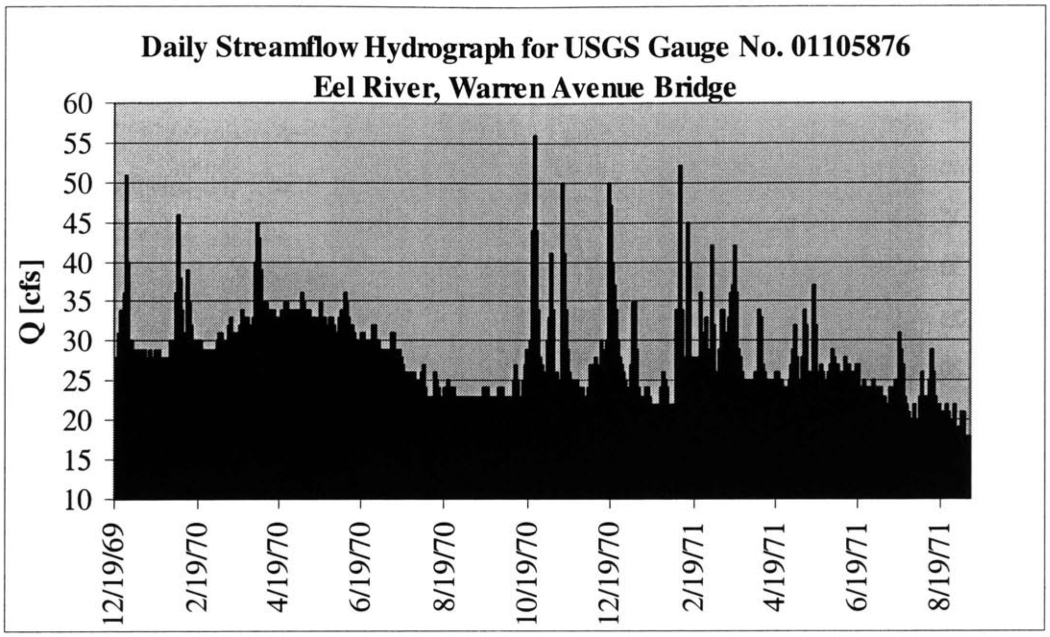
As mentioned above, the Eel River Watershed is underlain by the highly conductive Plymouth-Carver Aquifer, encompassing an area of 140 sq. mi (89,600 ac). It is the second largest aquifer in areal extent in Massachusetts. The aquifer is characterized by fine to coarse sand and gravel with occasional, limited lenses of silt and clay (Hansen and Lapham, 1992). These surficial deposits consist of unconsolidated stratified glacial materials deposited during the last glacial retreat, approximately 15,000 years ago. The average horizontal hydraulic conductivity of stratified sand and gravel deposits ranges from 55 to 313 ft/d, with a mean value of 188 ft/d (Hansen and Lapham, 1992).

2.6 Streamflow Record

2.6.1 United States Geological Survey (USGS)

The USGS maintained a daily stream flow record for the Eel River for the period from December 9, 1969 to September 9, 1971. The stream gauge (No. 01105876) was located near the mouth of the Eel River, at the Warren Avenue Bridge (see Figure 5). The streamflow record is relatively constant, which reflects the large baseflow component of the runoff. Average streamflow for the period of record is 28 cfs, with a minimum of 18 cfs recorded for a total of eight days in August and September of 1971, and a maximum of 56 cfs on October 24, 1970 (USGS Water Resources, NWIS Site Inventory). The recorded daily hydrograph from this gauging station is shown in Figure 6 below.

Figure 6: USGS Gauge Daily Streamflow Hydrograph



2.6.2 CDM Investigations & Technical Advisory Committee

Prior to construction of the waste water treatment plant, several environmental investigations were performed by Camp Dresser & McKee, Inc. (CDM, 1997; CDM, 2000; CDM, 2001; TAC, 2000). During the course of these evaluations, stream flow was measured at a number of locations on a monthly to semi-monthly basis from the period May 28, 1998 to February 22, 2000. The results are depicted in Figure 7 and summarized in Table 3. The relatively flat hydrograph response is again noted at all sampling locations.

Figure 7: CDM Streamflow Measurements

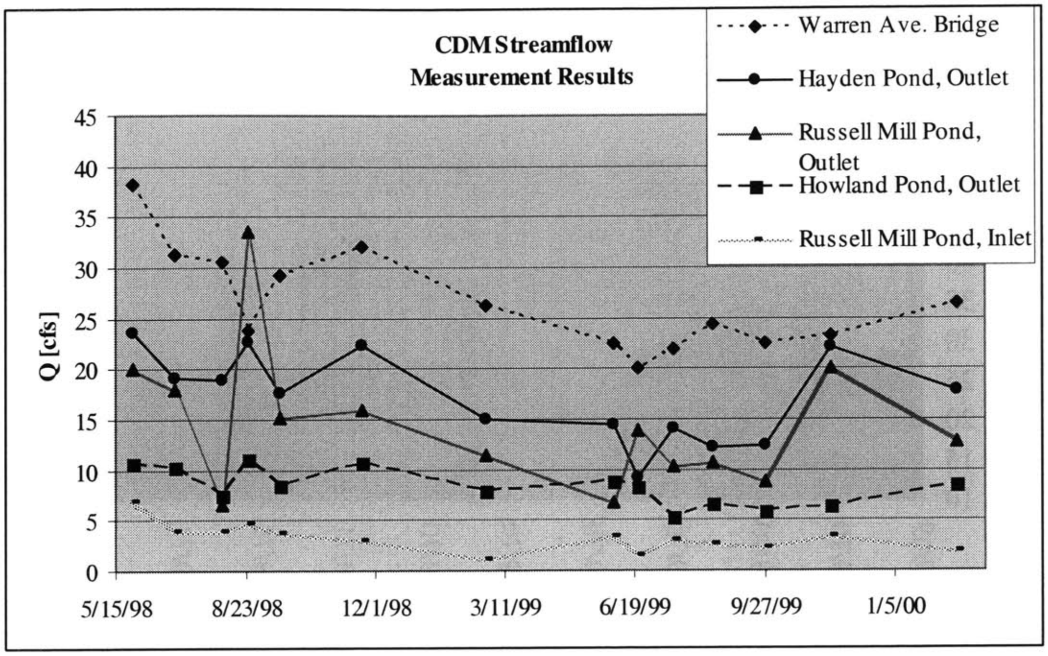


Table 3: CDM Streamflow Measurement Summary

Mouth of Eel River		Western Branch						Eastern Branch	
Warren Ave. Bridge		Russell Mill Pond, Outlet		Russell Mill Pond, Inlet		Hayden Pond, Outlet		Howland Pond, Outlet	
Date	**Q [cfs]**	**Date**	**Q [cfs]**	**Date**	**Q [cfs]**	**Date**	**Q [cfs]**	**Date**	**Q [cfs]**
5/28/98	38.26	5/28/98	20.13	5/28/98	6.99	5/28/98	23.61	5/28/98	10.73
6/29/98	31.33	6/29/98	18.01	6/29/98	3.96	6/29/98	19.15	6/29/98	10.26
8/4/98	30.56	8/4/98	6.58	8/4/98	3.99	8/4/98	18.92	8/4/98	7.45
8/25/98	23.83	8/25/98	33.47	8/25/98	4.75	8/25/98	22.75	8/25/98	11.1
9/18/98	29.25	9/18/98	15.22	9/18/98	3.66	9/18/98	17.59	9/18/98	8.52
11/20/98	32.14	11/20/98	15.89	11/20/98	2.91	11/20/98	22.31	11/20/98	10.77
2/24/99	26.22	2/24/99	11.49	2/24/99	1.18	2/24/99	14.92	2/24/99	7.91
6/3/99	22.51	6/3/99	6.73	6/3/99	3.33	6/3/99	14.5	6/3/99	8.89
6/22/99	20	6/22/99	13.8	6/22/99	1.56	6/22/99	9.11	6/22/99	8.34
7/19/99	21.9	7/19/99	10.37	7/19/99	3.01	7/19/99	14.11	7/19/99	5.25
8/18/99	24.37	8/18/99	10.78	8/18/99	2.55	8/18/99	12.19	8/18/99	6.48
9/28/99	22.59	9/28/99	8.82	9/28/99	2.32	9/28/99	12.44	9/28/99	5.81
11/17/99	23.22	11/17/99	20.03	11/17/99	3.38	11/17/99	22.12	11/17/99	6.34
2/22/00	26.48	2/22/00	12.82	2/22/00	1.79	2/22/00	17.86	2/22/00	8.47
MINIMUM	20.00	**MINIMUM**	6.58	**MINIMUM**	1.18	**MINIMUM**	9.11	**MINIMUM**	5.25
AVERAGE	26.62	**AVERAGE**	14.58	**AVERAGE**	3.24	**AVERAGE**	17.26	**AVERAGE**	8.31
MAXIMUM	38.26	**MAXIMUM**	33.47	**MAXIMUM**	6.99	**MAXIMUM**	23.61	**MAXIMUM**	11.10

3.0 SURFACE WATER MODEL SELECTION

Due to the complexity of the surface water network in the ERW, a modeling approach was deemed crucial to understanding nutrient loading and transport processes. Donigian and Huber (1991) provide guidance for the successful implementation of a modeling simulation of watershed-scale nonpoint source pollution:

- Clearly defined research goals;
- Use of the simplest model available to achieve these research goals;
- Use of a model consistent with the detail of available data, including spatial and temporal resolution;
- Limiting predictions to the identified parameters of concern within a suitable time scale;
- Using sensitivity analysis to understand model response to parameter modifications;
- Calibration and verification of model results, within data restraints;
- Use of operational models, which are (i) clearly documented, (ii) supported (by agency or developer), and (iii) proven through experience.

These criteria were given full consideration during the model screening process, described in detail below.

3.1 Model Screening Process

Because of the large number of surface water hydrology models currently available, a review of available technologies was performed prior to choice and implementation. The models most seriously considered are discussed below.

3.1.1 HSPF (Hydrological Simulation Program-Fortran)

HSPF originated with the Stanford Watershed Model in 1966, but additionally incorporates nonpoint source modeling efforts of the U.S. EPA Athens laboratory (Donigian and Huber, 1991). It offers the ability for comprehensive watershed scale modeling of both urban and non-urban areas, with runoff and hydraulic routing capabilities. All streamflow components, including surface runoff, interflow, and baseflow are considered. HSPF also has the capability to simulate the fate and transport of pesticides and nutrients via buildup and washoff algorithms, as well as specific agrichemical modules (Bicknell et al, 2000). Several model advancements (e.g., BASINS and WinHSPF) have been made to increase the functionality and ease of implementation for HSPF, as discussed below.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

BASINS is a multipurpose environmental analysis system for performing watershed-scale studies of water quality impacts. It was developed by the U.S. EPA's Office of Water to allow an integrated assessment tool via a suite of specialized ArcView GIS applications, modeling programs, and data management utilities (U.S. EPA, 2001).

The core BASINS functions which relate to the implementation of a HSPF model include:

- Watershed characterization and delineation;
- Creation of the HSPF User Control File (UCI);
- Meteorological input data preparation and viewing through WDMUtil;
- Viewing and analysis of calibration and output scenarios through GenScn. (U.S. EPA, 2001)

Together, these tools provide a framework which allows for a holistic assessment of watershed pollutant impacts.

WinHSPF

Although not a separate surface water model, WinHSPF is an interactive Windows interface to HSPF, also integrated within the BASINS framework. WinHSPF allows for rapid modification and visualization of the model watershed represented by the HSPF UCI file. It greatly increases user productivity in creating and calibrating the HSPF model (Duda et al., 2001).

3.1.2 CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems)

CREAMS is a field-scale model which was designed for the analysis of agricultural best management practices by the agricultural research community. It simulates surface runoff processes only (i.e., subsurface and leaching losses are removed from the model system) in order to understand specific effects of agricultural management systems (Donigian and Huber, 1991).

3.1.3 ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation)

ANSWERS was developed by Beasley and Huggins (1981) at Purdue University as a single storm, event-based, distributed-parameter model. It was designed to simulate hydrologic and erosion response in agricultural watersheds. High resolution spatial data is required for

ANSWERS due to its detailed discretization scale (2.5 to 10 acres). Nutrient simulation modules are included within the model (Donigian and Huber, 1991).

3.1.4 AGNPS (Agricultural Nonpoint Source Pollution Model)

AGNPS was developed by the USDA Agricultural Research Service (Young et al., 1986). It allows for the modeling of runoff, sediment, and nutrient transport for watershed-scale areas. Similar to ANSWERS, it offers a distributed-parameter approach, also with correspondingly high spatial data requirements. The model was designed specifically to compare the effects of differing management practices on pollution control (Donigian and Huber, 1991).

3.1.5 STORM (Storage, Treatment, Overflow, Runoff Model)

STORM was developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC, 1977; Roesner et al., 1974) for continuous simulations in urban areas. It was designed to determine optimization for combined sewer overflows (Donigian and Huber, 1991).

3.1.6 SWMM (Storm Water Management Model)

SWMM was originally developed by Metcalf and Eddy for the EPA as a single-event assessment model for Combined Sewer Overflows. Since its release, its operational scope has expanded dramatically, but remains focused on urban watershed hydrology and hydraulics (Donigian and Huber, 1991).

3.2 Specific Model Selection Criteria

In order to characterize hydrological and nutrient transport processes in the ERW, the surface water model HSPF was chosen, as implemented within the BASINS 3.0 and WinHSPF framework. Based on the previously defined research goals, the following factors were used in model selection.

- **Timeframe:** Although the system setup and assessment phase effort requirements are estimated at a relatively high level (days to weeks for setup, and weeks to months for assessment), the integrated framework of BASINS 3.0 and readily available digital data resources was believed to compensate for the high level of effort (Donigian and Huber, 1991).

- **Complexity**: Model complexity is a mixed factor for HSPF, as it allows for sophisticated watershed characterization, but is difficult to use because of its high degree of parameterization. However, its modular framework allows for varying levels of complexity in model simulations.
- **Proven Success**: HSPF has a record of proven success in a wide range of applications for assessing both point and nonpoint pollutant impacts. Some examples include:
  - Example #1: Hydrologic modeling of the Charles River Watershed (Munson, 1998; Socolofsky, 1997). Produced a model of the Charles River Basin which addresses management impacts on water quality, including detailed bacteria transport modeling.
  - Example #2: Chesapeake Bay Watershed nutrient impact assessment (Donigian, 1994). Assessed management actions on nutrient and sediment loads to the Chesapeake Bay. The watershed encompasses 64,100 sq. mi. in six states, and is primarily (~57% forested) undeveloped.
  - Example #3: LeSueur Basin, Southern Minnesota (Donigian, 1996). Modeled point and nonpoint source contributions to evaluate best management practices on the Minnesota River, in the LeSueur Watershed, with a drainage area of 17,000 sq. mi.
- **Data Requirements:** The data requirements for HSPF are relatively high and include detailed meteorological data, land use data, watershed characteristics, nutrient loading estimates, and reach characteristics. The integration of HSPF with an ArcView GIS framework reduces field data requirements via the use of digital data from high-quality sources, such as BASINS 3.0, MassGIS and USGS DEMs.
- **Land Use Applicability**: HSPF is designed for use in either urban or agricultural settings, and is readily applicable to a predominantly undeveloped watershed.
- **Scale**: HSPF is designed as an aggregate watershed-scale assessment tool, although typical use is on larger watersheds than the Eel River.
- **Hydrologic Modeling Component**: HSPF considers the full range of streamflow components, including surface runoff, interflow, and baseflow, as well as contaminant transport in each of these components. Given the groundwater-dominated nature of the flow regime in the Eel River, this factor is important.
- **Water Quality Component**: HSPF allows for water quality constituent (i.e., nitrogen) simulation via two separate methods. First, constituent transport may be modeled

through buildup and washoff relationships as a screening tool. HSPF also has additional agrichemical modules, which allow for simulation of specific nitrogen and phosphorous transport with speciation. Although beyond the scope of this research, these latter processes may be important for future studies.

4.0 WATERSHED CHARACTERIZATION AND DELINEATION

As documented in Section 3.2 above, HSPF was selected as an appropriate surface water modeling tool. To assist in preparing the necessary model inputs, several tools, including ArcView GIS 3.2 and BASINS 3.0 were used for watershed assessment, characterization, and delineation.

The first major step in modeling the Eel River Watershed was definition of the drainage basin contributing to the Eel River. Several sources of prior delineation exist, including the USGS and CDM (Hansen and Lapham, 1992; TAC, 2000), which were used to aid in the process.

4.1 BASINS 3.0 Project Creation Procedure

The creation of a BASINS project is relatively straightforward for a site located within the United States. The BASINS 3.0 software may be downloaded, free-of-charge, from the EPA and installed on a PC which also has ArcView 3.1 or higher installed. Essentially, BASINS is a sophisticated suite of GIS extensions which provides toolsets for data integration and analysis.

Once the software has been properly installed, required data may be obtained from the BASINS website (http://www.epa.gov/ost/basins/). The data obtained include:

- **Core Data**: Primary GIS data set.
- **RF3 and DEM Data**: Contains the U.S. EPA Reach File Version 3, as well as DEM grid and shape files.
- **Meteorological Data**: Contains watershed data management (WDM) files, which are the driving input for the HSPF model.

The BASINS Project Builder is then used to create a customized GIS interface that links all of the incorporated data sets. Additional data sets may later be added to the project, as was performed for the ERW (described in the Data Acquisition section below).

4.2 Data Acquisition

Accurate and relevant data is necessary for creating a model depiction of a physical system. However, as is often the case, time and budget constraints, as well as physical conditions, prevent the acquisition of high quality field data with sufficient spatial and temporal resolution to provide the desired results. Therefore, one of the goals of this research was to bridge this physical data gap via the use of GIS data. In recent years, the increased availability of high-quality data from a wide range of governmental and other sources allows for expedited and partially automated site analysis of sites, when an extensive field component is prohibitive. The data sources used in analysis and modeling of the ERW are described in detail below.

4.2.1 BASINS 3.0 Data Sources

One of the attractive components of BASINS 3.0 is the inclusion of a comprehensive database, designed specifically to aid in watershed analysis. It provides an excellent starting point for characterizing and delineating the Eel River Watershed. The datalayers provided within the BASINS 3.0 are extensive, as summarized in Tables 4 through 6 below.

Table 4: BASINS Spatially Distributed Data
1:250,000 Scale Quadrangles of Landuse/Landcover GIRAS Spatial Data of CONUS in BASINS
Land use data collected by the USGS and coded using the Anderson classification system. Conversion into ARC/INFO format was performed by the USEPA and the datalayer is maintained in the USEPA's Spatial Data Library. The data covers the time period from 1977 to the early 1980's.
1990 TIGER Urbanized Areas/Polygons for CONUS, Alaska, and Hawaii in BASINS
The dataset includes the boundaries of urban areas, as defined by the census, on a scale of 1:24,000.
Populated Place Point Locations for CONUS, Alaska, and Hawaii in BASINS
This dataset includes the locations of populated places, as derived from the USGS Geographic Names Information System II and originally represented on USGS topographic maps. The time period of coverage is from 1989 to 1994.
U.S. EPA Reach File 1 (RF1) for the Conterminous United States in BASINS
The U.S. EPA RF1 is a database of approximately 700,000 miles of streams and other surface water bodies within the United States. It has been used by the U.S. EPA, individual states, the National Weather Service, and the U.S. Fish and Wildlife Service since its creation in 1982. It was prepared by the EPA from NOAA aeronautical charts at a scale of 1:500,000. The data layer contains mean annual flow and low flow estimates at the downstream ends, coupled with travel time estimates, for 60,000 reaches. These data were estimated using approximately 4,000 USGS stream gauges for flow measurements and drainage area estimates, with extrapolation of additional data. This is one of the inherent data limitations of this set.
USEPA/OW River Reach File 3 (RF3) Alpha for CONUS, Hawaii, Puerto Rico, and the U.S. Virgin Islands
The USEPA RF3 dataset is an updated version of the RF1 dataset, although its data are unvalidated. The National Hydrography Dataset provides a validated, final compendium of both the RF1 and RF3.
State Soil Geographic (STATSGO) Database for CONUS, Alaska, and Hawaii in BASINS
The STATSGO database is a broad based inventory of soil types developed by the National Cooperative Soil Survey, prepared by aggregating the more detailed soil survey maps. The data were collected in 1- by 2-degree topographic quadrangles, and aggregated to form statewide coverages.
USGS 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM) for CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands
This dataset contains topographic data compiled in a digital raster form, described as a Digital Elevation Model (DEM). The level of detail provided in this dataset is a set of gridded 300m x 300m cells. The dataset covers a time period from 1979 to 1990.
DOT/FHA Major Roads for CONUS, Alaska, and Hawaii in BASINS
This dataset was derived from the National Highway Planning network, which includes the country's main highways and other National Highway System routes. The scale of the data set is 1:100K, with a time period of coverage from 1992 to 1996.

Hydrologic Unit Boundaries of the Conterminous United States in BASINS
This recent datalayer, published in 1998, is based on major watershed delineations as depicted on the Hydrologic Unit Maps published by the USGS Office of Water Data Coordination. The data are stored within the EPA Spatial Data Library System (ESDLS). The data are typically at a scale of 1:250K, with some limited areas ranging from 1:100K to 1:2M.
Drinking Water Supply Sites from Public Water Systems for BASINS
The Safe Drinking Water Inventory System contains various information on public water systems and their compliance with drinking water regulations. It is primarily used by the EPA to ensure and document system compliance.
National Inventory of Dams in BASINS
This dataset provides the locations and select attributes of over 75,000 dams in the US. The dataset was originally developed by the US Army Corps of Engineers and the Federal Emergency Management Agency to compile dam related problems. The BASINS related dataset is dated 1996.
USEPA Regional Boundaries in the United States for BASINS
This dataset provides the boundaries for each of the ten USEPA regions within the US. It was derived from USGS State Boundaries, at a scale of 1:2M, and published in 1998.
State Boundaries in the United States for BASINS
This dataset provides state boundaries within the United States, as derived from USGS basemaps at a scale of 1:2M, with the original data source being the National Atlas of the United States.
Counties and County Equivalents Boundaries in the United States for BASINS
This dataset provides county boundaries within the US. It was also derived from USGS basemaps at the 1:2M scale, with the National Atlas of the United States providing the originating source.
Federal, State, Tribal, or Local Government Managed Areas for CONUS in BASINS
This data layer provides an inventory of governmentally managed and protected land areas, as originated in the Managed Areas Database (MAD). It contains various types of managed areas, from a wide source of governmental agencies. It was developed at a scale of 1:2M, with a minimum contributing land area of approximately 100 hectares.
Level III Ecoregions of the Conterminous United States in BASINS
This data coverage provides boundaries ecoregions, or regions of generally similar ecosystems, as digitized from 1:250K USGS base maps.

Reference: U.S. EPA, 2001

Table 5: BASINS Environmental Monitoring Data
EPA's STORET Water Quality Monitoring and Data Summaries for CONUS
This dataset is extracted from the USEPA's Storage and Retrieval of US Waters Parametric Data (STORET). It provides statistical summaries of water quality sampling for 47 parameters for 5-year intervals between 1970-1994 and a three year interval from 1995 to 1997.
EPA's STORET Water Quality Observation Data for CONUS
This dataset is similar to the above STORET data layer, with the exception that it provides the raw data results for water quality stations. A maximum of 15 stations per HUC are provided within the BASINS data layer.
EPA's STORET Bacteria Monitoring Stations and Data Summaries for CONUS
Also derived from the EPA STORET database, this data layer provides a location map for water quality monitoring sites for 10 bacteria-related parameters.
USEPA STORET Stream Flow Data from Gauging Stations in CONUS
This data layer provides data on stream flow gauging stations, including low flows and average monthly flow data.
NOAA's National Climatic Data Centers (NCDC) Weather Data Management (WDM) Stations Point Locations in the United States, Puerto Rico, and the U.S. Virgin Islands
This data layer provides locational information on WDM sites, with associated meteorological data.
1996 National Listing of Fish Consumption Advisories for the United States
The Listing of Fish Consumption Advisories Database contains information on fish consumption advisories issued by the government, at federal, state, and territorial levels. Select Canadian coverage is also included.
USEPA National Sediment Inventory (NSI) Version 1.2 for the Conterminous U.S.
This dataset describes the accumulation of chemical contaminants within sediments associated with surface water bodies including rivers, lakes, oceans, and estuaries. Over 21,000 sites were screened for inclusion within the database.
The 1995 National Shellfish Register of Classified Growing Waters
This datalayer provides information for over 4,000 state shellfish-growing areas, comprising approximately 25 million acres, including pollution status and ongoing restoration efforts.
1996 EPA/OW Clean Water Needs Survey (CWNS) for the United States and U.S. Territories
This datalayer provides the results of the EPA's estimates on cost eligibility for State Revolving Fund assistance under the Clean Water Act. It provides current and potential future planning information for POTWs throughout the nation.

Reference: U.S. EPA, 2001

Table 6: BASINS Point Source Data
EPA/OW Industrial Facilities Discharge Database for CONUS
This datalayer provides information on select industrial or municipal point source discharges to surface waters, as extracted from the USEPA's Industrial Facilities Discharge database.
EPA/OW Permit Compliance System (PCS) for BASINS Version 3 in CONUS
PCS is a computerized management information system which tracks NPDES-related data for greater than 75,000 sites nationwide.
USEPA Toxic Release Inventory Facilities in the United States
The TRI dataset contains data on annual estimated releases of over 300 toxic chemicals to various media by specific industries, as reported by the industry producing the emission.
EPA Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) or Superfund for the United States
This dataset contains information on listed Superfund sites within the US.
EPA/OSW Resource Conservation and Recovery Information System (RCRIS) for the United States
This dataset supports information management for RCRA, which requires that generators, transporters, treaters, storers and disposers of hazardous waste provide information to environmental agencies to assist in tracking hazardous waste.
USBM Mineral Availability System (MAS)/Mineral Industry Location in CONUS
This dataset lists information, including known mining operations, mineral deposits and occurrences, as well as processing plants for over 221,000 locations. The original data source is the Mineral Availability System (MAS) / Mineral Industry Location System (MILS), produced by the Bureau of Mines.

Reference: U.S. EPA, 2001

Although valuable for understanding certain aspects of watershed processes, many of these data layers were deemed unnecessary for inclusion in the BASINS project created. Many were unrelated to the research goals of this thesis and removed from consideration (i.e., USBM Mineral Availability System). Additionally, the resolution of several datalayers (i.e., 1:100K DEM) was inadequate to accurately represent the ERW. Therefore, only selected essential data layers were retained for use in watershed delineation and characterization.

These data layers include:

- 1:250,000 Scale Quadrangles of Landuse/Landcover GIRAS Spatial Data of CONUS in BASINS;
- U.S. EPA Reach File 1 (RF1) for the Conterminous United States in BASINS;
- USEPA/OW River Reach File 3 (RF3) Alpha for CONUS, Hawaii, Puerto Rico, and the U.S. Virgin Islands;
- USGS 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM) for CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands;
- DOT/FHA Major Roads for CONUS, Alaska, and Hawaii in BASINS;
- Hydrologic Unit Boundaries of the Conterminous United States in BASINS;
- Counties and County Equivalents Boundaries in the United States for BASINS
- U.S. EPA's STORET Water Quality Monitoring and Data Summaries for CONUS
- NOAA's National Climatic Data Centers (NCDC) Weather Data Management (WDM) Stations Point Locations in the United States, Puerto Rico, and the U.S. Virgin Islands.

Many of these data sources were supplemented by additional, higher-resolution coverage in order to better represent the watershed, as discussed below.

4.2.2 Supplemental Data Sources

Fortunately, several excellent sources of digital data are currently available for the Commonwealth of Massachusetts. These were used to supplement gaps in the BASINS database caused by insufficient resolution.

USGS National Hydrography Dataset

The USGS National Hydrography Dataset is based on the USGS Digital Line Graphic 1:100K hydrography dataset, incorporated with the U.S. EPA Reach File Version 3 Data. It supersedes the individual datasets by adding greater quality control to the RF3 data set. The BASINS toolset includes an automatic NHD download tool which allows for access to the most recent version of the representative data set for the watershed assessment.

1:24K USGS Digital Elevation Models

These high-resolution 1:24K DEMs are identical to those included with the BASINS data set, with the exception of much higher resolution, which is appropriate for a smaller scale watershed such as the ERW. The higher resolution translates into a tenfold reduction in grid size from 300m x 300m to 30m x 30m. A total of four adjoining quadrangles were obtained from GISDataDepot, an on-line geo-spatial data repository to cover the full extent of the ERW (http://www.gisdatadepot.com/). These include Plymouth, Manomet, Wareham, and Sagamore. Using Arc/Info, the four individual quadrangles were merged into a single seamless DEM. Preprocessing was also performed to remove sinks caused by null values and erroneous data.

MassGIS Hydrography

The MassGIS hydrography dataset was produced as a hybrid between the USGS 1:25,000 Hydrography Digital Line Graph (DLG) quadrangle files, the USGS 1:100,000 Hydrography DLG files, and digitized hydrographic features from the USGS 1:25,000 Topographic Quadrangles. A wide variety of surface water bodies are identified in the representative attribute tables, including streams, rivers, wetlands, cranberry bogs, and wetlands (MassGIS).

MassGIS Land Use

The MassGIS land use was produced on the basis of interpretation from 1:25,000 aerial photography, using statewide coverages for 1971, 1985, and 1999. The aerial photo interpretation and automation were performed by the Resource Mapping Project at the University of Massachusetts, Amherst. Twenty-one land use classifications, as well as a more detailed thirty-seven land use classification are contained within the data layer. For the purpose of this research, the twenty-one land use classification was deemed more than sufficient resolution (MassGIS).

4.3 Watershed Delineation

4.3.1 Process Description

One of the main benefits of using the BASINS framework is automatic watershed delineation via the use of advanced GIS functions. The delineation serves to discretize the watershed into subbasins on the basis of drainage areas and relatively uniform characteristics. The automatic delineation tool requires Spatial Analyst (Version 1.1 or higher) and Dialog Designer (Version

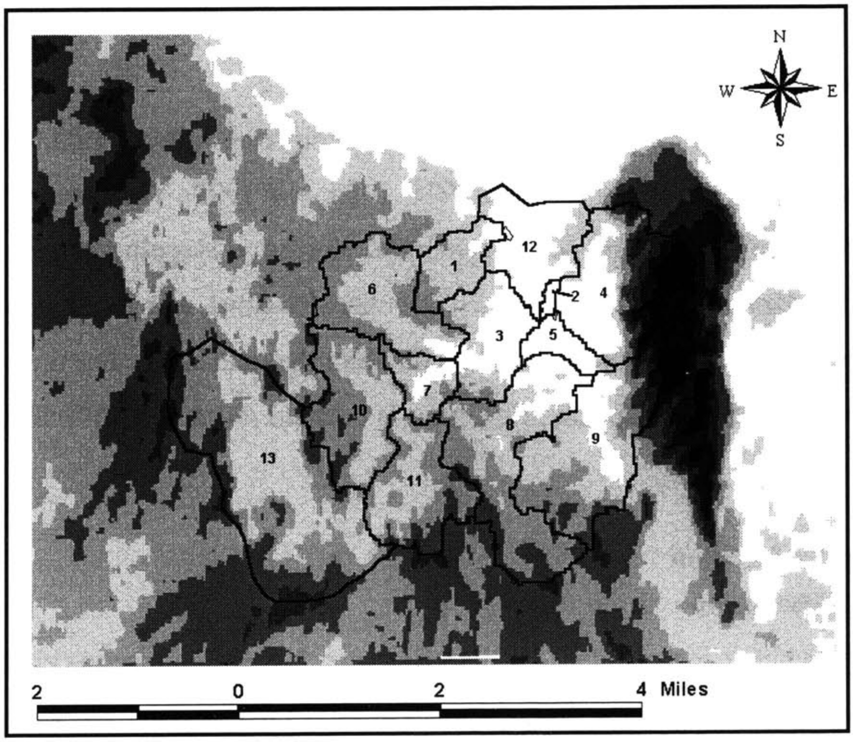
3.1 or later). It also requires a DEM in the ArcInfo grid format. The BASINS delineation provides the necessary input files for HSPF model representation, which is a markedly strong advantage.

4.3.2 DEM Preprocessing

The delineation process proceeded as follows. First, the automatic watershed delineation extension is activated and the automatic delineation tool is chosen. The appropriate grid file DEM is then loaded into the delineation tool. In order to focus a specific area of the watershed, a "mask" shape file may then be created, which roughly outlines the watershed and focuses later processing on this selected area. This was performed to expediate processing time.

The next major steps include preprocessing of the DEM, which begins with removing of "sinks", or null/erroneous values within the data grid. This happened to be a redundant step in this case, since this had already been performed during the merging and processing of the 1:24K DEMs.

Figure 8: Eel River Watershed Digital Elevation Model (1:24K)



4.3.3 Reach Representation

During the course of automatic delineation, BASINS creates a descriptive "Streams" shape file and associated attribute table which represents the drainage network within the watershed. This is prepared on the basis of three main factors: (1) a digitized stream network (optional), (2) the user-input subbasin drainage area, and (3) the topographic characteristics of the watershed. On the basis of these three factors, a synthetic drainage network is created, and later modeled in HSPF.

A digitized stream network was first imported to burn in the centerline of the Eel River stream network. This took the form of a polyline shape file, created on the various hydrography datasets, including the EPA RFV1 and RFV3 and USGS NHD, but mainly the higher resolution 1:24K MassGIS hydrography dataset. The stream network was defined as a drainage network between surface impoundments, running through the centerline of larger bodies of the system. Its function was to transform a heterogeneous network of water bodies into a system which could be discretized and modeled as individual subbasins and reaches using HSPF.

4.3.4 Subbasin Definition

A closely coupled step is the discretization of watershed subbasins, on the basis of drainage area. Through several attempts, a minimum drainage area of 125 ha was determined, which creates 13 subbasins within the watershed. This step is coupled with the creation of the drainage network, in that as drainage area per subbasin decreases, the stream network increases in the number and extent of reaches. As the drainage area is increased, the network becomes more focused until it converges on a limited reach size. These two factors were evaluated through a sensitivity analysis, to provide an optimal discretization of thirteen subbasins.

4.3.5 Outlet Selection

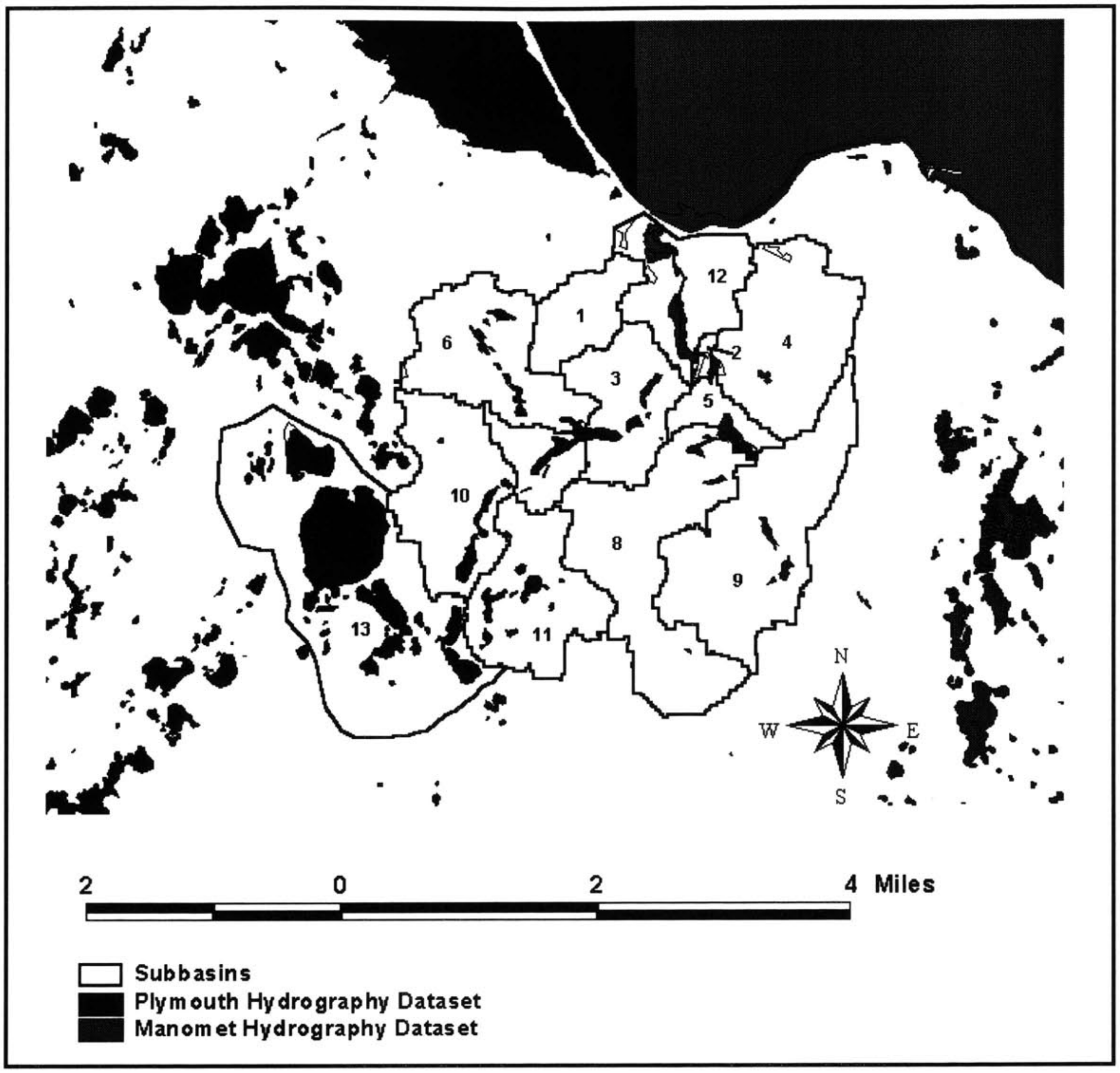
The final step in delineation was the selection of the main watershed outlet, which was chosen to coincide with the location of the USGS stream gauge. This would allow for uniform comparison during the calibration procedure.

4.4 Difficulties Encountered

Several problems were encountered during the delineation procedure. The first of these was the exclusion of the entire mouth of the ERW, including Eel River Pond, by the automatic delineation process. The likely explanation for this exclusion is the broad, flat surface of the Eel River prior to discharge at Plymouth Harbor. For this reason, it is believed that the automatic delineation tool set was unable to distinguish the Eel River from Plymouth Harbor, since both are at 0 mean sea level.

To fix this problem, the intermediate files, including the stream network shape file ("Streams" theme), outlet shape file ("Outlets" theme), subbasin shape file ("Subbasins" theme), and watershed shape file ("Watershed" theme), were modified, including the shape file and attribute table. The files were then imported directly via the "Predefined Delineation" toolset. Once this was successfully completed, the HSPF input file could be created from the delineated, discretized watershed (see Figure 9).

Figure 9: Watershed Delineation and Discretization

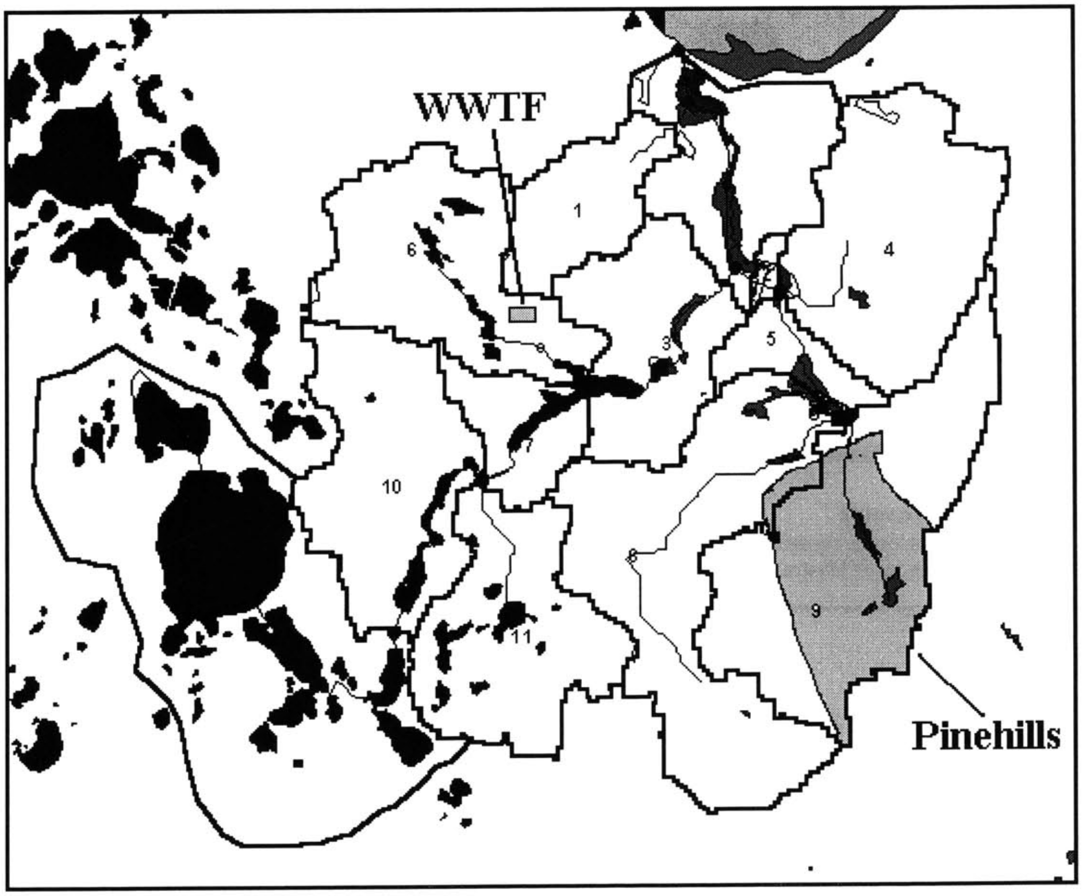


5.0 HSPF SURFACE WATER MODELING OF THE EEL RIVER WATERSHED

5.1 Modeling Goals

The overall goal of the HSPF surface water model was to provide an estimate of nutrient transport and loading under current baseline conditions, as well as under projected development scenarios. The development scenarios include the discharge of 1.25 MGD of wastewater treatment effluent from the new WWTF, as well as residential and recreational development in the Pinehills (see Figure 10 below).

Figure 10: WWTF and Pinehills Location Map



Due to physical data limitations, including limited field data on flow and water quality, as well as time constraints, the HSPF model was designed to be an assessment tool of large scale nutrient impacts, rather than a detailed description of specific nutrient fate and transport. For a detailed on the groundwater fate and transport of nitrate within the Eel River Watershed, please refer to Aahanin, 2002.

5.2 Conceptual Eel River Watershed Model Description

One of the most important phases in preparing a model to simulate watershed conditions is the recognition that it serves to simplify a complex system to focus on components of specific concern (Donigian and Huber, 1991). Thus, in order to recognize if the model is functioning correctly, it is important to determine the key watershed characteristics which will be retained during model discretization.

In the case of the ERW, several physical factors were considered as crucial components to represent during model preparation and calibration. These include: (1) the dominant groundwater flow (i.e., interflow and baseflow) component of the runoff; (2) the undeveloped nature of the watershed; (3) the high infiltration capacity and hydraulic conductivity of the underlying sand and gravel aquifer; (4) simplification of the spatially heterogeneous surface water system via reach discretization. Keeping these factors in mind, the HSPF model was prepared.

5.3 HSPF Model Description

5.3.1 BASINS 3.0 Input Files

As mentioned previously, one of the primary advantages of using BASINS 3.0 is the ease of HSPF model preparation. By using the delineation toolsets within BASINS, several intermediate files are created which WinHSPF uses to create the actual User Control Input (UCI) file which controls the HSPF model. The intermediate files created during the final step in the delineation process are as follows (please see Appendix A for the UCI file).

- **Watershed File (*.wsd)**: The watershed file contains information relating to the various land segments which contribute to each reach. Attributes included are land use name, pervious or impervious type, area, slope, and distance from the reach.
- **Reach File (*.rch)**: The reach file contains information for the stream network synthesized during the watershed delineation process, including the segment length, change in height, and linkage references to identify the upstream and downstream reaches.
- **Channel Geometry File (*.ptf):** The channel geometry file contains data related to the channel dimensions for each reach.

- **Point Sources File (*.psr)**: This file contains data related to point source dischargers in the watershed. This file was left null (U.S. EPA, 2001).

5.3.2 Precipitation Data

The BASINS system also allows access and retrieval of meteorological data for the HSPF watershed model, in the required *.WDM file format. Using the BASINS system, the MA.WDM file was retrieved. It contained meteorological data for the period January 1970 to December 1995 for eight weather stations in Massachusetts. The data include hourly measurements of precipitation, evaporation, temperature, wind speed, solar radiation, potential ET, dew point temperature, and cloud cover. It also provides aggregate daily statistics on maximum temperature, minimum temperature, wind speed, cloud cover, dew point temperature, solar radiation, ET, and evaporation.

Of the stations provided, the Bridgewater station was chosen because of its proximity to the Eel River Watershed. Although more localized data is available from alternate sources, the high-quality and extent of the data, as well as the time savings provided, were deemed sufficient to use the Bridgewater data. To estimate the error associated with using this data, an error / uncertainty analysis was performed, as discussed in Section 8.0 below.

5.3.3 WinHSPF Model Creation

Once the required UCI file was created, the HSPF model was run to simulate runoff within the period of record for the Bridgewater station. As created within the BASINS framework, the initial UCI file is limited, including only core modules which allow for basic simulation. During the modeling process, additional HSPF modules were added for increased functionality.

5.3.4 Initial Parameter Estimates

There are several sources for the initial parameter estimates in HSPF. The first is BASINS 3.0, which assesses watershed characteristics given the input files used. The second is a set of default values for which physical measurement is generally not possible or feasible. The third are calculations of physical parameters, performed by the user. Parameter estimation was guided by the results of prior studies (Munson, 1998; Socolofsky, 1997; U.S. EPA 2000; U.S. EPA, 1999; Lumb et al., 1994).

5.4 Hydrologic Model Calibration

Model calibration entails comparing modeled versus actual response for a key parameter over a discrete time period. For the purposes of this research, the main parameter of concern was considered to be the outflow at the end of RCH12, since a stream gauge (USGS Stream Gauge #01105876) was located in this location for the time period of 1970-1971 (see Figure 5). This provides a means to evaluate the degree to which the modeled system is representing actual watershed response. It should be noted that the field studies by CDM provided some estimates of streamflow at discrete locations within the watershed for the period from 1998-2000. These measurements were used for model validation purposes, as discussed in Section 5.5.

Model calibration in HSPF is a lengthy and often difficult task, due to the high degree of parameterization within the model. Fortunately, a large body of literature exists to aid in calibration (U.S. EPA 2000; U.S. EPA, 1999, Lumb et al., 1994). As described below, calibration proceeded at different temporal levels until a satisfactory hydrograph response was obtained. The USEPA program GenSCN, a time-series viewing and analysis tool, was used to increase productivity during the calibration procedure. Finally, during the procedure, every effort was made to stay true to the conceptual model of the watershed (see Section 5.2 above).

5.4.1 Annual (Water Budget) Calibration

The calibration procedure typically begins with assessment of annual average flow. Essentially, this ensures that the long-term requirements of the water balance are being met, as described by the following equation:

$$\frac{dS}{dt} = PA - EA - R$$

where,

S = Storage [L^3]

t = Time [T]

P = Precipitation [L/T]

E = Evaporation [L/T]

R = Runoff [L^3/T]

A = Area [L^2]

For a long-term steady-state condition, $\frac{dS}{dt}$ is assumed to equal zero, a reasonable assumption given the nature of the aquifer. The effects of aquifer pumping and surface diversions are also assumed negligible for the ERW due to the low extent of development. This provides a simplified form, where the input precipitation is equal to losses from evapotransporation and runoff. Thus, terms which affect the quantity of the E and R terms, are modified in the annual calibration process (Socolofsky, 1997).

The four main parameters which affect the magnitude of E and R include lower zone nominal storage (LZSN), upper zone nominal storage (UZSN), the infiltration rate of the soil (INFILT), and finally, the lower zone evapotranspiration parameter (LZETP). UZSN is the volume of water, in inches, which accumulates in surface depressions, such as cracks and puddles, and does not produce runoff. From this surface storage, the water either evaporates or infiltrates into the soil, depending on the relative "strength" of these processes. LZSN, measured in inches, can be considered a measure of the storage capacity of the lower subsurface zone (Bicknell et al, 2000).

LZETP is a unitless parameter which defines the potential for ET in the lower zone, similar to a crop coefficient. Calibration of this parameter affects the volume of water transferred to ET from the subsurface to the atmosphere. Finally, INFILT, measured in inches, quantifies the rate of transfer from surface storage into the subsurface. Modification of this parameter affects the transfer of precipitation input into runoff versus groundwater storage, effectively dampening the hydrograph response at higher values (Bicknell et al, 2000).

All four parameters were initially given default values by HSPF. These parameters were modified using a range of appropriate values determined through a literature review until an optimal hydrograph response was obtained. The exception to this is INFILT, which was modified beyond the range of literature values based on daily hydrograph response, not on average annual flow (Lumb et al, 1994; U.S. EPA, 1999).

During the remaining calibration steps, it was found that both the seasonal and daily storm modeled hydrographs showed significantly greater fluctuation than the observed hydrograph, translating into an insufficient baseflow component. Conceptually, the ERW is groundwater-dominated due to the high infiltrative capacity of the underlying sand and gravel aquifer. However, using literature values provided an insufficient response in the higher discretion time scales. Therefore, a site specific value was obtained using estimates of hydraulic conductivity in the watershed (Hansen and Lapham, 1992). From this range of conductivity estimates, an optimal value of 60 inches/hour was obtained, which best represents conditions in the aquifer.

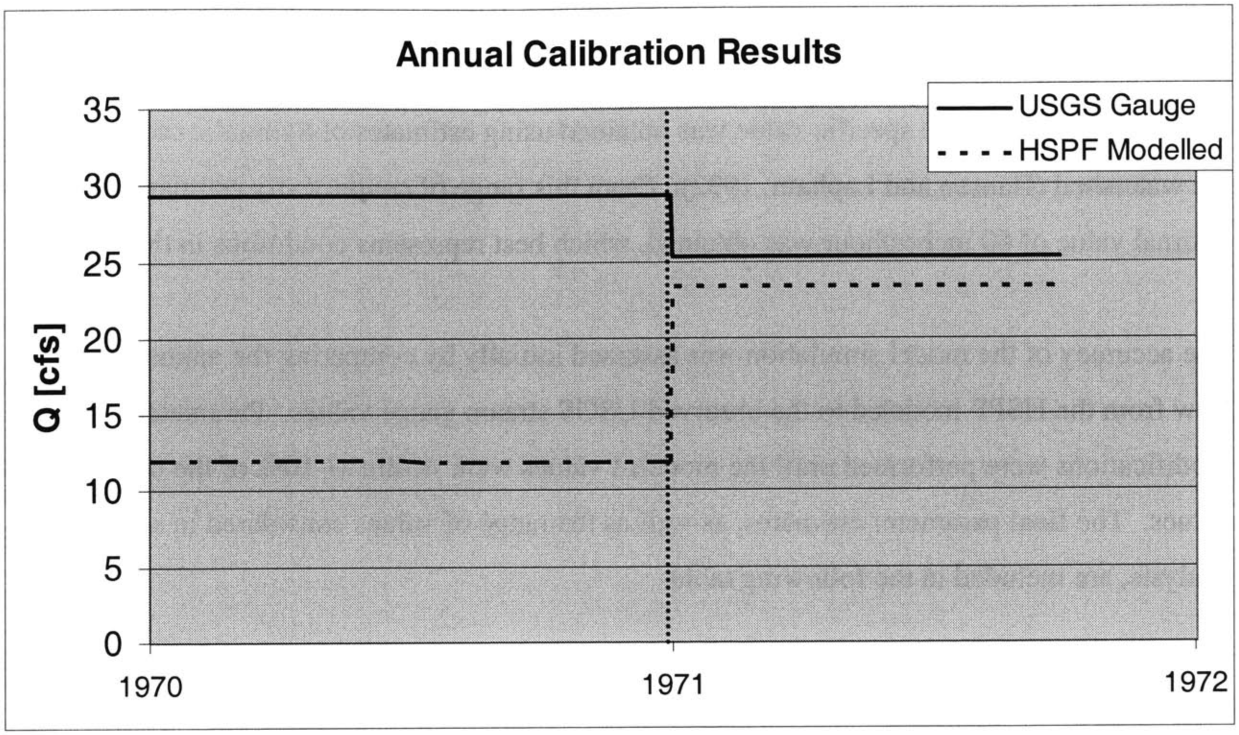
The accuracy of the model simulation was assessed initially by comparing the annual average flow from the HSPF modeled to the observed USGS stream gauge values. Parameter modifications were performed until the modeled values were within +/-10% of the observed values. The final parameter estimates, as well as the range of values considered in sensitivity analysis, are included in the following table

Table 7: HSPF Annual Calibration Parameter Estimates

Parameter	**Optimal Value**	**Range of Values Evaluated During Calibration**
UZSN	7 inches	0.1-7
INFILT	60 inches / hour	0.2-75
LZSN	2 inches	0.05-100
LZETP	0.1 [Unitless]	0.1-0.9

The resultant annual average outflow at the location of the USGS stream gauge is depicted below. The results show generally good agreement for the calendar year 1971. However, the initial year, 1970 shows a dramatic divergence. This is likely caused by the equilibration period of the model itself, during which water is transferred between various compartments until the system is in synch. Various authors suggest an initial start-up period of several years to avoid the effects of this initial equilibration period. However, due to data restraints, this was not possible for the study performed (Lumb et al, 1994; U.S. EPA, 1999).

Figure 11: Annual Calibration Results



5.4.2 Seasonal Calibration

Once the magnitude of the runoff has been calibrated on an annual basis, its timing is considered. The main physical processes which are modified to affect runoff timing include snow accumulation and melt, as well as the rate of groundwater recession. Snow accumulation and melt affects the seasonal timing of the runoff in spring, once air temperatures rise sufficiently to melt snow pack. Groundwater recession works to modify the rate at which runoff decreases, or recedes, subsequent to a peak storm flow. This has the greatest effect on the magnitude of summer baseflow (Bicknell, 2000; Socolofsky, 1997).

Sophisticated algorithms are present within HSPF to model the runoff timing response, with several key, driving variables. These variables are summarized in Table 8.

Table 8: HSPF Seasonal Parameter Descriptions

SEASONAL PARAMETER	DESCRIPTION
AGWRC	Groundwater recession rate
KVARY	Exponent in groundwater recession rate equation
SHADE	Fraction of land surface shaded from solar radiation
TSNOW	Threshold temperature for snow to form as precipitation
SNOWCF	Snow gauge multiplication factor
COVIND	Snow depth at which entire land surface is covered with snow
SNOEVP	Parameter to adjust calculated snow evaporation rate to field conditions
CCFACT	Parameter to adjust calculated snow condensation and convection melt equations to field conditions

Similar to the procedure for annual calibration, the default HSPF values were modified based on literature-obtained values. Additional sensitivity analysis was performed to determine the effects of individual and conjunctive parameter modification. The range of parameters considered, as well as final estimates, is summarized below.

Table 9: HSPF Seasonal Parameter Estimates

Parameter	Optimal Value	Range of Values Evaluated During Calibration
AGWRC	0.994/day	0.01-1
KVARY	0	0-5
SHADE	Variable (0.1-0.5) based on LU	0.1-1
TSNOW	32 °F	25-37
SNOWCF	1.2	0.5-4.0
COVIND	10	0.1-10
SNOEVP	0.1	0.1-0.5
CCFACT	1	0.1-1

Various combinations of the parameters, within the ranges stated above, were performed until an optimal response was obtained. The basis of this optimal response was obtaining a modeled value within 10% of the measured USGS stream gauge value, which was actually achieved in two phases.

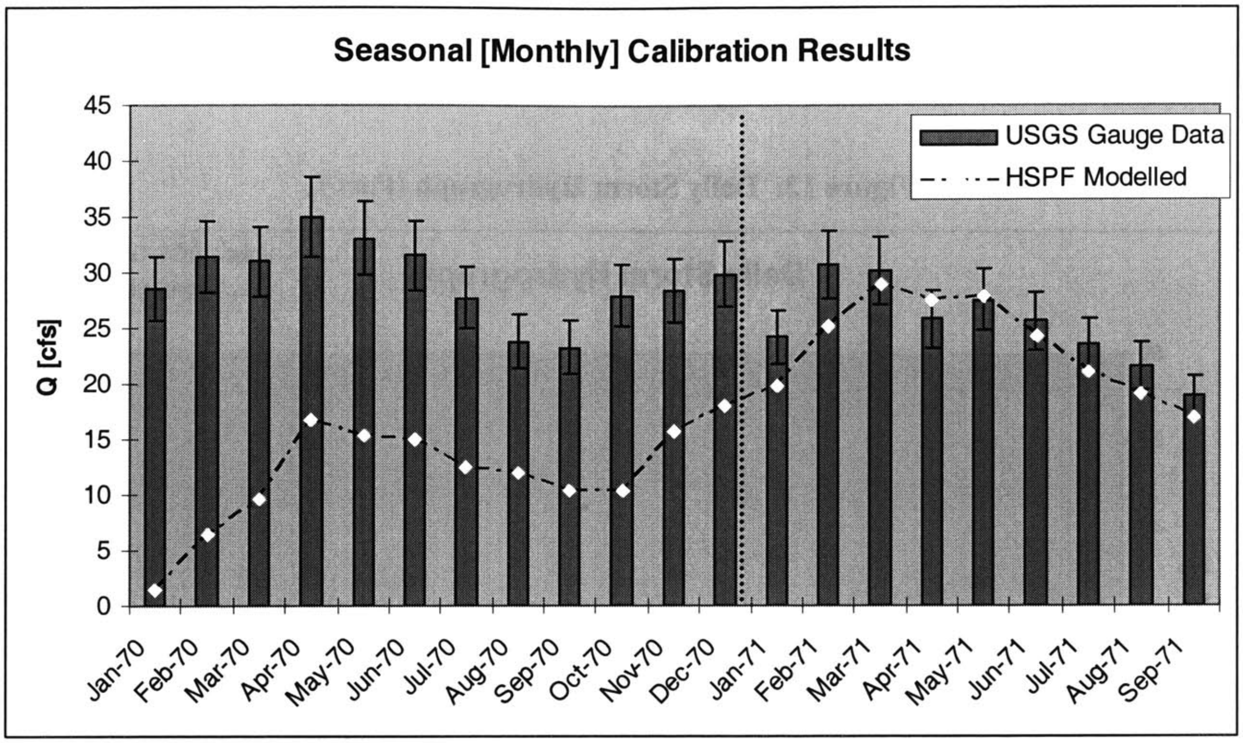
During the calibration sequence, the percent of pervious land surface within the watershed was initially underestimated. The initial % perviousness for each land use was estimated using the runoff coefficient as:

$$\% Pervious = (1 - R_{coeff})$$

where R_{coeff} is the runoff coefficient. This underestimation translated into an increase in the timing and magnitude of storm versus base flow, which appeared in the seasonal calibration as overestimation of peak spring flow and underestimation of summer baseflow. The error was determined and impervious land surface was modified to include transportation and industrial land uses only.

After modifying the pervious land surface percentage, the calibration results were quite favorable. The exception to the 10% criteria, however, was the initial equilibration period (~1 year), where a generally poor match was obtained for the reasons discussed previously. For the second year of record, 1971, a quite good match was obtained, as seen in Figure 12 below.

Figure 12: Seasonal [Monthly] Calibration Results



5.4.3 Daily Storm Calibration

The final, most discrete time-scale of calibration, is the daily storm hydrograph. The period of record considered was from January 1, 1971 to September 9, 1971. As the name implies, this stage of calibration is concerned with matching daily storm response. In terms of nutrient transport modeling, this time scale has a large impact on the wash-off response of the nutrients.

The main parameters controlling the shape of the individual storm hydrographs are the groundwater recession parameters, AGWRC (discussed in Section 5.4.2 above), and the interflow parameters, INTFW and IRC. INTFW is the interflow parameter and works as a control which divides water which reaches the land surface between interflow and surface runoff. IRC is the exponential interflow recession rate parameter (Bicknell, 2000; U.S. EPA, 1999). These parameters were set at 10 and 0.5/day, respectively.

Calibration proceeded initially via modification of the percent pervious land surface. Once the percent perviousness modification was performed, results improved significantly. However, modeled peak flow was still slightly higher than observed and summer baseflow lower than observed flow. This was corrected by adjusting the AGWRC to a value of 0.994/day. Once this modification was made, both INTFW and IRC were left constant, as the results seemed acceptable, and these parameters were within the expected range (U.S. EPA, 1999).

Figure 13: Daily Storm Hydrograph (Part I)

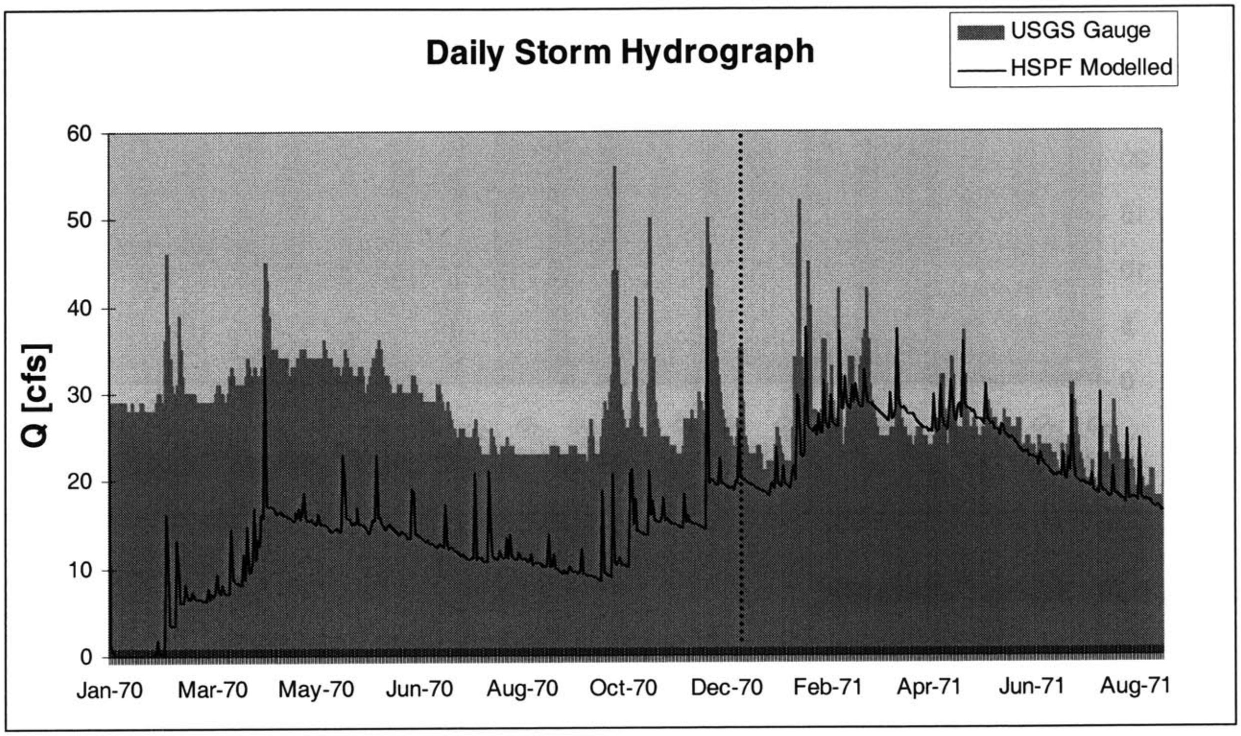
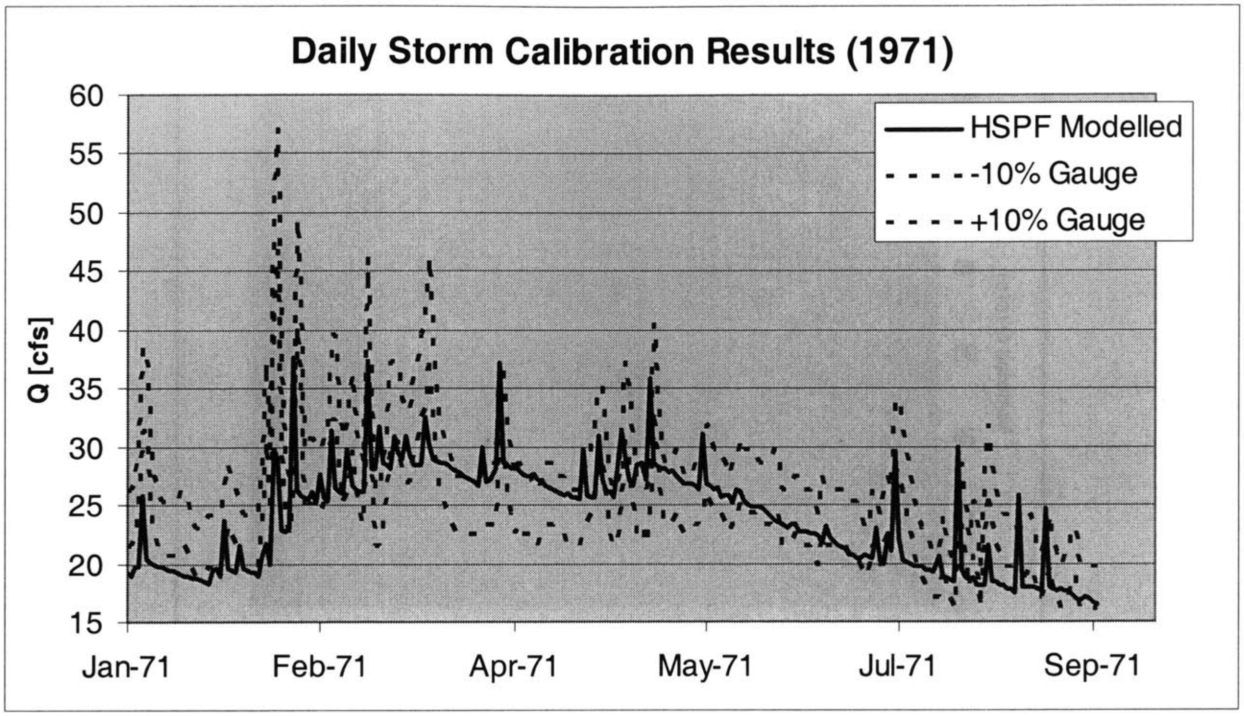
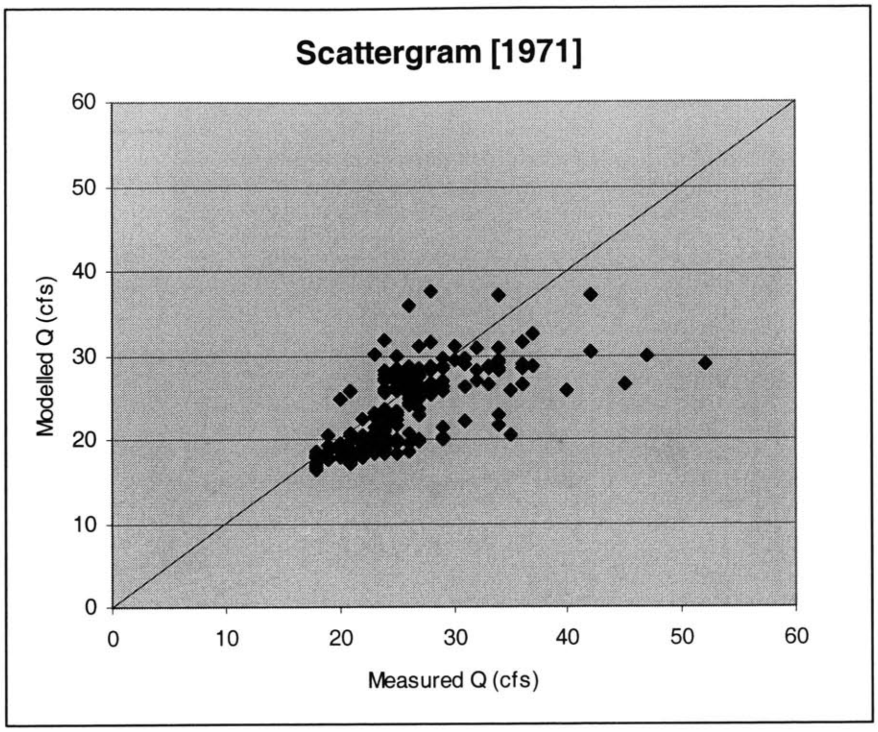


Figure 14: Daily Storm Hydrograph (Part II)



In order to evaluate the goodness of the modeled fit, several statistical analyses were performed. As mentioned above, the initial 1970 period is considered to represent a model equilibration period and therefore and removed from further analysis. This leaves the 1971 period for further discussion. The first step is visual inspection, as depicted in Figure 14 above, but also through the use of a scattergram of modeled versus measured values (see Figure 15 below) (Yeh and Mock, 1996). Visually, the scattergram indicates generally low levels of bias, in that values are clustered around the 45° line, with the majority of values between 20 and 30 cfs, as expected. Model bias is evidenced mainly in severe storm events, where modeled flow underestimates observed values.

Figure 15: Scattergram of Streamflow Modeling



Several statistical indicators of model error were also calculated to determine the accuracy of the model. The first is mean error, which provides an estimate of the model bias, as well as error magnitude to a lesser extent. Also calculated are mean absolute error and root mean square error, which provide better estimates of the magnitude of the error (Hahn, 1977). The results are indicated in Table 10 below.

Table 10: Hydrologic Model Accuracy Statistics

Sum (RESIDUALS) [cfs]	-481.40	Sum ABS(RES) [cfs]	816.6	SSE $[cfs]^2$	5045.96
Mean Error [cfs]	-1.918	Mean Abs. Error [cfs]	3.25	MSE $[cfs]^2$	20.10
				RMSE [cfs]	4.48

The results corroborate the visual assessment of the scattergram. The mean error indicates that there is an average underestimation by the model on the order of 1.9 cfs. The mean absolute error and root mean square error indicate that the total error ranges from approximately 3.3 to 4.5 cfs, depending on the measure of accuracy. This translates into 12-17% of total flow, based on the long-term annual average.

5.5 Hydrologic Modeling Results Verification

Typically, once a model has been hydrologically calibrated, it is verified using an additional period of recorded streamflow. For the Eel River Watershed, there is only one continuous period of record available, 1970-1971, which was used for calibration. Semi-monthly measurements, performed by CDM, are available for an additional period of record from May 1998 to February 2000 at several locations, including the location of the USGS stream gauge (see Table 3 above), but not on a continuous basis. Additionally, detailed precipitation data was not available for the 1998-2000 period. Therefore, a modified approach was used for model verification.

5.5.1 Long-Term Annual Runoff Trends

The long-term annual runoff trend was used as a verification tool for the calibrated HSPF model. Two important factors support this type of evaluation, including:

- The lack of significant change (i.e., development) within the watershed during this period;
- The runoff response of the Eel River is noted to be relatively constant for two distant, unique periods of record: 1970-1971 and 1998-2000, corresponding to 28 and 27 cfs, respectively (Hansen and Lapham, 1992; TAC, 2000).

Therefore, the long-term response of the model was determined by performing a model run for the entire period of record, from 1970-1995. The results indicated a long-term average flow of approximately 23 cfs. However, a period of exceptional precipitation was noted in the early 1980's. After removing this period, an average value of approximately 26 cfs was reported. This value is within 10% of the observed streamflow, considered an adequate model response, as seen in Table 11 below (Lumb, 1994).

Table 11: Long-Term Modeled Runoff Response

Stream Flow Measurement	Q [cfs]	Range of Q [cfs]	Period of Record / Model Period	Within USGS Range of Q?	Within CDM Range of Q?
Long-Term HSPF Modeled Response (w/ Drought Period)	23.4	N/A	1970-1995	No	No
Long-Term HSPF Modeled Response (w/o Drought Period)	25.6	N/A	1970-1995	Yes	Yes
USGS	28.0	[25.2-30.8]	1970-1971	Yes	Yes
CDM	26.6	[23.9-29.3]	1998-2000	Yes	Yes

Thus, as can be seen, a satisfactory response is obtained when removing the effects of extraordinary periods of precipitation (i.e., 1980-1983), whose effects are not represented within the limited periods of record measured by both CDM and the USGS.

5.5.2 Runoff Coefficient / Error Determination

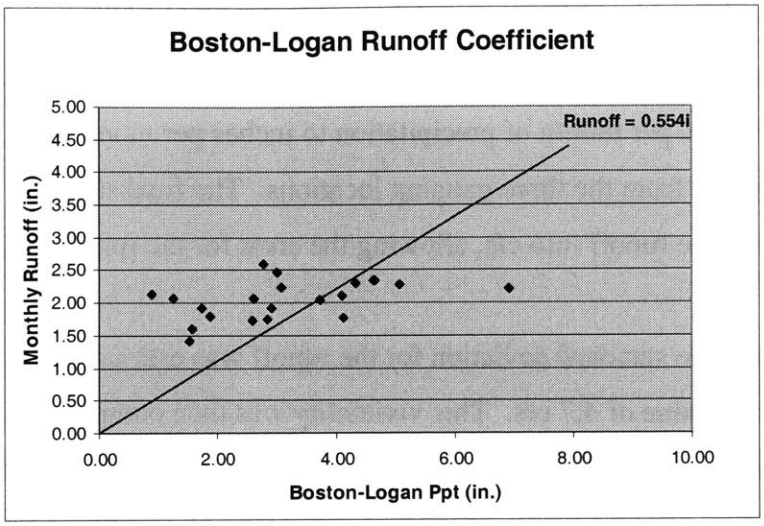
An alternate method for verifying the results of the HSPF calibration is through quantifying the variability in the precipitation input, which is the driving force for the modeled runoff. To reiterate, the precipitation record used is from a meteorological station in Bridgewater, MA, located roughly 20 miles from the Eel River Watershed. Thus there are two potential sources for input variability: (1) using a point location estimate to represent a spatially variable parameter, and (2) spatial variability in atmospheric conditions between Bridgewater, MA and Plymouth, MA.

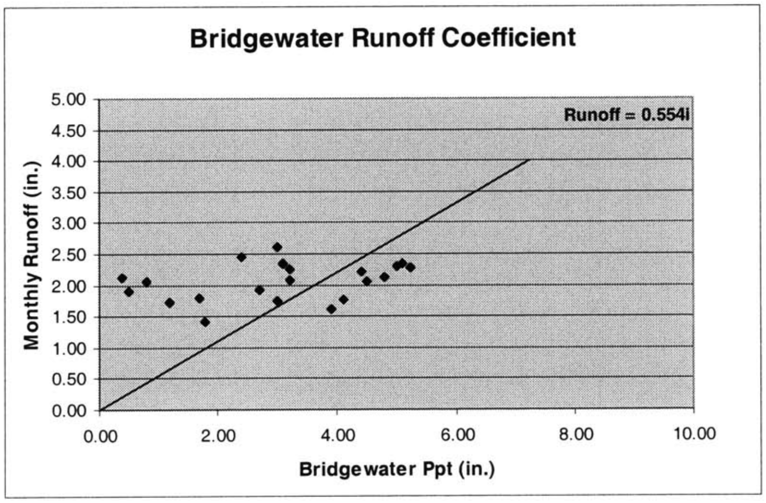
To assess the magnitude of these effects, additional data was obtained from other first order meteorological stations in the region, and a statistical comparison was performed. The stations used in this analysis, and approximate distances, include Bridgewater, (~20 miles W), Boston Logan International (~40 miles NW), and New Bedford (~30 miles SW).

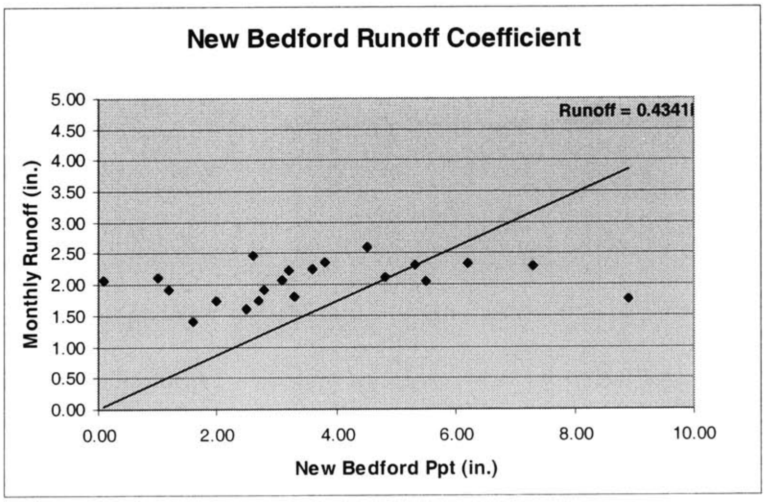
The first step in the analysis was the calculation of runoff coefficients for each of the meteorological stations. The resultant values of 0.554 for both Boston-Logan and Bridgewater and 0.434 for New Bridgewater (see Figure 16 below) were obtained. Descriptive statistics, including mean, minimum, maximum, variance, and standard deviation were then calculated on a monthly basis for precipitation at each of the three stations. The standard deviation was transformed from inches per month of precipitation to inches per month of runoff using the mean runoff coefficient value from the three gauging locations. The final step was changing the standard deviation of the runoff into cfs, allowing the error for the runoff to be estimated.

Using this technique, the standard deviation for the runoff was estimated to range from 2.0 to 10.3 cfs, with a mean value of 4.7 cfs. This variability was then compared to both the monthly and daily modeled streamflow for 1971. The results are quite favorable, with the exception of the initial equilibration period (1970). Excluding this time period, 89% and 80% of the modeled flow values fall within the error range for monthly and daily flows, respectively.

Figure 16: Runoff Coefficient Calculation


Boston-Logan Runoff Coefficient


Bridgewater Runoff Coefficient


New Bedford Runoff Coefficient

5.6 Hydrologic Modeling Error Analysis

In order to understand possible reasons for the discrepancies between modeled and observed values, potential sources of error were determined, as follows.

Stream Gauge: The stated accuracy of the U.S. Geological Survey's streamflow measurement gauges is +/- 5% (USGS, 2002). Based on a long-term average annual flow of 26.6 to 28 cfs, (CDM 2000; USGS Stream Gauge #01105876) this translates into a mean streamflow error of approximately 1.3-1.4 cfs.

Precipitation Data Input: As detailed in Section 5.5.2 above, precipitation estimates were obtained from three first order meteorological stations in the area of the ERW. Statistical analyses were performed to determine the standard deviation of monthly rainfall between the three gauges, and translated into runoff using the calculated runoff coefficient. The results indicated a standard deviation of 4.7 cfs for streamflow; based on the average flow, the maximum potential error caused by precipitation data is approximately 17%.

GIS Datalayers: Although difficult to quantify, the potential for data errors within the GIS datasets exists. Although detailed error estimates are not available for the most important data used, including USGS DEMs, MassGIS Hydrography and Land Use datasets, an upper bound can be determined based on the cell size. Since 1:24K-1:25K data were used for these purposes, the associated upper bound is estimated at the grid cell size, which is 30m.

6.0 NUTRIENT LOAD ASSESSMENT

The next step after completing the hydrologic model calibration was the assessment of nutrient loading and transport. Two elements were considered vital to the success of this phase:

- Accurate modeling of daily storm flow hydrographs, which serves as the driving force of nutrient transport. Performance of this step is described in Section 5.4.3.
- Assessing nutrient loads based on land use within the ERW (described in Section 6.3 below).

Once these steps were performed, the HSPF algorithms simulating nutrient buildup and washoff were integrated with the calibrated hydrologic model.

6.1 Non Point Source Nutrient Loading Factors

The determination of accurate nutrient load estimates rests on obtaining representative and site-specific values. Loading estimates are based on associating a certain mass of the constituent of concern (e.g., nutrients, pesticides, bacteria) with an aggregate land use characteristic (Reckhow et al., 1980; U.S. EPA, 1999).

In order to assess nonpoint nutrient impacts associated with the Eel River Watershed, nutrient loads were determined upon the basis of land use, as obtained from MassGIS (MassGIS). An extensive body of literature is available on representative nitrogen and phosphorous loading factors. When reviewing this literature, climate and soil type are considered critical screening factors. Using these factors, a likely range of values can be determined. From this range, a most likely loading factor is estimated (Reckhow et al., 1980). The results are described in Tables 12 and 13 below. Also included in the table for comparison purposes are previously reported loading factors for the Eel River Watershed (TAC, 2000).

Table 12: Non Point Source / Land Use Based Total Nitrogen Loading Factors

Land Use Type	N-Loading Rate[1] (kg/ha-yr)	Most Likely N-Loading Rate[2] (kg/ha-yr)	Range	[2,3]N-Loading Reference
Commercial	15.1	10	20.5	Comm., shopping center, MI [Landon, 1977]
			4	Comm., lt. Industry and business, MI. [Landon, 1977]
			9.97	Residential & lt. Commercial, Cincinnati, Ohio. [Weibel et al, 1964]
			[4-20.5]	
Cropland	8.5	4	3.96	Corn, Lancaster, WI. [Minshall et al. (1970)]
			7.97	Corn, Lancaster, WI. [Minshall et al. (1970)]
			3.38	Corn, Lancaster, WI. [Minshall et al. (1970)]
			2.88	Corn, Lancaster, WI. [Minshall et al. (1970)]
			4.33	Corn, WI. [Hensler et al. (1970)]
			15.25	Corn, WI. [Hensler et al. (1970)]
			4.22	Corn, WI. [Hensler et al. (1970)]
			3.88	Corn, WI. [Hensler et al. (1970)]
			3.7	Tobacco and corn, MD, sandy loam. [Correll et al, 1977]
			[3.7-15.25]	
Forest	0.57	3	6.26	75-100 yr. Old jack pine & black spruce w/ birch & aspen, Ontario, Canada [Schindler et al. , 1976]
			2.37	Jack pine-black spruce, sandy loam, Ontario, CA [Nicholson, 1977]
			1.38	Jack pine-black spruce, sandy loam, Ontario, CA [Nicholson, 1977]
			N/A	Mixed deciduous forests, sandy soils, igneous formation. [Dillon and Kirchner, 1975]
			4.01	Maple, birch, and beech, Hubbard Brook Exp. Forest, NH. [Likens et al, 1977]
			2.82	Deciduous hardwood and pine, 85.4-92.8 cm/yr ppt., Conshocton, OH. [Taylor et al., 1971]
			[1.38-6.26]	
Industrial	15.1	10	[4-20.5]	Classify with commercial/industrial.
Low Density Residential	9.5	4	5	Madison, WI. Kluesener and Lee (1974)
			1.52	Low density res, large lots, MI. [Landon, 1977]
			6.9	Low density res., grassed areas, small lots, MI. [Landon, 1977]
			[1.52-6.9]	
Medium Density Residential	9.5	4	5	Madison, WI. Kluesener and Lee (1974)
			1.52	Low density res, large lots, MI. [Landon, 1977]
			6.9	Low density res., grassed areas, small lots, MI. [Landon, 1977]
			4.8	High density res., townhouse complex, MI. [Landon, 1977]
			[1.52-6.9]	
Mining	14.8	10	[4-20.5]	
Multifamily Residential	9.5	4	5	Madison, WI. Kluesener and Lee (1974)
			1.52	Low density res, large lots, MI. [Landon, 1977]
			6.9	Low density res., grassed areas, small lots, MI. [Landon, 1977]
			4.8	High density res., townhouse complex, MI. [Landon, 1977]
			[1.52-6.9]	
Nonforested Wetland	3	3	[1.38-6.26]	Classify with "Forest" [see above]
Open Areas with no vegetation	0.57	10	[4-20.5]	Classify with commercial/industrial.
Participation Recreation	38	50	176.77	Pinehills draft permit, golf course = 3.5 lb N/1000sf/yr
			45.46	Pinehills draft permit, lawn area = 3.5 lb N/1000sf/yr
			79.6	Max. values for row crops [EPA 440/5-80-011]
			13.5	Kunimatsu, et al. 1999.
			[13.5-177]	
Pasture	5	20	30.85	Winter grazed/summer rotational, Coshocton, OH. [Chichester et al, 1979]
			13	Cont. grazing, supp. winter feeding, MD. [Correll et al., 1977]
			[13-30.85]	
Saltwater Wetland	3	3	[1.38-6.26]	Classify with "Forest" [see above]
Transportation	15	10	[4-20.5]	Classify with commercial/industrial.
Urban Open	5	10	[4-20.5]	Classify with commercial/industrial.
Water	11.1	6.54	N/A	P from Forest Atmospheric Inputs, Finger Lakes
Water Based Recreation	11.1	6.54	N/A	Area, NY; N from Hubbard Brook Exp. Forest, NH
Woody Perennial	23	10	[1.38-6.26]	Classify with "Forest" [see above]

NOTES: [1]Using loading rates from TAC Report (January 2000) for consistency in comparison.

Table 13: Non Point Source / Land Use Based Total Phosphorous Loading Factors

Land Use Type	Most Likely P-Loading Rate[3] (kg/ha·yr)	Range	[2,3]N- & P- Loading Reference
Commercial	1	1.7	Comm., shopping center, MI [Landon, 1977]
		0.66	Comm., lt. Industry and business, MI. [Landon, 1977]
		N/A	Residential & lt. Commercial, Cincinnati, Ohio. [Weibel et al, 1964]
		[0.66-1.7]	
Cropland	1.4	1.22	Corn, Lancaster, WI. [Minshall et al. (1970)]
		2	Corn, Lancaster, WI. [Minshall et al. (1970)]
		0.75	Corn, Lancaster, WI. [Minshall et al. (1970)]
		0.95	Corn, Lancaster, WI. [Minshall et al. (1970)]
		1.3	Corn, WI. [Hensler et al. (1970)]
		3.4	Corn, WI. [Hensler et al. (1970)]
		0.81	Corn, WI. [Hensler et al. (1970)]
		0.94	Corn, WI. [Hensler et al. (1970)]
		1.4	Tobacco and corn, MD, sandy loam. [Correll et al, 1977]
		[0.75-3.4]	
Forest	0.03	0.309	75-100 yr. Old jack pine & black spruce w/ birch & aspen, Ontario, Canada [Schindler et al. , 1976]
		0.06	Jack pine-black spruce, sandy loam, Ontario, CA [Nicholson, 1977]
		0.036	Jack pine-black spruce, sandy loam, Ontario, CA [Nicholson, 1977]
		0.047	Mixed deciduous forests, sandy soils, igneous formation. [Dillon and Kirchner, 1975]
		0.019	Maple, birch, and beech, Hubbard Brook Exp. Forest, NH. [Likens et al, 1977]
		0.035	Deciduous hardwood and pine, 85.4-92.8 cm/yr ppt., Conshocton, OH. [Taylor et al., 1971]
		[0.019-0.309]	
Industrial	1	[0.66-1.7]	Classify with commercial/industrial.
Low Density Residential	1	1.1	Madison, WI. Kluesener and Lee (1974)
		0.19	Low density res, large lots, MI. [Landon, 1977]
		2.7	Low density res., grassed areas, small lots, MI. [Landon, 1977]
		[0.19-2.7]	
Medium Density Residential	1	1.1	Madison, WI. Kluesener and Lee (1974)
		0.19	Low density res, large lots, MI. [Landon, 1977]
		2.7	Low density res., grassed areas, small lots, MI. [Landon, 1977]
		1.1	High density res., townhouse complex, MI. [Landon, 1977]
		[0.19-2.7]	
Mining	1	[0.66-1.7]	Classify with commercial/industrial.
Multifamily Residential	1	1.1	Madison, WI. Kluesener and Lee (1974)
		0.19	Low density res, large lots, MI. [Landon, 1977]
		2.7	Low density res., grassed areas, small lots, MI. [Landon, 1977]
		1.1	High density res., townhouse complex, MI. [Landon, 1977]
		[0.19-2.7]	
Nonforested Wetland	0.03	[1.38-6.26]	Classify with "Forest" [see above]
Open Areas with no vegetation	1	[0.66-1.7]	Classify with commercial/industrial.
Participation Recreation	18.6	N/A	Pinehills draft permit, golf course = 3.5 lb N/1000sf/yr
		N/A	Pinehills draft permit, lawn area = 3.5 lb N/1000sf/yr
		18.6	Max. values for row crops [EPA 440/5-80-011]
		30.4	Kunimatsu, et al. 1999.
		[18.6-30.4]	
Pasture	3.7	3.6	Winter grazed/summer rotational, Coshocton, OH. [Chichester et al, 1979]
		3.8	Cont. grazing, supp. winter feeding, MD. [Correll et al., 1977]
		[3.6-3.8]	
Saltwater Wetland	0.03	[1.38-6.26]	Classify with "Forest" [see above]
Transportation	1	[0.66-1.7]	Classify with commercial/industrial.
Urban Open	1	[0.66-1.7]	Classify with commercial/industrial.
Water	0.181	N/A	P from Forest Atmospheric Inputs, Finger
Water Based Recreation	0.181	N/A	Lakes Area, NY; N from Hubbard Brook Exp.
Woody Perennial	1	[1.38-6.26]	Classify with "Forest" [see above]

6.2 Development-Related Nutrient Loads

Using site-specific data for the ERW, development-related nutrient loads were also determined for the following sources:

- **WWTF, Final Capacity**: The WWTF at its final permitted discharge from the infiltration beds of 1.25 MGD, with a maximum permitted total nitrogen concentration of 10 mg/L (TAC, 2000; WWTF Permit).
- **Pinehills**: A planned retirement community lying partially within the Eel River Watershed. A maximum total nitrogen load of 7,416 lb/year was obtained from the Pinehills Groundwater Discharge Permit. Although the maximum load is noted here, in subsequent analysis, an incremental load, compared to current conditions, was used.

The locations of these nutrient sources are included in Figure 17 below. The results of this loading assessment are summarized below, in order of decreasing load. It should be noted that an attenuation factor of 25% for total nitrogen was based on a prior Cape Cod study regarding nitrogen attenuation (DeSimone and Howes, 1998), as well as site-specific data previously obtained by CDM (CDM, 2000).

Figure 17: Additional Nutrient Discharge Locations

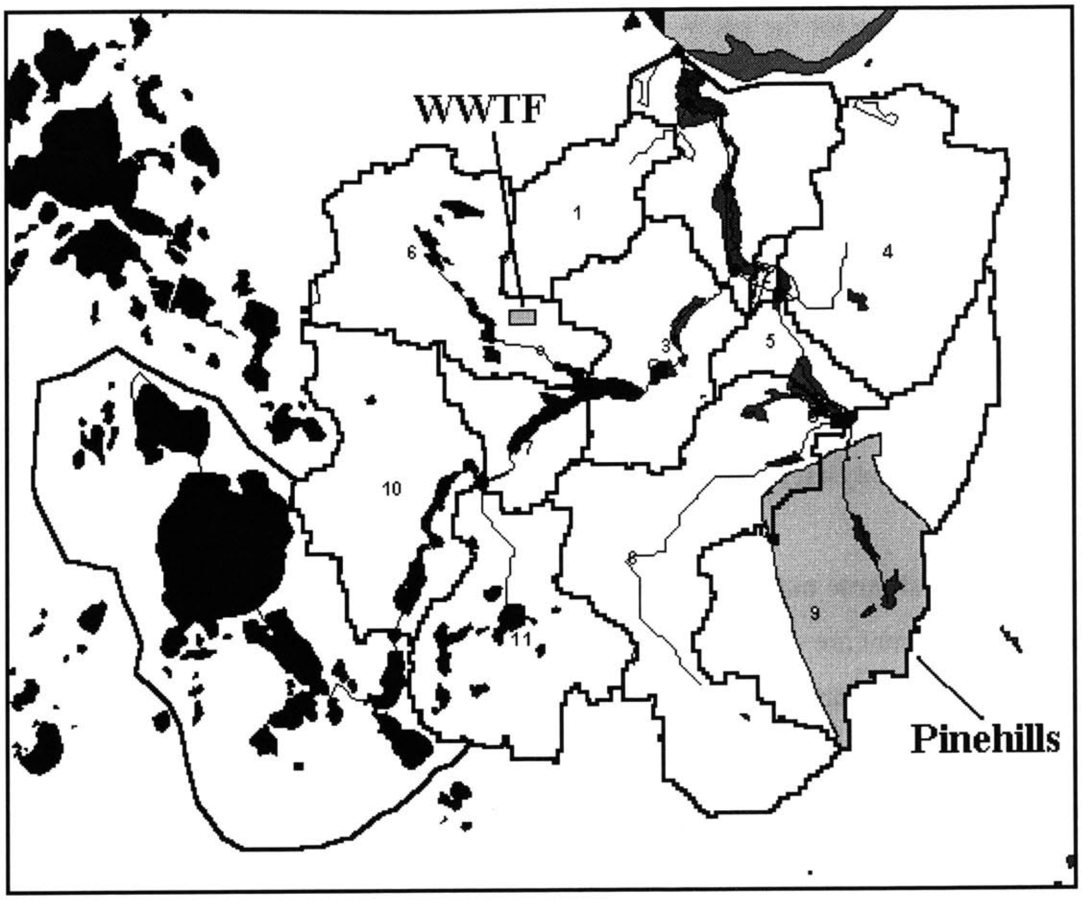


Table 14: Development-Related Total N&P Loads

Source	Loading Estimate (kg/yr)	Loading Rate (kg/yr)	Gross P Loading Rate (kg/yr)	Attenuated N Load (kg/yr)[6]	Attenuated P Load (kg/yr)[7]
Pine Hills	7,543	3,371[1]	1,339[2]	**2,528**	**543**
WWTF @ 1.25 MGD	5,858	17,306[3]	17,318[4]	**12,980**	7,023
			3,586[5]		1,454
				Range:	[1,454-7,023]
				Expected:	**2,000**

NOTES:

[1] Based on PineHills Groundwater Discharge Permit maximum load.

[2] Assume P loading ~ Forges Field; P Load=18.6kg/ha [see Most Likely Loading Scenarios]

[3] N = 10 mg/L based on permit limitations.

[4] P = 10 mg/L based on secondary treatment effluent. [EPA 841-B-99-007, USEPA 1999]

[5] Based on P Removal Treatment Type. [Reckhow, 1980. EPA 440/5-80-011]

[6] Assume % Attenuation-N = 25%

[7] Assume % Attenuation-P = 59%

6.3 Results of Nutrient Loading Calculations

The nutrient loading calculations indicate the potential for a dramatic increase in both nitrogen and phosphorous loads to the Eel River Watershed, driven primarily by the presence of the WWTF. The results for the three major drainage basins are summarized below, following a discussion of baseline conditions.

6.3.1 Baseline Nutrient Loading

In order to assess baseline nutrient loading conditions, the watershed was again divided into three major drainage basins: the East Branch, the West Branch, and the mouth of the Eel River. Using the land use distribution previously determined, coupled with the loading factors, a range of nutrient load estimates were determined for each of the drainage basins. Also calculated were median loads, using EPA-determined median loading factors, as well as the most-likely annual load. Finally, a previously reported value by CDM is included (TAC, 2000). Attenuation factors of 30% and 60% for total nitrogen and total phosphorous, respectively, were obtained from prior studies (DeSimone and Howes, 1998; CDM, 2000). The results of the baseline nutrient load are depicted in Tables 15 and 16 below.

Table 15: Nitrogen Baseline Loading

	Most Likely Annual N Load (kg/yr)	Min. Annual N Load (kg/yr)	Max. Annual N Load (kg/yr)	Median Annual N-Load (kg/yr)	CDM-Values Annual N Load (kg/yr)	Annual N Load based on CDM Measured Conc. (kg/yr)
Mouth	2692	993	7344	1385	2599	
W. Branch	8688	4452	15823	6999	8691	
E. Branch	9818	3564	28407	4307	6452	
TOTAL	**21,198**	**9,009**	**51,573**	**12,691**	**17,742**	**13,618**
	% Attenuation-N	**30.3%**	From CDM Data			
	% Attenuation-N	**25%**	From Cape Cod Study			

Table 16: Total Phosphorous Baseline Loading

	Most Likely Annual P Load (kg/yr)	Min. Annual P Load (kg/yr)	Max. Annual P Load (kg/yr)	Median Annual P-Load (kg/yr)	Annual P Load based on CDM Measured Conc. (kg/yr)
Mouth	621	555	8115	225	
W. Branch	658	407	2633	837	
E. Branch	2309	2192	33576	610	
TOTAL	**3,588**	**3,154**	**44,324**	**1,672**	**1,455**
	% Attenuation-P	**59.4%**	From CDM Data		

6.3.2 Projected Impacts

The projected loads from the additional point sources were then compared with the baseline conditions to forecast the nutrient impact effects on the watershed. These are summarized in the following table.

Table 17: Nutrient Loading Impacts

Total N	Baseline Loading (kg/yr)	Incremental Pine Hills Loading (kg/yr)	WWTF@ 1.25 MGD Loading (kg/yr)	Total Increase (kg/yr)	Final Load (kg/yr)	% Inc.
Mouth	2,692	0	0	0	2,692	0%
W. Branch	8,688	0	12,980	12,980	21,668	249%
E. Branch	9,818	1,285	0	1,285	11,103	113%
TOTAL	21,198	1,285	12,980	14,265	35,463	167%
Total P						
Mouth	621	0	0	0	621	0%
W. Branch	658	0	2,000	2,000	2,658	404%
E. Branch	2,309	543	0	543	2,852	124%
TOTAL	3,588	543	2,000	2,543	6,131	171%

As shown, the western branch of the Eel River shows potential for the greatest impact from the new WWTF. Dramatic increases in attenuated loads of both total nitrogen and phosphorous are calculated. The eastern drainage basin shows a smaller, but substantial, potential impact from nutrient loading, driven by increased development. On a watershed-scale basis, the nutrient loads are predicted to increase by 67% for total nitrogen and 71% for total phosphorous, with the WWTF contributing the bulk of this load. Finally, the relatively higher loads of nitrogen and phosphorus in the eastern branch of the baseline scenario are also reflective of recent development, mainly the Forges Field recreational facility.

To understand how the increased nutrient loads translate into elevated concentrations in surface water bodies, these data were integrated into the HSPF hydrological model.

7.0 NITRATE TRANSPORT MODELING

Nutrient transport modeling was focused on nitrogen for the purpose of this thesis. As explained in more detail below, the algorithms were believed to better represent the transport of nitrogen, with relatively little sorption, versus phosphorous, which becomes tightly bound to iron oxides coating sand within the aquifer (USGS, 1992). As such, phosphorous transport modeling is a more complex undertaking and is beyond the scope of this thesis, due to physical data limitations.

7.1 Conceptual Description

Nutrient transport modeling in HSPF may be performed via two alternate methods. The first method involves the use of generalized water quality "build-up/wash-off" algorithms (PQUAL). Essentially, these algorithms simulate the accumulation of a constituent on a land surface ("build-up"), where it is subject to removal triggered by storm events and transported via surface overland flow to a discrete reach segment ("wash-off"). This is a bulk parameter simulation, in that constituent dynamics are not simulated. However, it provides an excellent screening tool in assessing the magnitude of water quality impacts, which can be built upon using the second of the methods (Bicknell et al., 2000; Shenk and Linker, 2002).

The second method involves the use of the specific agrichemical sections which are capable of detailed nutrient process simulations, including species interactions. However, because of the high level of process detail involved, the data requirements are more intensive than the PQUAL simulation method (Bicknell et al., 2000).

For the purpose of this study, the generalized algorithms were considered appropriate for several reasons. First, the data resolution is insufficient to support more detailed simulations; additional field data collection is necessary to do so. Second, one form of nitrogen, nitrate, is expected to predominate, due to the aerobic nature of the aquifer. Thus, the modeling of more specific nutrient interactions was not deemed necessary for this study (Hansen and Lapham, 1992).

7.2 Build-up / Wash-off Algorithms

The generalized water quality sections are designated as PQUAL for pervious land segments, IQUAL for impervious land segments, and GQUAL for reaches. Section PQUAL offers several options for transport simulation including: (1) Sediment-associated removal (QUALSD); (2) Accumulation and removal via overland flow and constant unit rate (QUALOF); (3) Interflow-associated outflow (QUALIF); and (4) Groundwater-associated outflow (QUALGW). Section IQUAL offers QUALOF only, since the other components are not present within impervious land segments.

GQUAL offers several options for transport within the stream reach, including advective transport and specific decay processes, including daughter-product formation, for dissolved material. Additionally, sediment-associated constituents may be modeled using various relationships, including advective transport, deposition/scour, decay processes, and adsorption/desorption (Bicknell et al., 2000).

For this model simulation, the QUALOF algorithms were considered, which generally simulate nutrient build-up and wash-off processes. Sediment-associated transport was not considered due to the lack of nitrate-sorption expected, as well as the lack of adequate field data required for sediment characterization. Two main equations govern these processes. The first of these, the build-up equation, is:

$$SQO = ACQOP + SQOS(1.0 - REMQOP)$$

where,

SQO = constituent storage on the land surface [lb/ac*day]
ACQOP = constituent daily accumulation rate [lb/ac*day]
SQOS = initial value for SQO [lb/ac]
REMQOP = unit removal rate [1/day], calculated as follows:

$$REMQOP = \frac{ACQOP}{SQOLIM}$$

where,

ACQOP = defined above
SQOLIM = maximum constituent load (i.e., limit for SQO as time approaches infinity and no washoff occurs) [lb/ac]

Based on these variables, the wash-off equation is defined as:

$$SOQO = SQO * [1.0 - EXP(-SURO * WSFAC)]$$

where,

SOQO = constituent wash-off from the land surface [lb/ac]
SQO = defined above [lb/ac]
SURO = surface overland flow as calculated by HSPF [in/hr]
WSFAC = Washoff "susceptibility" [hr/in], defined below

$$WSFAC = \frac{2.3}{WSQOP}$$

where,

WSQOP = Rate of surface runoff which will result in 90% washoff in a one hour period [in/hr]

Once transported to the reach as SOQO (wash-off from the land surface), the dissolved phase advective transport was calculated by HSPF (Bicknell et al., 2000).

7.3 Model Implementation

Model implementation involved adding the necessary sections to the user control input file (e.g., PQUAL, IQUAL, and GQUAL), followed by parameter estimation. The majority of these parameters were determined using prior nutrient load estimates (see Section 6.0 above). Daily loading rates (ACQOP) were calculated using the most-likely daily loading estimate, while the initial loading values (SQOS) were determined as a three-day load. SQOLIM was defined as a twenty-day load of the constituent without washoff. SURO is HSPF calculated, leaving WSFAC to be determined as 0.0172 in/hr by solving the above equation for a 90% removal rate, using the average value of SURO over the modeling period (1970-1995).

Once the necessary sections were added to the user control input file and values modified as discussed above, a model simulation was performed of the period from 1970-1995 to determine the average nutrient concentrations in surface water bodies within the watershed. The results are discussed below.

7.4 Modeling Results

7.4.1 Baseline Conditions

A long-term HSPF simulation was performed to establish a baseline scenario representing average nitrogen concentrations. The concentrations obtained are assumed to represent the predominant nitrate species. These average modeled nitrate concentrations were subsequently reduced by a factor of 25%, to account for attenuation which is not implicitly considered in the model algorithms used (DeSimone and Howes, 1998). The results were compiled for reach sections corresponding to water bodies within the ERW.

In order to assess the accuracy of the nutrient transport model, several rounds of prior sampling performed by CDM were compiled and averaged for these same representative water bodies. Since the HSPF modeled values are temporal (1970-1995) and spatial (entire reach) averages, while the CDM values are time-averaged alone (1998-2000), some discrepancy is expected. However, as a whole, the results match well, given the nature of the comparison, as shown in Table 18 below.

Table 18: Baseline Nitrate Modeling Comparison

Reach #	Corresponding Water Body	Sampled Avg. Nitrate Conc. [mg/L]	HSPF Modeled Avg. Nitrate Conc. [mg/L]	% Difference [(Samp.-Mod)/Samp.]*100
7	Russell Mill Pond	0.004	0.002	-50%
2	Howland Pond	0.02	0.042	+110%
3	Hayden Pond	0.072	0.070	-3%
12	Eel River Pond	0.07	0.080	+14%
6	Warren Wells Brook	0.231	0.194	-16%
Average	-	-	-	11%

An error analysis was performed, beginning with the scattergram.

Figure 18: Scattergram of Nutrient Concentrations

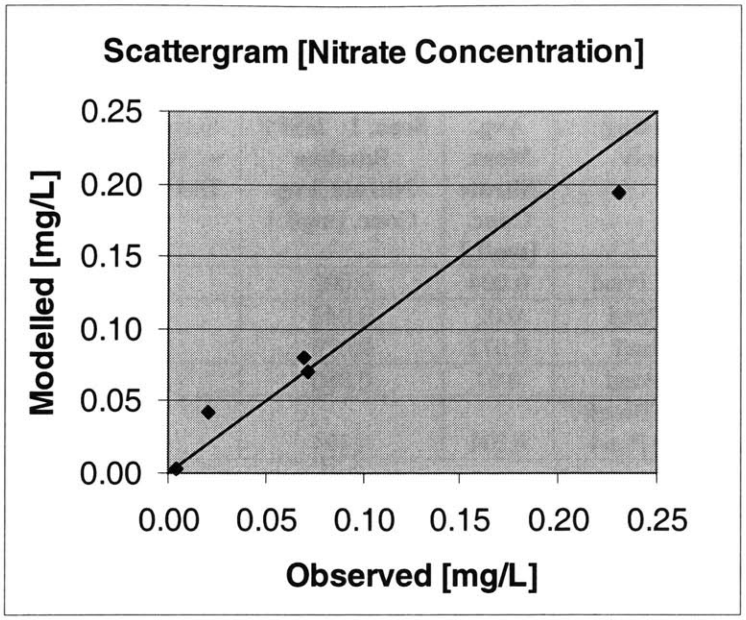


Table 19: Transport Model Accuracy Statistics

Sum (RESIDUALS) [mg/L]	-0.010	Sum ABS(RES) [mg/L]	0.073	SSE $[mg/L]^2$	2.0e-03
Mean Error [mg/L]	-0.0020	Mean Abs. Error [mg/L]	0.010	MSE $[mg/L]^2$	3.9e-04
				RMSE [mg/L]	0.020

As seen through the scattergram and mean error estimate, very little bias is present. The negative value in the mean error is likely skewed somewhat due to the highest value, which shows the greatest residual. The magnitude of the error ranges from 0.010 mg/L, calculated via the mean absolute error to 0.020 mg/L, as calculated through the root mean square error.

7.4.2 Wastewater Treatment Facility @ 1.25 MGD

An additional model simulation was performed to simulate the effect of effluent discharge from the WWTF at a rate of 1.25 MGD. This was essentially performed by assigning an increased loading rate (52 lb/acre*day) to the area roughly corresponding to the infiltration beds (2 acres), with a total load of 104 lb/day. The value of WSFAC was reduced to allow for wash-off of this load on a daily basis.

The results were compared to the baseline scenario, as depicted in the following table.

Table 20: Modeled Impact of WWTF

Reach #	Corresponding Water Body	Avg. Meas. Nitrate Conc. [mg/L]	Scen. 1: HSPF Baseline Nitrate Avg. Conc. [mg/L]	Scenario 2: HSPF w/ WWTF Effluent Disch. Avg. Conc. [mg/L]	% Increase [Scen 1 to Scen 2]
7	Russell Mill Pond	0.004	0.002	0.002	0
2	Howland Pond	0.02	0.042	0.042	0
3	Hayden Pond	0.072	0.070	0.070	0
12	Eel River Pond	0.07	0.080	0.080	0
6	Warren Wells Brook / Russell Mill Pond	0.231	0.194	0.226	16.5%

Thus, the effects of the WWTF appear to be localized to subbasin 6, where a substantial increase in nitrate of 15-20% is expected.

7.5 Nutrient Loading & Transport Error Estimates

Nutrient Load Estimates: Since nutrient loads were estimated using both literature-based and site-specific values of high-quality and specific methodologies (EPA, 1980), the accuracy of these estimates is believed to be high. Additionally, they largely corroborate the results of other ERW nutrient loading assessments (CDM, 2000).

Sampling Data: Several potential errors are associated with the sampling data used for nutrient level comparisons. First, as previously mentioned, one of the difficulties in using point sample data is its translation into values which represent a discrete model segment. Either high-resolution temporal data or average data are required for meaningful results. Finally, the accuracy and precision of the laboratory data is not known, but must be assumed to be of sufficient quality for governmental QA/QC review.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the performance of this research, in conjunction with the MERIT study, the following conclusions and recommendations have been made.

8.1 Assessment of Surface Water Nitrogen Impacts

The impact of increased nitrogen loading in the ERW via the discharge of WWTF effluent is fairly significant, but localized. The expected increase in nitrate levels in Reach 6, corresponding to Warren Wells Brook and portions of Russell Mill Pond, is on the order of 15-20%. Given the current mesotrophic state of the western branch, this additional nutrient load may trigger increased eutrophication, resulting in degraded water quality within the watershed. As discussed in Section 1.3, the effects of eutrophication may take many forms, ranging from aesthetics and inconvenience (i.e., noxious odor and restricted access) to toxic effects in animals and humans (UN 2000).

8.2 Assessment of Surface Water Phosphorous Impacts

The potential impact of additional phosphorous loading is also substantial. Based on loading calculations, the expected increase in phosphorous load in the western branch is 404%; if aggregated over the entirety of the watershed, this translates into approximately 171%. Given the uncertainty over the limiting nutrient in the watershed, this may also trigger further eutrophication.

Unfortunately, HSPF modeling of phosphorous transport was beyond the scope of this thesis, due to the higher data requirements caused by its increased modeling complexity. This complexity is largely driven by the high sorption affinity of phosphate to iron oxide sand coatings; this sorption could better be simulated using the agrichemical HSPF modules if additional field data is collected.

8.3 The Implementation of GIS Data

The use of GIS data appears to provide sufficient resolution for HSPF modeling of hydrology and nutrient transport. It allows for relatively rapid assessment of the magnitude of nutrient impacts by filling gaps in field data. However, for more refined estimates of speciated nutrient fate and transport, this level of resolution is likely insufficient. Additional physical data collection is required, specifically targeted at assessing reach characteristics, where the GIS data used has the greatest deficiency.

8.4 Assessment of BASINS Capabilities for Small-Scale Watersheds

One of the goals of this research was to assess the capabilities of BASINS for delineating and characterizing a small-scale watershed, versus its typical large-scale watershed usage. As discussed previously, BASINS had some initial operational difficulties with the ERW. The default data provided within the BASINS database was of insufficient resolution for the ERW. Supplemental higher resolution data was required from sources including MassGIS and the USGS. Additionally, the BASINS watershed delineation toolsets had some difficulties (i.e., excluding the mouth of the watershed) which caused increased time expenditure.

Therefore, using ArcView GIS with its own set of hydrologic analysis extensions, prior to the use of BASINS, would have allowed more rapid delineation and characterization of the ERW. Once this phase was completed, the required files and corresponding attribute tables (i.e., streams, subbasins, and outlets) could be imported into the BASINS framework using the pre-defined delineation toolset. This would then generate the required HSPF input files, thereby maximizing operational efficiency.

8.5 Future Study Recommendations

Use of the more detailed and robust agrichemical modules within the HSPF framework would allow for a more detailed depiction of the fate and transport of individual nitrogen and phosphorous species. It would also allow for HSPF simulation of phosphorous transport, including the sediment-bound phase. This added detail would be especially desirable for the purposes of the in-stream water quality model (RWQMWASP), due to its high resolution data requirements (Nair, 2002).

8.6 Additional Data Acquisition

Supplementary data acquisition is suggested prior to additional study. The types of data recommended include:

- **Reach Definition**: More accurate information on the reaches, including physical dimensions and morphology, is necessary for more precision modeling.
- **Meteorological Data**: Localized meteorological data at multiple locations is desired, given the inherent limitations of point rain gauge estimates. This would reduce error associated with the precipitation model input, which functions as the driving force for the model. Additional time periods (1995-current) would also be valuable for more direct model verification (see below).
- **Streamflow Data**: An additional period of continuous, or semi-continuous, streamflow which coincides with the period of meteorological data is desired. This would allow direct model verification.
- **Nutrient Data**: Additional spatially-averaged, time-variant data are desired in order to calibrate the nutrient transport portion of the model, including both dissolved phase and sediment-bound component in representative surface water bodies.
- **Waste Water Treatment Effluent**: Since the waste water treatment effluent is currently operational, effluent sample data would increase the accuracy of assessing its impacts. This is particularly true of phosphorous effluent concentrations, for which there are no permitted values to base loading upon. Instead, literature values have been used, which should be supplanted by site-specific data.

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APPENDIX A: HSPF User Control Input File [Baseline Nutrient Transport]

```
RUN

GLOBAL
  UCI Created by WinHSPF for er2
  START       1970/01/01 00:00  END    1995/12/31 24:00
  RUN INTERP OUTPT LEVELS    1    0
  RESUME     0 RUN     1                         UNITS      1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
MESSU      24   wqG01.WQA01.ERF100.ech
           91   wqG01.WQA01.ERF100.out
WDM1       25   ..\er2a\er2a.wdm
WDM2       26   ..\..\data\ma.wdm
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND     101
      PERLND     102
      PERLND     103
      PERLND     104
      PERLND     105
      PERLND     106
      PERLND     107
      PERLND     108
      PERLND     109
      PERLND     110
      PERLND     111
      PERLND     112
      PERLND     113
      PERLND     114
      PERLND     115
      PERLND     116
      PERLND     117
      IMPLND     101
      IMPLND     102
      IMPLND     103
      IMPLND     104
      IMPLND     105
      IMPLND     106
      IMPLND     107
      IMPLND     108
      IMPLND     109
      IMPLND     110
      IMPLND     111
      IMPLND     112
      IMPLND     113
      IMPLND     114
      IMPLND     115
      RCHRES       1
      RCHRES       4
      RCHRES       6
      RCHRES       9
      RCHRES       8
      RCHRES      13
      RCHRES      10
      RCHRES      11
      RCHRES       5
      RCHRES       7
      RCHRES       2
      RCHRES       3
```

```
      RCHRES      12
      COPY         1
      COPY         2
      COPY         3
    END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
*** <PLS >               Active Sections                               ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  117    1    1    1    0    0    0    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** < PLS>                       Print-flags                           PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  101  117    4    4    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name                  Unit-systems   Printer
*** <PLS >                                t-series Engl Metr
*** x -  x                                 in  out
  101     Cropland                          1    1    0    0
  102     Forest                            1    1    0    0
  103     Open Areas with no v              1    1    0    0
  104     Medium Density Resid              1    1    0    0
  105     Low Density Resident              1    1    0    0
  106     Commercial                        1    1    0    0
  107     Industrial                        1    1    0    0
  108     Urban Open                        1    1    0    0
  109     Woody Perennial                   1    1    0    0
  110     Pasture                           1    1    0    0
  111     Participation Recrea              1    1    0    0
  112     Water                             1    1    0    0
  113     Nonforested Wetland               1    1    0    0
  114     Saltwater Wetland                 1    1    0    0
  115     Transportation                    1    1    0    0
  116     Mining                            1    1    0    0
  117     Water Based Recreati              1    1    0    0
  END GEN-INFO

  ICE-FLAG
*** <PLS > Ice-
*** x -  x flag
  101  117    1
  END ICE-FLAG

  SNOW-FLAGS
*** <PLS >
*** x -  x SNOP  VKM
  101  117    0    0
  END SNOW-FLAGS

  SNOW-PARM1
*** < PLS>       LAT     MELEV     SHADE    SNOWCF    COVIND     KMELT     TBASE
*** x  - x   degrees      (ft)                          (in)  (in/d.F)       (F)
  101            40.       20.       0.4       1.2        5.        0.       32.

  102            40.       20.       0.5       1.2        5.        0.       32.
  103            40.       20.       0.1       1.2        5.        0.       32.
  104            40.       20.       0.2       1.2        5.        0.       32.
```

```
  105            40.       20.       0.5       1.2        5.        0.       32.
  106            40.       20.       0.3       1.2        5.        0.       32.
  107            40.       20.       0.4       1.2        5.        0.       32.
  108            40.       20.       0.1       1.2        5.        0.       32.
  109            40.       20.       0.5       1.2        5.        0.       32.
  110            40.       20.       0.2       1.2        5.        0.       32.
  111            40.       20.       0.1       1.2        5.        0.       32.
  112  117       40.       20.        0.       1.2        5.        0.       32.
  END SNOW-PARM1

  SNOW-PARM2
*** <PLS >     RDCSN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** x -  x             (deg F)                                (in/day)
  101  117      0.15       32.       0.1        1.      0.03      0.01
  END SNOW-PARM2

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
  101  117    1    1    1    1    0    0    0    0    1    1    0    0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101            0.2        2.       60.      300.    0.0458        0.     0.994
  102            0.5        2.       60.      300.    0.0458        0.     0.994
  103             0.        2.       60.      300.    0.0458        0.     0.994
  104  105       0.2        2.       60.      300.    0.0458        0.     0.994
  106  107       0.1        2.       60.      300.    0.0458        0.     0.994
  108            0.2        2.       60.      300.    0.0458        0.     0.994
  109            0.5        2.       60.      300.    0.0458        0.     0.994
  110            0.5        2.       60.      300.    0.0944        0.     0.994
  111            0.2        2.       60.      300.    0.0944        0.     0.994
  112             0.        2.       60.      300.    0.0944        0.     0.994
  113            0.2        2.       60.      300.    0.0574        0.     0.994
  114            0.2        2.       60.      300.     0.025        0.     0.994
  115             0.        2.       60.      300.     0.025        0.     0.994
  116             0.        2.       60.      300.    0.0485        0.     0.994
  117             0.        2.       60.      300.    0.0723        0.     0.994
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101  117       40.       35.        2.        2.        0.      0.02        0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                         (1/day)
  101  117       0.1        7.       0.2       10.       0.5       0.1
  END PWAT-PARM4

  PWAT-PARM5
*** <PLS >       FZG      FZGL
*** x -  x
  101  117        1.       0.1
  END PWAT-PARM5

  PWAT-PARM6
*** <PLS >     MELEV      BELV    GWDATM       PCW       PGW      UPGW
*** x -  x      (ft)      (ft)      (ft)
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  101  117        0.        1.        1.      0.01      0.01      0.01
  END PWAT-PARM6

  PWAT-PARM7
*** < PLS>    STABNO      SRRC     SREXP     IFWSC     DELTA    UELFAC    LELFAC
*** x  - x               (/hr)                (in)      (in)
  101  117        0.       0.1        1.        1.     0.001        4.       2.5
  END PWAT-PARM7

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  117      0.01      0.01        2.      0.01     0.075      0.01      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  117   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  END MON-INTERCEP

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  117   .2   .2   .3   .3   .4   .4   .4   .4   .4   .3   .2   .2
  END MON-LZETPARM

  NQUALS
*** <PLS >
*** x -  xNQUAL
  101  117    1
  END NQUALS

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  117Nitrogen        LB      0    0    0    1    1    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***           SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3 qty/ft3
*** x -  x                        ac.day
  101         0.18      0.      0.    0.06     3.6   0.017      0.      0.
  102         0.14      0.      0.    0.05     2.8   0.017      0.      0.
  103         0.45      0.      0.    0.15      9.   0.017      0.      0.
  104  105    0.18      0.      0.    0.06     3.6   0.017      0.      0.
  106  109    0.45      0.      0.    0.15      9.   0.017      0.      0.
  110         0.91      0.      0.     0.3    18.2   0.017      0.      0.
  111         2.27      0.      0.    0.76    45.4   0.017      0.      0.
  112          0.3      0.      0.     0.1      6.   0.017      0.      0.
  113         0.15      0.      0.    0.05     2.8   0.017      0.      0.
  114         0.14      0.      0.    0.05     2.8   0.017      0.      0.
  115  116    0.45      0.      0.    0.15      9.   0.017      0.      0.
  117          0.3      0.      0.     0.1      6.   0.017      0.      0.
  END QUAL-INPUT

  MON-ACCUM
*** <PLS >  Value at start of each month for accum rate of QUALOF (lb/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101       .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  102       .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05
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  103       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  104  105  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  106  109  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  110        .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  111       .76  .76  .76  .76  .76  .76  .76  .76  .76  .76  .76  .76
  112        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  113  114  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05
  115  116  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  117        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101       .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12
  102        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  103        .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  104  105  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12
  106  109   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  110        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  111      1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52
  112        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  113  114   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  115  116   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  117        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  END MON-SQOLIM

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  115    1    1    1    0    0    1
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  115    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name             Unit-systems   Printer
*** <ILS >                           t-series Engl Metr
*** x -  x                            in  out
  101     Cropland                    1    1    0    0
  102     Forest                      1    1    0    0
  103     Open Areas with no v        1    1    0    0
  104     Medium Density Resid        1    1    0    0
  105     Low Density Resident        1    1    0    0
  106     Commercial                  1    1    0    0
  107     Industrial                  1    1    0    0
  108     Urban Open                  1    1    0    0
  109     Woody Perennial             1    1    0    0
  110     Participation Recrea        1    1    0    0
  111     Multifamily Resident        1    1    0    0
  112     Transportation              1    1    0    0
  113     Pasture                     1    1    0    0
  114     Nonforested Wetland         1    1    0    0
  115     Mining                      1    1    0    0
  END GEN-INFO
```

```
  ATEMP-DAT
*** <ILS >     ELDAT    AIRTEMP
*** x -  x      (ft)    (deg F)
  102  115        0.        60.
  END ATEMP-DAT

  ICE-FLAG
*** <ILS > Ice-
*** x -  x flag
  101  115    1
  END ICE-FLAG

  SNOW-FLAGS
*** <ILS >
*** x -  x SNOP  VKM
  101  115    0    0
  END SNOW-FLAGS

  SNOW-PARM1
*** < ILS>       LAT     MELEV     SHADE    SNOWCF    COVIND     KMELT     TBASE
*** x  - x   degrees      (ft)                          (in)  (in/d.F)       (F)
  101            40.       20.       0.3       1.2       10.        0.       32.
  102            40.       20.       0.5       1.2       10.        0.       32.
  103            40.       20.       0.1       1.2       10.        0.       32.
  104  107       40.       20.       0.2       1.2       10.        0.       32.
  108            40.       20.       0.1       1.2       10.        0.       32.
  109            40.       20.       0.5       1.2       10.        0.       32.
  110            40.       20.       0.1       1.2       10.        0.       32.
  111            40.       20.       0.2       1.2       10.        0.       32.
  112            40.       20.       0.1       1.2       10.        0.       32.
  113            40.       20.       0.3       1.2       10.        0.       32.
  114            40.       20.       0.5       1.2       10.        0.       32.
  115            40.       20.       0.1       1.2       10.        0.       32.
  END SNOW-PARM1

  SNOW-PARM2
*** <ILS >     RDCSN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** x -  x             (deg F)                                (in/day)
  101  115      0.15       32.       0.1        1.      0.03      0.01
  END SNOW-PARM2

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  115    1    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (ft)
  101  109     819.2    0.0458       0.1     0.065
  110  112     974.6    0.0944       0.1     0.065
  113          495.9    0.0521       0.1     0.065
  114          719.8     0.025       0.1     0.065
  115          955.1    0.0485       0.1     0.065
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  115       40.       35.
  END IWAT-PARM3
```

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  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  115      0.01      0.01
  END IWAT-STATE1

  NQUALS
*** <ILS >
*** x -  xNQUAL
  101  115    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
  101  115NITROGEN        LB      0    0    1    1
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
  101         0.18      0.      0.     3.6   0.017
  102         0.14      0.      0.     2.8   0.017
  103         0.45      0.      0.      9.   0.017
  104  105    0.18      0.      0.     3.6   0.017
  106  109    0.45      0.      0.      9.   0.017
  110         2.27      0.      0.    50.4   0.017
  111         0.18      0.      0.     2.8   0.017
  112         0.45      0.      0.      9.   0.017
  113         0.91      0.      0.    18.2   0.017
  114         0.14      0.      0.     2.8   0.017
  115         0.45      0.      0.      9.   0.017
  END QUAL-INPUT

  MON-ACCUM
*** <ILS >  Value at start of each month for accum rate of QUALOF (qty/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101       .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  102       .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05  .05
  103       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  104  105  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  106  109  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  110       .76  .76  .76  .76  .76  .76  .76  .76  .76  .76  .76  .76
  111       .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  112       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  113        .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  114       .05  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06  .06
  115       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  END MON-ACCUM

  MON-SQOLIM
*** <ILS >  Value at start of month for limiting storage of QUALOF (qty/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101       .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12
  102        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  103        .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  104  105  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12
  106  109   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  110      1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52 1.52
  111       .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12  .12
  112        .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
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```
  113          .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  114          .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  115          .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3   .3
  END MON-SQOLIM

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
    1   13    1    1    0    0    0    1    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1   13    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***              Name        Nexits   Unit Systems   Printer
*** RCHRES                               t-series  Engl Metr LKFG
*** x -  x                                 in  out
    1   13                        1         1    1   91    0    0
  END GEN-INFO

  HYDR-PARM1
***          Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit     possible   exit
    1   13   0  1  0  0    4  0  0  0  0      0  0  0  0  0       1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR        KS      DB50
*** x -  x             (miles)      (ft)      (ft)                (in)
    1         0.   1.     0.37       82.       3.2       0.5      0.01
    2         0.   2.     0.15       23.       3.2       0.5      0.01
    3         0.   3.     1.19       69.       3.2       0.5      0.01
    4         0.   4.      0.7       20.       3.2       0.5      0.01
    5         0.   5.     0.83       52.       3.2       0.5      0.01
    6         0.   6.     1.09       52.       3.2       0.5      0.01
    7         0.   7.      0.8       59.       3.2       0.5      0.01
    8         0.   8.      2.4      112.       3.2       0.5      0.01
    9         0.   9.     1.08       39.       3.2       0.5      0.01
   10         0.  10.     1.17       13.       3.2       0.5      0.01
   11         0.  11.     0.76        7.       3.2       0.5      0.01
   12         0.  12.     1.47        0.       3.2       0.5      0.01
   13         0.  13.     2.67        2.       3.2       0.5      0.01
  END HYDR-PARM2

  MON-CONVF
*** RCHRES  Monthly f(VOL) adjustment factors
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    1   13  .97  .89  .89  .91  .93  .93  .94  .95  .95  .98  .98  .97
  END MON-CONVF

  HYDR-INIT
***          Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible exit,ft3
    1           0.25        4.2  4.5  4.5  4.5  4.2         2.1  1.2   .5  1.2  1.8
```

```
    2    3      12.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
    4           0.25       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
    5           12.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
    6            2.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
    7           12.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
    8    9      0.25       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
   10   11       2.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
   12            25.       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
   13           12.5       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
  END HYDR-INIT

  ADCALC-DATA
*** RCHRES  Data for section ADCALC
*** x -  x      CRRAT       VOL (ac-ft)
    1   13       1.5         0.
  END ADCALC-DATA

  NCONS
*** RCHRES
*** x -  xNCONS
    1   13    1
  END NCONS

  CONS-DATA
*** RCHRES
*** x -  x        Substance-id      Conc         ID      CONV     QTYID
    1   13                            0.              251.3
  END CONS-DATA

  GQ-GENDATA
*** RCHRES NGQL TPFG PHFG ROFG CDFG SDFG PYFG  LAT
*** x -  x                                     deg
    1   13    1    2    2    2    2    2    2    0
  END GQ-GENDATA

  GQ-AD-FLAGS
***        Atmospheric Deposition Flags
*** RCHRES GQUAL1 GQUAL2 GQUAL3
*** x -  x <F><C> <F><C> <F><C>
    1   13   0  0   0  0   0  0
  END GQ-AD-FLAGS

  GQ-QALDATA
*** RCHRES                GQID      DQAL    CONCID       CONV     QTYID
*** x -  x                        concid
    1     N                         0.25      MG      16187.
    2     N                         0.19      MG      16187.
    3     N                         0.59      MG      16187.
    4    5N                         0.19      MG      16187.
    6    7N                         0.34      MG      16187.
    8    9N                         0.19      MG      16187.
   10   11N                          0.5      MG      16187.
   12     N                         0.25      MG      16187.
   13     N                          0.5      MG      16187.
  END GQ-QALDATA

  GQ-QALFG
*** RCHRES HDRL OXID PHOT VOLT BIOD  GEN SDAS
*** x -  x
    1    3    0    0    0    0    0    0    0
    5   13    0    0    0    0    0    0    0
  END GQ-QALFG
```

```
  GQ-VALUES
*** RCHRES       TWAT      PHVAL        ROC        CLD      SDCNC        PHY
*** x  -  x     deg F               mole/l     tenths       mg/l       mg/l
    1   13       60.         7.         0.         0.         0.         0.
  END GQ-VALUES

END RCHRES

FTABLES

  FTABLE      1
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.      0.17        0.        0.
      0.05      0.17      0.01      0.14
      0.46      0.21      0.09      6.44
      0.58      0.27      0.11      9.37
      0.72      0.67      0.21     12.83
      0.86       0.7      0.31     23.84
     14.84      3.19     27.45  14905.94
     28.82      5.68     89.39  72239.45
  END FTABLE  1

  FTABLE      4
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.      0.61        0.        0.
      0.07      0.63      0.04      0.18
      0.68      0.73      0.46      8.27
      0.85       0.9      0.59     12.02
      1.07      2.29      1.07     16.12
      1.28      2.36      1.57      29.8
     22.01       9.4    123.53  16553.74
     42.74     16.45    391.47  77539.78
  END FTABLE  4

  FTABLE      6
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.      2.26        0.        0.
      0.11       2.3      0.26      1.27
      1.12      2.59      2.71     58.72
       1.4      3.07      3.45     85.18
      1.75      8.04      6.22    111.97
       2.1      8.24      9.07      206.
     35.99     27.76    619.23 100444.45
     69.88     47.28   1890.93 449605.47
  END FTABLE  6

  FTABLE      9
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.      1.12        0.        0.
      0.08      1.14      0.09      0.29
      0.76      1.32      0.93     13.42
      0.95      1.62      1.19     19.48
      1.19      4.14      2.16     26.01
      1.43      4.27      3.16     48.02
     24.53     16.35     241.3  25865.39
```

```
    47.62     28.44     758.6  119968.1
 END FTABLE  9

 FTABLE      8
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      0.93        0.        0.
     0.06      0.95      0.06      0.09
     0.64      1.11      0.66      4.26

      0.8      1.39      0.84      6.19
       1.       3.5      1.53      8.33
      1.2      3.62      2.25     15.41
    20.68      14.7    180.64   8716.62
    40.16     25.79    574.98  41056.13
 END FTABLE  8

 FTABLE     13
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      1.06        0.        0.
     0.66      1.48      0.83      1.09
     6.56       5.3     20.86      88.6
      8.2     11.66     30.41    146.14
    10.25     19.61     67.89    295.77
     12.3     22.25     110.8     615.3
   211.15    279.24  30087.331303783.63
     410.    536.23 111166.21  7453499.
 END FTABLE 13

 FTABLE     10
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      0.57        0.        0.
     0.06      0.59      0.04      0.07
     0.62      0.69      0.39      3.36
     0.78      0.86       0.5      4.88
     0.97      2.17      0.92      6.58
     1.17      2.24      1.35     12.18
    20.02      9.22    109.33   6951.74
    38.87     16.19    348.78  32835.71
 END FTABLE 10

 FTABLE     11
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      2.48        0.        0.
     0.08      2.53      0.19      0.32
     0.76      2.92      2.05     14.94
     0.95      3.59      2.62      21.7
     1.19      9.16      4.76     28.97
     1.42      9.44      6.96      53.5
    24.43     36.22    532.19  28854.01
    47.44     63.01    1673.7 133887.19
 END FTABLE 11

 FTABLE      5
rows cols                               ***
   8    4
```

```
    depth      area    volume  outflow1 ***
       0.      1.41        0.        0.
      0.1      1.43      0.15      1.03
     1.03      1.62      1.56     47.43
     1.29      1.93      1.99     68.81
     1.62      5.03      3.59     90.71
     1.94      5.17      5.24    167.01
    33.28     17.85    365.93  83022.11
    64.62     30.54   1124.25 374365.84
 END FTABLE  5

 FTABLE      7
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      1.07        0.        0.
     0.09      1.09       0.1      0.68
     0.89      1.24      1.03     31.49
     1.11       1.5      1.31      45.7
     1.39      3.88      2.38     60.61
     1.67      3.99      3.47    111.74
    28.64     14.52    253.13  57736.11
    55.62     25.04    786.67 264022.63
 END FTABLE  7

 FTABLE      2
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.       0.3        0.        0.
     0.12      0.31      0.04      2.43
     1.17      0.34      0.38    112.18
     1.47      0.41      0.48    162.72
     1.83      1.07      0.87    213.52
      2.2       1.1      1.27    392.69
    37.73      3.63     85.33 189296.03
    73.27      6.17     259.6  843537.5

 END FTABLE  2

 FTABLE      3
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      0.87        0.        0.
     0.06      0.88      0.06      0.19
     0.64      1.04      0.61      8.82
      0.8      1.29      0.78     12.81
       1.      3.26      1.43     17.23
      1.2      3.37      2.09     31.88
    20.67     13.69    168.14  18025.62
    40.14     24.02    535.21  84900.99
 END FTABLE  3

 FTABLE     12
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      0.58        0.        0.
     0.66      0.82      0.46      2.83
     6.56      2.92     11.48     230.7
      8.2      6.41     16.74    380.52
    10.25     10.79     37.36    770.14
```

```
      12.3     12.25     60.96   1602.16
    211.15    153.65  16555.083394848.25
      410.    295.05  61167.48 19407742.
  END FTABLE 12
END FTABLES

COPY
  TIMESERIES
  Copy-opn***
*** x -  x  NPT  NMN
    1    3    0    7
  END TIMESERIES

END COPY

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name> x x ***
*** Met Seg MA000840
WDM2    51 PREC     ENGLZERO          SAME PERLND 101 117 EXTNL  PREC
WDM2    53 ATEM     ENGL              SAME PERLND 101 117 EXTNL  GATMP
WDM2    57 DEWP     ENGL              SAME PERLND 101 117 EXTNL  DTMPG
WDM2    54 WIND     ENGL              SAME PERLND 101 117 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME PERLND 101 117 EXTNL  SOLRAD
WDM2    56 PEVT     ENGL              SAME PERLND 101 117 EXTNL  PETINP
*** Met Seg MA000840
WDM2    51 PREC     ENGLZERO          SAME IMPLND 101 115 EXTNL  PREC
WDM2    53 ATEM     ENGL              SAME IMPLND 101 115 EXTNL  GATMP
WDM2    57 DEWP     ENGL              SAME IMPLND 101 115 EXTNL  DTMPG
WDM2    54 WIND     ENGL              SAME IMPLND 101 115 EXTNL  WINMOV

WDM2    55 SOLR     ENGL              SAME IMPLND 101 115 EXTNL  SOLRAD
WDM2    56 PEVT     ENGL              SAME IMPLND 101 115 EXTNL  PETINP
*** Met Seg MA000840
WDM2    51 PREC     ENGLZERO          SAME RCHRES   1  13 EXTNL  PREC
WDM2    53 ATEM     ENGL              SAME RCHRES   1  13 EXTNL  GATMP
WDM2    57 DEWP     ENGL              SAME RCHRES   1  13 EXTNL  DEWTMP
WDM2    54 WIND     ENGL              SAME RCHRES   1  13 EXTNL  WIND
WDM2    55 SOLR     ENGL              SAME RCHRES   1  13 EXTNL  SOLRAD
WDM2    58 CLOU     ENGL              SAME RCHRES   1  13 EXTNL  CLOUD
WDM2    52 EVAP     ENGL              SAME RCHRES   1  13 EXTNL  POTEV
END EXT SOURCES

SCHEMATIC
<-Volume->                  <--Area-->     <-Volume->  <ML#> ***       <sb>
<Name>   x                  <-factor->     <Name>   x        ***        x x
PERLND 102                         190     RCHRES   1      2
IMPLND 102                           0     RCHRES   1      1
PERLND 116                                 RCHRES   1      2
PERLND 103                           3     RCHRES   1      2
PERLND 105                          31     RCHRES   1      2
IMPLND 105                           0     RCHRES   1      1
PERLND 106                           4     RCHRES   1      2
IMPLND 106                           0     RCHRES   1      1
PERLND 108                           8     RCHRES   1      2
IMPLND 108                           0     RCHRES   1      1
PERLND 115                          12     RCHRES   1      2
IMPLND 112                          48     RCHRES   1      1
PERLND 101                          90     RCHRES   4      2
IMPLND 101                           0     RCHRES   4      1
PERLND 110                           3     RCHRES   4      2
PERLND 102                         594     RCHRES   4      2
IMPLND 102                           0     RCHRES   4      1
```

```
PERLND 103                     4     RCHRES   4      2
PERLND 111                    39     RCHRES   4      2
IMPLND 110                     0     RCHRES   4      1
IMPLND 111                           RCHRES   4      1
PERLND 104                     4     RCHRES   4      2
IMPLND 104                     0     RCHRES   4      1
PERLND 105                    54     RCHRES   4      2
IMPLND 105                     0     RCHRES   4      1
IMPLND 112                           RCHRES   4      1
PERLND 112                     5     RCHRES   4      2
PERLND 109                           RCHRES   4      2
PERLND 101                    11     RCHRES   6      2
IMPLND 101                     0     RCHRES   6      1
PERLND 102                   246     RCHRES   6      2
IMPLND 102                     0     RCHRES   6      1
PERLND 113                     5     RCHRES   6      2
PERLND 116                   128     RCHRES   6      2
IMPLND 115                     0     RCHRES   6      1
PERLND 103                    66     RCHRES   6      2
IMPLND 103                     0     RCHRES   6      1
PERLND 111                     7     RCHRES   6      2
IMPLND 110                     0     RCHRES   6      1
PERLND 105                    13     RCHRES   6      2
IMPLND 105                     0     RCHRES   6      1
PERLND 106                    57     RCHRES   6      2
IMPLND 106                     0     RCHRES   6      1
PERLND 107                    12     RCHRES   6      2
IMPLND 107                    35     RCHRES   6      1
PERLND 108                    49     RCHRES   6      2
IMPLND 108                     0     RCHRES   6      1
PERLND 115                     9     RCHRES   6      2

IMPLND 112                    35     RCHRES   6      1
PERLND 112                     4     RCHRES   6      2
PERLND 109                     5     RCHRES   6      2
PERLND 101                     7     RCHRES   9      2
IMPLND 101                     0     RCHRES   9      1
PERLND 102                   931     RCHRES   9      2
IMPLND 102                     0     RCHRES   9      1
PERLND 113                     4     RCHRES   9      2
PERLND 103                    49     RCHRES   9      2
IMPLND 103                     0     RCHRES   9      1
PERLND 111                    22     RCHRES   9      2
IMPLND 110                     0     RCHRES   9      1
PERLND 105                     2     RCHRES   9      2
IMPLND 105                     0     RCHRES   9      1
PERLND 115                     6     RCHRES   9      2
IMPLND 112                    22     RCHRES   9      1
PERLND 112                    11     RCHRES   9      2
PERLND 109                     2     RCHRES   9      2
PERLND 110                           RCHRES   8      2
PERLND 102                   620     RCHRES   8      2
IMPLND 102                     0     RCHRES   8      1
PERLND 113                     6     RCHRES   8      2
PERLND 103                    90     RCHRES   8      2
IMPLND 103                     0     RCHRES   8      1
PERLND 111                   208     RCHRES   8      2
IMPLND 110                     0     RCHRES   8      1
PERLND 105                    53     RCHRES   8      2
IMPLND 105                     0     RCHRES   8      1
PERLND 108                    18     RCHRES   8      2
IMPLND 108                     0     RCHRES   8      1
PERLND 115                     6     RCHRES   8      2
```

```
IMPLND 112                            22     RCHRES    8        1
PERLND 112                             8     RCHRES    8        2
PERLND 109                            13     RCHRES    8        2
IMPLND 109                             0     RCHRES    8        1
PERLND 102                          1221     RCHRES   13        2
IMPLND 102                             0     RCHRES   13        1
PERLND 113                                   RCHRES   13        2
PERLND 103                            22     RCHRES   13        2
IMPLND 103                             0     RCHRES   13        1
PERLND 104                            52     RCHRES   13        2
IMPLND 104                             0     RCHRES   13        1
PERLND 105                            46     RCHRES   13        2
IMPLND 105                             0     RCHRES   13        1
PERLND 112                           482     RCHRES   13        2
PERLND 109                            39     RCHRES   13        2
IMPLND 109                             0     RCHRES   13        1
PERLND 101                            10     RCHRES   10        2
IMPLND 101                             0     RCHRES   10        1
PERLND 102                           467     RCHRES   10        2
IMPLND 102                             0     RCHRES   10        1
PERLND 103                            38     RCHRES   10        2
IMPLND 103                             0     RCHRES   10        1
PERLND 104                            22     RCHRES   10        2
IMPLND 104                             0     RCHRES   10        1
PERLND 105                            86     RCHRES   10        2
IMPLND 105                             0     RCHRES   10        1
PERLND 106                             3     RCHRES   10        2
IMPLND 106                             0     RCHRES   10        1
PERLND 107                                   RCHRES   10        2
IMPLND 107                             2     RCHRES   10        1
PERLND 108                            14     RCHRES   10        2
IMPLND 108                             0     RCHRES   10        1
PERLND 109                            47     RCHRES   10        2
IMPLND 109                             0     RCHRES   10        1
RCHRES  13                                   RCHRES   10        3
PERLND 101                             2     RCHRES   11        2
PERLND 110                             3     RCHRES   11        2
PERLND 102                           353     RCHRES   11        2
IMPLND 102                             0     RCHRES   11        1
PERLND 113                             3     RCHRES   11        2
PERLND 103                            18     RCHRES   11        2
IMPLND 103                             0     RCHRES   11        1
PERLND 104                           126     RCHRES   11        2
IMPLND 104                             0     RCHRES   11        1
PERLND 105                            77     RCHRES   11        2
IMPLND 105                             0     RCHRES   11        1
PERLND 108                             3     RCHRES   11        2
IMPLND 108                             0     RCHRES   11        1
PERLND 112                            15     RCHRES   11        2
PERLND 109                            36     RCHRES   11        2
IMPLND 109                             0     RCHRES   11        1
PERLND 101                            33     RCHRES    5        2
IMPLND 101                             0     RCHRES    5        1
PERLND 110                             7     RCHRES    5        2
IMPLND 113                             0     RCHRES    5        1
PERLND 102                            67     RCHRES    5        2
IMPLND 102                             0     RCHRES    5        1
PERLND 103                            16     RCHRES    5        2
IMPLND 103                             0     RCHRES    5        1
PERLND 105                            16     RCHRES    5        2
IMPLND 105                             0     RCHRES    5        1
PERLND 112                            15     RCHRES    5        2
PERLND 109                             2     RCHRES    5        2
```

```
RCHRES   9                                 RCHRES    5       3
RCHRES   8                                 RCHRES    5       3
PERLND 101                                 RCHRES    7       2
PERLND 102                        182      RCHRES    7       2
IMPLND 102                          0      RCHRES    7       1
PERLND 103                         18      RCHRES    7       2
IMPLND 103                          0      RCHRES    7       1
PERLND 117                                 RCHRES    7       2
PERLND 105                          4      RCHRES    7       2
IMPLND 105                          0      RCHRES    7       1
PERLND 112                         22      RCHRES    7       2
RCHRES  10                                 RCHRES    7       3
RCHRES  11                                 RCHRES    7       3
PERLND 101                         11      RCHRES    2       2
IMPLND 101                          0      RCHRES    2       1
PERLND 102                         10      RCHRES    2       2
IMPLND 102                          0      RCHRES    2       1
PERLND 105                          7      RCHRES    2       2
IMPLND 105                          0      RCHRES    2       1
PERLND 112                                 RCHRES    2       2
RCHRES   4                                 RCHRES    2       3
RCHRES   5                                 RCHRES    2       3
PERLND 101                         58      RCHRES    3       2
IMPLND 101                          0      RCHRES    3       1
PERLND 102                        291      RCHRES    3       2
IMPLND 102                          0      RCHRES    3       1
PERLND 103                         12      RCHRES    3       2
IMPLND 103                          0      RCHRES    3       1
PERLND 105                         79      RCHRES    3       2
IMPLND 105                          0      RCHRES    3       1
PERLND 108                          3      RCHRES    3       2
IMPLND 108                          0      RCHRES    3       1
PERLND 115                          6      RCHRES    3       2
IMPLND 112                         25      RCHRES    3       1

PERLND 112                         26      RCHRES    3       2
RCHRES   6                                 RCHRES    3       3
RCHRES   7                                 RCHRES    3       3
PERLND 101                         24      RCHRES   12       2
IMPLND 101                          0      RCHRES   12       1
PERLND 102                        176      RCHRES   12       2
IMPLND 102                          0      RCHRES   12       1
PERLND 113                         29      RCHRES   12       2
IMPLND 114                          0      RCHRES   12       1
PERLND 103                          2      RCHRES   12       2
PERLND 111                         63      RCHRES   12       2
IMPLND 110                          0      RCHRES   12       1
PERLND 104                         58      RCHRES   12       2
IMPLND 104                          0      RCHRES   12       1
PERLND 105                         90      RCHRES   12       2
IMPLND 105                          0      RCHRES   12       1
PERLND 114                          6      RCHRES   12       2
PERLND 106                          4      RCHRES   12       2
IMPLND 106                          0      RCHRES   12       1
PERLND 108                         30      RCHRES   12       2
IMPLND 108                          0      RCHRES   12       1
PERLND 115                          4      RCHRES   12       2
IMPLND 112                         17      RCHRES   12       1
PERLND 112                         24      RCHRES   12       2
RCHRES   1                                 RCHRES   12       3
RCHRES   2                                 RCHRES   12       3
RCHRES   3                                 RCHRES   12       3
PERLND 101                        223      COPY      1      90
```

```
IMPLND 101                            24       COPY      1      91
PERLND 102                          4813       COPY      1      90
IMPLND 102                           535       COPY      1      91
PERLND 113                            47       COPY      1      90
IMPLND 114                                     COPY      1      91
PERLND 103                           304       COPY      1      90
PERLND 111                           237       COPY      1      90
IMPLND 110                           102       COPY      1      91
PERLND 104                           131       COPY      1      90
IMPLND 104                           131       COPY      1      91
PERLND 105                           390       COPY      1      90
IMPLND 105                           168       COPY      1      91
PERLND 114                             6       COPY      1      90
PERLND 106                            20       COPY      1      90
IMPLND 106                            48       COPY      1      91
PERLND 108                            98       COPY      1      90
IMPLND 108                            27       COPY      1      91
PERLND 115                            43       COPY      1      90
IMPLND 112                           170       COPY      1      91
PERLND 112                           613       COPY      1      90
PERLND 116                           103       COPY      1      90
IMPLND 103                            34       COPY      1      91
PERLND 110                            13       COPY      1      90
IMPLND 111                                     COPY      1      91
PERLND 109                           138       COPY      1      90
IMPLND 113                                     COPY      1      91
IMPLND 115                            26       COPY      1      91
PERLND 107                            13       COPY      1      90
IMPLND 107                            37       COPY      1      91
PERLND 117                                     COPY      1      90
IMPLND 109                             7       COPY      1      91
PERLND 101                            74       COPY      2      90
IMPLND 101                             8       COPY      2      91
PERLND 102                          2484       COPY      2      90
IMPLND 102                           276       COPY      2      91
PERLND 103                           156       COPY      2      90
IMPLND 103                            18       COPY      2      91
PERLND 105                           213       COPY      2      90
IMPLND 105                            92       COPY      2      91
PERLND 108                            54       COPY      2      90
IMPLND 108                            15       COPY      2      91
PERLND 115                            15       COPY      2      90
IMPLND 112                            60       COPY      2      91
PERLND 112                           549       COPY      2      90
PERLND 113                             9       COPY      2      90
PERLND 116                           102       COPY      2      90
IMPLND 115                            26       COPY      2      91
PERLND 111                             5       COPY      2      90
IMPLND 110                             2       COPY      2      91
PERLND 106                            18       COPY      2      90
IMPLND 106                            42       COPY      2      91
PERLND 107                            13       COPY      2      90
IMPLND 107                            37       COPY      2      91
PERLND 109                           121       COPY      2      90
PERLND 117                                     COPY      2      90
PERLND 104                           100       COPY      2      90
IMPLND 104                           100       COPY      2      91
IMPLND 109                             6       COPY      2      91
PERLND 110                             3       COPY      2      90
PERLND 101                           127       COPY      3      90
IMPLND 101                            14       COPY      3      91
PERLND 102                          2000       COPY      3      90
IMPLND 102                           222       COPY      3      91
```

```
PERLND 105                          92     COPY     3     90
IMPLND 105                          40     COPY     3     91
PERLND 112                          40     COPY     3     90
PERLND 110                          10     COPY     3     90
PERLND 103                         143     COPY     3     90
PERLND 111                         188     COPY     3     90
IMPLND 110                          81     COPY     3     91
IMPLND 111                                 COPY     3     91
PERLND 104                           2     COPY     3     90
IMPLND 104                           2     COPY     3     91
IMPLND 112                          45     COPY     3     91
PERLND 109                          17     COPY     3     90
IMPLND 113                                 COPY     3     91
IMPLND 103                          16     COPY     3     91
PERLND 113                          10     COPY     3     90
PERLND 115                          12     COPY     3     90
PERLND 108                          14     COPY     3     90
IMPLND 108                           4     COPY     3     91
IMPLND 109                                 COPY     3     91
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
RCHRES   6 GQUAL  DQAL   1 1          AVER WDM1  2277 DQAL   1 ENGL AGGR REPL
RCHRES   6 GQUAL  RDQAL  1 1          AVER WDM1  2278 RDQAL  1 ENGL AGGR REPL
RCHRES   6 GQUAL  RODQAL 1 1          AVER WDM1  2279 RODQAL 1 ENGL AGGR REPL
RCHRES   5 GQUAL  DQAL   1 1          AVER WDM1  2271 DQAL   1 ENGL AGGR REPL
RCHRES   5 GQUAL  RDQAL  1 1          AVER WDM1  2272 RDQAL  1 ENGL AGGR REPL
RCHRES   5 GQUAL  RODQAL 1 1          AVER WDM1  2273 RODQAL 1 ENGL AGGR REPL
RCHRES   7 GQUAL  DQAL   1 1          AVER WDM1  2274 DQAL   1 ENGL AGGR REPL
RCHRES   7 GQUAL  RDQAL  1 1          AVER WDM1  2275 RDQAL  1 ENGL AGGR REPL
RCHRES   7 GQUAL  RODQAL 1 1          AVER WDM1  2276 RODQAL 1 ENGL AGGR REPL
RCHRES   2 ROFLOW ROVOL  1 1 0.0038936     WDM   2251 SIMQ   1 ENGL AGGR REPL
RCHRES   2 HYDR   RO     1 1          AVER WDM1  2259 FLOW   1 ENGL AGGR REPL
RCHRES   2 GQUAL  DQAL   1 1          AVER WDM1  2265 DQAL   1 ENGL AGGR REPL
RCHRES   2 GQUAL  RDQAL  1 1          AVER WDM1  2266 RDQAL  1 ENGL AGGR REPL
RCHRES   2 GQUAL  RODQAL 1 1          AVER WDM1  2267 RODQAL 1 ENGL AGGR REPL
RCHRES   3 ROFLOW ROVOL  1 1 0.0026093     WDM   2243 SIMQ   1 ENGL AGGR REPL
RCHRES   3 HYDR   RO     1 1          AVER WDM1  2260 FLOW   1 ENGL AGGR REPL
RCHRES   3 GQUAL  DQAL   1 1          AVER WDM1  2268 DQAL   1 ENGL AGGR REPL
RCHRES   3 GQUAL  RDQAL  1 1          AVER WDM1  2269 RDQAL  1 ENGL AGGR REPL
RCHRES   3 GQUAL  RODQAL 1 1          AVER WDM1  2270 RODQAL 1 ENGL AGGR REPL
RCHRES  12 HYDR   RO     1 1          AVER WDM1  2208 FLOW   1 ENGL AGGR REPL
RCHRES  12 ROFLOW ROVOL  1 1 0.0014109     WDM   2235 SIMQ   1 ENGL AGGR REPL
RCHRES  12 GQUAL  DQAL   1 1          AVER WDM1  2261 DQAL   1 ENGL AGGR REPL
RCHRES  12 GQUAL  RDQAL  1 1          AVER WDM1  2262 RDQAL  1 ENGL AGGR REPL
RCHRES  12 GQUAL  RODQAL 1 1          AVER WDM1  2263 RODQAL 1 ENGL AGGR REPL
RCHRES  12 ROFLOW ROSQAL 3 1          AVER WDM1  2264 ROSQAL 1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   1 1 1.1758e-4     WDM   2236 SURO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   2 1 1.1758e-4     WDM   2237 IFWO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   3 1 1.1758e-4     WDM   2238 AGWO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   4 1 1.1758e-4     WDM   2239 PETX   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   5 1 1.1758e-4     WDM   2240 SAET   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   6 1 1.1758e-4AVER WDM   2241 UZSX   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   7 1 1.1758e-4AVER WDM   2242 LZSX   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   1 1 2.1744e-4     WDM   2244 SURO   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   2 1 2.1744e-4     WDM   2245 IFWO   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   3 1 2.1744e-4     WDM   2246 AGWO   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   4 1 2.1744e-4     WDM   2247 PETX   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   5 1 2.1744e-4     WDM   2248 SAET   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   6 1 2.1744e-4AVER WDM   2249 UZSX   1 ENGL AGGR REPL
COPY     2 OUTPUT MEAN   7 1 2.1744e-4AVER WDM   2250 LZSX   1 ENGL AGGR REPL
```

```
COPY     3 OUTPUT MEAN   1 1 3.2446e-4     WDM   2252 SURO   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   2 1 3.2446e-4     WDM   2253 IFWO   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   3 1 3.2446e-4     WDM   2254 AGWO   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   4 1 3.2446e-4     WDM   2255 PETX   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   5 1 3.2446e-4     WDM   2256 SAET   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   6 1 3.2446e-4AVER WDM   2257 UZSX   1 ENGL AGGR REPL
COPY     3 OUTPUT MEAN   7 1 3.2446e-4AVER WDM   2258 LZSX   1 ENGL AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER PERO        0.0833333    RCHRES         INFLOW IVOL
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF   1
PERLND     PWTGAS POCO2M                   RCHRES         INFLOW OXIF   2
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT  1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PEST   POPST  1                 RCHRES         INFLOW IDQAL  1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  1 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  2 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  3 1
PERLND     SEDMNT SOSED  1                 RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED  1                 RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED  1                 RCHRES         INFLOW ISED   3
  END MASS-LINK    2

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO        0.0833333    RCHRES         INFLOW IVOL
IMPLND     IWTGAS SODOXM                   RCHRES         INFLOW OXIF   1
IMPLND     IWTGAS SOCO2M                   RCHRES         INFLOW OXIF   2
IMPLND     IWTGAS SOHT                     RCHRES         INFLOW IHEAT  1
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW IDQAL  1
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED   3
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3

  MASS-LINK       90
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER SURO                     COPY           INPUT  MEAN   1
PERLND     PWATER IFWO                     COPY           INPUT  MEAN   2
PERLND     PWATER AGWO                     COPY           INPUT  MEAN   3
PERLND     PWATER PET                      COPY           INPUT  MEAN   4
PERLND     PWATER TAET                     COPY           INPUT  MEAN   5
PERLND     PWATER UZS                      COPY           INPUT  MEAN   6
PERLND     PWATER LZS                      COPY           INPUT  MEAN   7
  END MASS-LINK   90

  MASS-LINK       91
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO                     COPY           INPUT  MEAN   1
```

```
IMPLND     IWATER PET                           COPY          INPUT  MEAN   4
IMPLND     IWATER IMPEV                         COPY          INPUT  MEAN   5
  END MASS-LINK   91
END MASS-LINK

END RUN
```