Attachment A

ESTIMATION OF NATIONAL SURFACE WATER QUALITY BENEFITS OF REGULATING CONCENTRATED ANIMAL FEEDING OPERATIONS (CAFOs) USING THE NATIONAL WATER POLLUTION CONTROL ASSESSMENT MODEL (NWPCAM)

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EXECUTIVE SUMMARY

A goal of the Clean Water Act (CWA) is to improve water quality conditions of the Nation's waters to attain "fishable and swimmable" status nationwide. In support of this goal, the United States Environmental Protection Agency (USEPA) is revising the National Pollutant Discharge Elimination System (NPDES) program regulations and the effluent limitation guidelines (ELGs) for concentrated animal feeding operations (CAFOs). Proposed changes to the NPDES regulations affect which animal feeding operations (AFOs) are considered CAFOs and are therefore subject to the NPDES permit program. Changes to the ELG determine what technology-based requirements apply to these CAFOs.

The National Water Pollution Control Assessment Model (NWPCAM) was employed to estimate national economic benefits to surface water quality resulting from implementation of various scenarios for regulating CAFOs. These scenarios include both revision of NPDES permit regulations and the ELGs for CAFOs. NWPCAM is a national-scale water quality model for simulating the water quality and economic benefits that can result from various water pollution control policies. NWPCAM is designed to characterize water quality for the Nation's network of rivers and streams, and, to a more limited extent, its lakes. NWPCAM is able to translate spatially varying water quality changes resulting from different pollution control policies into terms that reflect the value individuals place on water quality improvements. In this way, NWPCAM is capable of deriving economic benefit estimates for scenarios for regulating CAFOs.

Economic benefits associated with the various AFO/CAFO scenarios are based on changes in water quality use-support (i.e., boatable, fishable, swimmable) and the population benefitting from the changes. Benefits are calculated state-by-state at the State- (or local) scale as well as at the national-scale. For each State, benefits at the local-scale represent the value that the State population is willing to pay for improvements to waters within the State or adjoining the State. For each State, benefits at the national-scale represent the value that the State population is willing to pay for improvements to waters in all other states in the continental United States.

Based on the NWPCAM analysis, the total national willingness-to-pay (WTP) benefits at the local-scale for all water quality use-supports ranged from approximately $5.9 million (1999 dollars) for the least stringent scenario to $226.5 million for the most stringent scenario. The total national WTP benefits at the national-scale for all water quality use-supports ranged from approximately $0.4 million (1999 dollars) for the least stringent scenario to $52.9 million for the most stringent scenario. Total WTP benefits (i.e., sum of local-scale and national-scale) for all water quality use-supports ranged from approximately $6.3 million (1999 dollars) for the least stringent scenario to $285.6 million for the most stringent scenario.

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INTRODUCTION

1.1 BACKGROUND

Enactment of PL 92-500 in 1972, known as the Clean Water Act (CWA), established a national water pollution control policy based on technology-driven effluent standards for industrial waste waters and a minimum level of secondary treatment for municipal waste waters discharged to surface waters. The goal of the CWA was to improve water quality conditions of the Nation's waters to attain "fishable and swimmable" status nationwide. The Clean Water Act (CWA) requires that all point sources discharging pollutants into waters of the United States obtain a permit under the National Pollutant Discharge Elimination System (NPDES) program. The purpose of the NPDES program is to protect human health and the environment by controlling the types and amounts of pollutants that can be discharged into waters of the United States. NPDES permits implement a multifaceted approach to protecting water quality. At the core of these permits is a two-pronged pollution control strategy that incorporates both technology-based effluent limitation guidelines (ELGs) and more stringent site-specific limits based on water quality considerations.

The United States Environmental Protection Agency (USEPA) is revising the NPDES regulations for concentrated animal feeding operations (CAFOs) and the ELGs regulations for feedlots. Although similar changes are being considered regarding both regulations, the effects of such changes are different under each. Proposed changes to the NPDES regulations for CAFOs affect which animal feeding operations (AFOs) are considered CAFOs and are therefore subject to the NPDES permit program. Changes to the ELG regulations for feedlots determine what the technology-based requirements are that apply to these CAFOs.

1.2 FOCUS OF REPORT

This report presents the findings of modeling efforts designed to estimate national economic benefits to surface water quality resulting from implementation of various rule-making scenarios for regulating CAFOs. These scenarios include both revision of NPDES permit regulations as well as ELG for feedlot regulations for AFOs and CAFOs. Benefit analysis scenarios assessed include:

1. **Baseline (current regulations) scenario** (AFOs in 300-1000 animal size operation category are considered CAFOs if certain criteria are met; dry poultry and immature operations are excluded)

2. **ELG –based + NPDES Scenario 1** (Baseline scenario plus dry poultry and immature operations are considered CAFOs and nitrogen-based requirements apply to CAFOs)

3. **ELG N-based + NPDES Scenarios 2/3** (ELG N-based + new NPDES conditions for determining who is a CAFO; nitrogen-based requirements apply to CAFOs)

4. **ELG N-based + NPDES Scenario 4** (ELG N-based + All AFOs in the 300+ size category are considered CAFOs; nitrogen-based requirements apply to CAFOs)

5. **ELG N-based + NPDES Scenario 4a** (ELG N-based + All AFOs in the 500+ size category are considered CAFOs, excluding small farms; nitrogen-based requirements apply to CAFOs)

6. **ELG P-based + NPDES Scenario 1** (Baseline scenario plus dry poultry and immature operations are considered CAFOs; phosphorus-based requirements apply to CAFOs)

7. **ELG P-based + NPDES Scenarios 2/3** (ELG P-based + new NPDES conditions for determining who is a CAFO; phosphorus-based requirements apply to CAFOs)

8. **ELG P-based + NPDES Scenario 4** (ELG P-based + All AFOs in the 300+ size category are considered CAFOs; phosphorus-based requirements apply to CAFOs)

9. **ELG P-based + NPDES Scenario 4a** (ELG P-based + All AFOs in the 500+ size category are considered CAFOs; phosphorus-based requirements apply to CAFOs)

The National Water Pollution Control Assessment Model (NWPCAM) was employed to conduct the economic benefits analyses. Several additions to the most recent version of NWPCAM were developed and tested to address the specific issue of AFOs/CAFOs. These additions generally are consistent with the continued development and extension of NWPCAM for evaluating the environmental benefits of a variety of surface water quality policies. Specific modifications to NWPCAM needed to support the AFO/CAFO analyses include:

1. Adding a methodology to distribute AFOs/CAFOs and associated edge-of-field AFO/CAFO farm loadings (by county, animal type, facility size) for nutrients (nitrogen, phosphorus) and pollutants (fecal coliform, fecal streptococci, sediment) to agricultural landuses within watersheds;

2. Adding a methodology to transport edge-of-field AFO/CAFO loadings from agricultural landuses in a watershed to local waterbodies;

3. Adding a methodology to evaluate water quality use-support changes resulting from application of the various rule-making scenarios; and,

4. Linking the developed methodologies and tools for AFOs/CAFOs to NWPCAM.

1.3 REPORT OVERVIEW

Section 2 of the report presents a summary discussion of the technical approach, methodology, and modeling system design for the water quality benefits study. Section 3.0 presents the results and findings of the study. Section 4.0 presents a list of references/resources used in the study.

METHODOLOGY AND MODELING SYSTEM DESIGN

The National Water Pollution Control Assessment Model (NWPCAM) is a national-level water quality model for simulating the water quality and economic benefits that can result from various water pollution control policies. NWPCAM primarily is designed to characterize water quality for the Nation's network of rivers and streams, and, to a more limited extent, its lakes. NWPCAM incorporates a national scale water quality model into a system that is designed for conducting policy simulations and benefits assessments. NWPCAM is able to translate national scale and spatially varying water quality changes into terms that reflect the value that individuals place on water quality improvements. In this way, NWPCAM is capable of deriving benefit estimates for a wide variety of water pollution control policies.

NWPCAM's water quality modeling system is suitable for developing place-specific water quality estimates for virtually the entire inland regions of the country. The national-scale framework is based on a foundation that is allows hydraulic transport, routing and connectivity of surface waters to be performed in the entire continental United States. The model can be used to characterize source loadings (e.g., AFOs/CAFOs) under a number of alternative policy scenarios (e.g., loadings with controls). These loadings are processed through the NWPCAM water quality modeling system to estimate in-stream pollutant concentrations on a very large and detailed spatial scale and to provide estimates of policy-induced changes in water quality. The model then incorporates routines to translate water quality concentration estimates to measures of "beneficial use attainment" - categories including boating, fishing, and swimming - which are commonly used to characterize water quality for policy purposes. This allows for the calculation of categories of economic benefits associated with the estimated water quality improvements. NWPCAM therefore can be used to assess to assess both the water quality impacts and the social welfare implications of alternative policy scenarios.

NWPCAM provides a strong foundation upon which to simulate water quality and beneficial use attainment under different environmental policy scenarios. NWPCAM provides a framework for integrating geographic information systems (GIS) and environmental databases with several analytical tools to assess water quality improvements and compute attendant economic benefits from proposed environmental policies. The overall NWPCAM system has undergone several improvements in recent years to support increasingly more complex analyses as well as changes in information technology.

Section 2.1, which follows, presents a conceptual overview of the NWPCAM framework for the AFO/CAFO model and results discussed in this report. Section 2.2 discusses the major databases used for the AFO/CAFO analysis; these are important for understanding the methodology developed for the AFO/CAFO analysis. Section 2.3 discusses the methodology for the AFO/CAFO analysis.

2.1 CONCEPTUAL FRAMEWORK FOR AFO/CAFO MODEL

NWPCAM works within a national-scale framework. The foundation of this framework is the stream flow, transport, and flow-routing data obtained from the USGS' Hydro-Climatic Data Network (HCDN) database and USEPA's Reach File databases (RF1 and RF3). (The RF1 and RF3 databases contain information about the national network of rivers and streams in the United States. The RF3 database is more detailed than the RF1 database. RF3Lite is a subset of RF3). The RF3 database and associated hydrologic/reach routing framework at the core of NWPCAM have been developed so that RF3 can be replaced with the National Hydrography Dataset (NHD) when NHD is released. As a national-scale model, NWPCAM's framework is necessarily limited to readily available national databases that can be accessed and processed using automated input/output file management procedures. Types of waterbodies currently included in NWPCAM are: free-flowing streams and rivers, lakes characterized by inflows and outflows from streams and rivers, run-of-river reservoirs, and tidal rivers. Large open water systems of estuaries (e.g., Chesapeake Bay), embayments (e.g., Waquoit Bay), coastal waters (e.g., New York Bight, Southern California Bight), the Great Lakes, and other large lakes (e.g., Lake Champlain) are *not* incorporated in the current framework of NWPCAM.

At the conceptual level, the AFO/CAFO version of NWPCAM is comprised of several data management and analytical applications operating within the Microsoft Access environment on a Windows NT platform. NWPCAM essentially consists of several large databases integrated with numerous modeling and analysis modules (Figure 1). Table 1 presents a listing of the principal data requirements for NWPCAM. Within NWPCAM, a series of mathematical analyses is performed in accordance with the overall modeling process. Each analysis integrates new information and builds on the results of an earlier analysis. This process is completed semi-automatically by executing a series of computer programming modules written in Visual Basic under Microsoft Access. These modules perform various analytical or simulation routines required for the overall modeling process. Results from one module are passed to the subsequent module in the logical progression of the overall analysis. The purpose for these various modules or routines is presented in Section 2.3.

2.2 SPATIAL AND ENVIRONMENTAL DATABASES

The AFO/CAFO version of NWPCAM relies on several extensive datasets to support the various analytical routines developed to represent physical and chemical processes occurring within a watershed and along river reaches. Primary databases include: (1) land-use and land-cover information; (2) RF3/RF3Lite hydrologic/reach routing information; (3) AFO/CAFOs information; (4) watershed and stream discharge information; (5) non-point source nutrient export coefficients; and, (6) point source pollutant loading information. This section briefly describes the primary databases and the types of information each database contains. This discussion is intended to provide an overview of basic data requirements for the AFO/CAFO benefits analysis model process described in Section 2.3.

Figure 1

CONCEPTUAL SYSTEM-LEVEL FRAMEWORK OF NWPCAM

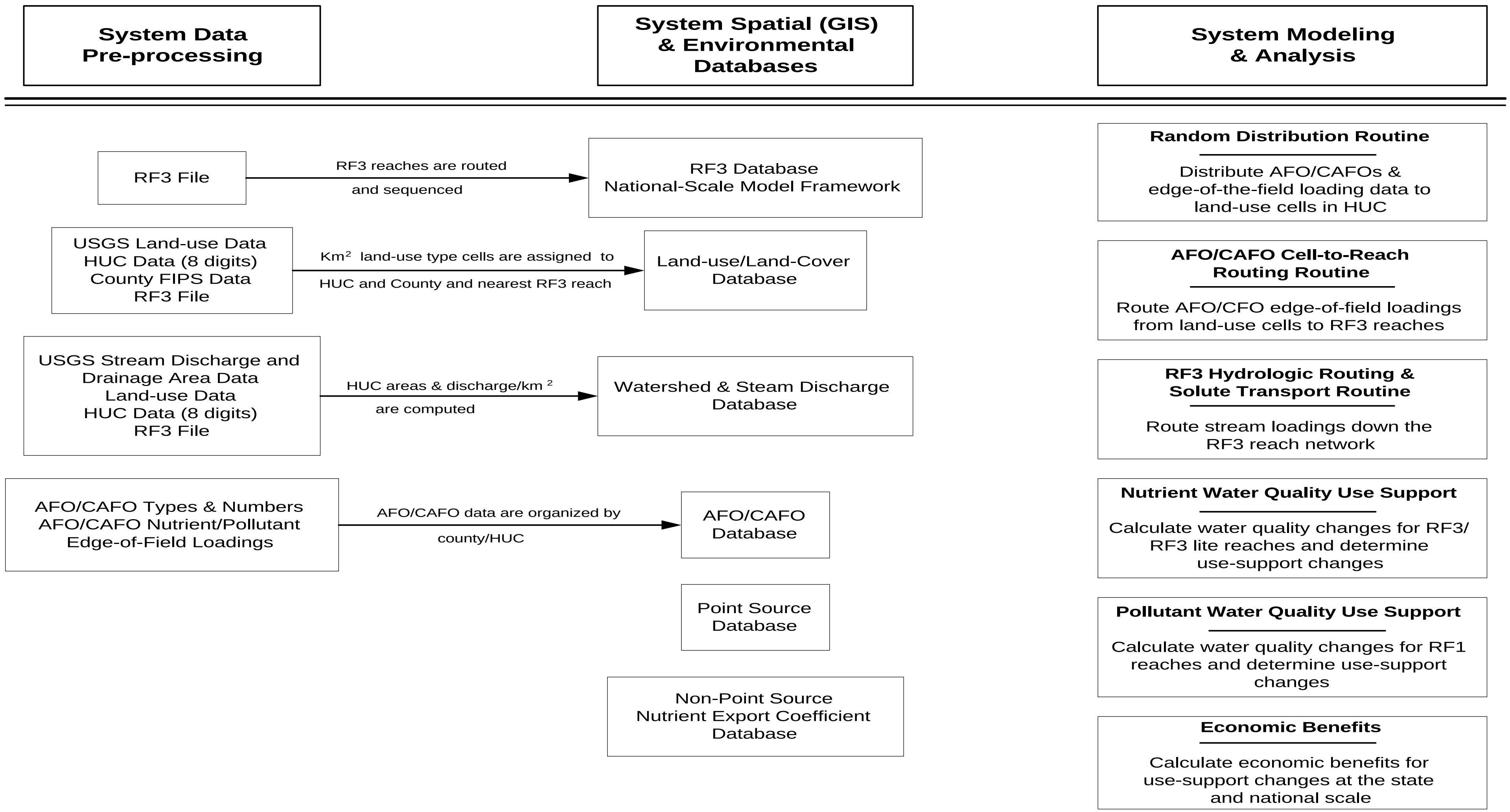


Table 1

ELEMENTS OF AFO/CAFO VERSION OF NWPCAM

Databases

- Reach File 3 (RF3) and Reach File 1 (RF1) routing data (ID, level, sequence number, stream order, routing parameters)
- Land-use/land-cover data (1 km^2 grid cells land-cover; land-use type, county, watershed, nearest reach and distance to nearest reach, elevation, slope, discharge per km^2/HUC based on USGS data)
- Watershed data for reaches and HUCs (drainage areas and discharges for watersheds; slope and sinuosity for reaches)
- AFO counts by county code (counts by animal operation type and size)
- Percentages of AFOs affected by rule-making scenarios (by scenario by State)
- AFO/CAFO edge-of-field nutrient loadings (nitrogen, phosphorus, nitrogen speciation, phosphorus speciation) (by animal operation type and size)
- AFO/CAFO edge-of-field pathogens and sediments loadings (by animal operation type/size)
- Point source nutrient loadings (source locations and loading data)
- Non-point source nutrient loadings (nutrient model export coefficient database) (based on land-use types and SPARROW results) (statistically based non-point source loading estimates)
- Point source/non-point source pollutant (sediments, fecal coliform, fecal streptococci) data
- State population data
- RF3 open waters data
- RF1 reach slopes data

Pre-Processing Routine

- Route and sequence RF3/RF3Lite
- Generate land-cover dataset with routed and sequenced RF3
- Calculate slopes and sinuosity for RF3 reaches and land-use cells
- Uniquely identify each AFO/CAFO animal operation and distribute by county code to correct hydroregion
- AFO/CAFO rule applications module (establish AFO/CAFO loads for analysis based on rule-making scenario)
- Calculate non-point source nutrient loadings to RF3Lite reaches (to establish non-point source nutrient loadings to streams)
- Calculate point source nutrient loadings to RF3Lite reaches (to establish point source nutrient loadings to streams)

Modeling & Analysis Module

- Distribution of AFO/CAFOs to agricultural land-use cells module (random distribution technique)
- Overland transport of nutrients/pollutants module (from agricultural land-use cells to reaches)
- RF3/RF3Lite hydrologic routing and transport module for nutrients/pollutants (discharge/velocity, nutrient/pollutant decay)
- RF3/RF3Lite Bathtub model with hydrodynamics module for determining effects of nutrients in lakes (chlorophyll " production)
- RF3Lite subset of RF3 hydrologic routing and transport module for determining effects of pollutants (fecal coliforms, fecal streptococci, sediment, etc.) (discharge/velocity, decay)
- Economic and water quality benefits/analyses module (calculate benefits based on differences in water quality use-support among different rule-making scenarios)

2.2.1 Hydrologic Routing File

The USEPA Reach Files are a series of hydrologic databases of the surface waters of the continental United States. The structure and content of the Reach File databases were created expressly to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature (i.e., the reach code). Reach codes uniquely identify, by watershed, the individual components of the Nation's rivers and lakes. A reach represents a segment of a river/stream. Several segments may be linked together to characterize (i.e., physically/hydraulically define) the total length and properties of a river/stream. The longer the river/stream, the more segments (reaches) are used to represent the full length of the river/stream.

USEPA's Reach File 3 (RF3) forms the national-scale model framework for the hydrologic routing routine upon which NWPCAM is based. The RF3 reach file is used to move water and pollutants in water from a point of origin within the continental United States toward the major rivers and ultimately toward the discharge of these waters/pollutants which usually is to the oceans. The RF3 reach file is discussed in several earlier reports (Bondelid, et al., 1999a; Bondelid et al., 1999b).

The RF3 file incorporates 1,821,245 RF3 reaches comprising some 2,595,657 river/stream miles within the 18 hydroregion system defining the river/stream network in the United States. The routing framework for Hydroregions 8 and 17 still is only available at the RF1 subset level of RF3 (known as RF3Lite) and includes 13,172 reaches comprising 99,217 miles. A key feature of RF3Lite is that it includes a much better and finer resolution and definition of impoundments (e.g., lakes) which are critical in the eutrophication analysis used to estimate chlorophyll ". RF3Lite includes 11,726 lakes representing 335,979 shoreline miles. For both reach datasets, hydrologic sequence numbers necessary for routing analyses are assigned starting at the most upstream reaches of a watershed and moving down the stream network. A small percentage of RF3 reaches are not networked in several of the hydroregions. In these cases where a sequence number is not assigned to a reach, the reach is considered to have no connectivity with the network and has been removed from the database for the AFO/CAFO version of NWPCAM.

2.2.2 Land-Use/Land-Cover File

The USGS conterminous United States Land Cover Characteristics (LCC) Data Set (Version 2) (Appendix A) forms the basis for the land-use/land-cover spatial coverage used by the AFO/CAFO version of NWPCAM. As discussed in Section 2.3, land-use/land-cover data are necessary for locating AFO/CAFO animal operations across the United States. The LCC dataset defines 27 land-use classifications.

Resolution of the land-use coverage dataset is a square kilometer (km^2). The coverage for the continental United States comprises approximately 7,686,100 million land-use cells at the square kilometer cell grid scale. The land-use coverage is overlain on the RF3 hydrologic routing framework to associate each land-use cell with a specific RF3 reach (RF3Lite in the case of Hydroregions 8 and 17), watershed, and hydroregion. Each land-use cell is assigned to the nearest routed RF3 reach for subsequent drainage area, stream discharge, and hydrologic routing purposes. Information in the dataset includes the land-use/land-cover code for each cell, the watershed (HUC) code and county code (COFIPS) in which the cell is located, the RF3 reach (RF3Lite for Hydroregions 8 and 17) associated with the cell, and related information. On a hydroregion basis, each land-use/land-cover cell is given a unique identification number for modeling purposes.

2.2.3 Stream Drainage Area and Discharge Data

Stream drainage area and discharge data and related hydrologic data at the RF3 reach level (RF3Lite for Hydroregions 8 and 17) are required for hydrologic routing and associated nutrient transport and decay processes simulated by NWPCAM. The USGS stream gages in the Hydro-Climatic Data Network (HCDN) were selected for the drainage area and discharge data comparisons because their predominant characteristic is that they represent relatively natural hydrologic conditions and are not influenced by controlled releases from reservoirs. Land-cover cells are assumed to drain into the nearest RF3 reach. The drainage area for each RF3 reach was calculated by assigning land-cover cells to the closest RF3 reach and then summing the areas of these cells. The drainage areas for downstream reaches (e.g., non-headwater RF3 reaches and RF3Lite reaches) were calculated based on drainage areas for upstream reaches. The drainage area for a RF3Lite reach was calculated by summing the drainage areas of any upstream RF3 reach. The RF3 reach network is routed from upstream to downstream, and RF3 reach drainage areas were summed until a RF3Lite reach is encountered. The summed drainage area then is added to the drainage area of the RF3Lite reach.

The HCDN dataset was used to derive unit runoff ($ft^3/sec/km^2$) values for land-use cells in each cataloging unit. Using a 200 mile maximum search radius from the centroid of each cataloging unit, the five (5) nearest HCDN gages were identified. In a small number of cases, less than five (5) gages were available within the 200 mile search radius. Runoff for the base 1 km^2 land-use cell (unit) was calculated using a weighted-average technique based on the distance of the HCDN gage from the centroid of the cataloging unit. For each cataloging unit, a land-use cell (unit) runoff was calculated based on mean annual discharge for the HCDN gages. Aggregation of the resulting unit cell runoffs for a reach would represent the total discharge originating from the land-use cells associated with the reach. Total discharge for a reach would equal the sum of the land-use cells related discharge plus the discharge originating from upstream reaches.

2.2.4 AFO/CAFO Dataset File

AFO/CAFO datasets were provided by USEPA. These datasets provide county-by-county listings of AFO/CAFO counts by animal operation type and size. The datasets also provide State-by-State percentages of AFOs that are considered CAFOs for various rule-making scenarios. In addition, the files provide edge-of-field nutrient (nitrogen and phosphorus) and pollutant (pathogens and sediment) loading values by animal operation type and size for various rule-making scenarios. Appendix B lists the animal operation types and sizes and corresponding average edge-of-field loading values for various rule-making scenarios. Approximately 67,000 unique AFO/CAFOs (representing 39 different animal operations in the five (5) defined regions of the United States, or a total of 195 animal operation loading categories) were distributed to 3,078 counties across the United States.

Animal operations and their associated edge-of-field nutrient and pollutant loadings for different NPDES rulemaking scenarios are distributed to agricultural land-use cells within the respective county of the AFO/CAFO during the modeling process. Nutrient and pollutant loadings were established based on the rulemaking scenarios and the percent of animal operations in each State affected by the scenarios. The relationship between land-use cells and RF3 reaches functions to establish which RF3 reach will receive runoff from an agricultural cell and any AFO/CAFOs associated with the cell.

2.2.5 Point Sources (Non-CAFO) Loadings Dataset

Point sources and associated nutrient load data and pollutant load data (fecal coliform, fecal streptococci, sediments), as available, from the earlier version of NWPCAM were used in the analyses. Point sources were delivered directly to the RF3Lite reaches for hydrologic routing through the river/stream network. Approximately 23,860 industrial and 8,942 municipal point sources were used in the analyses. Municipal wastewater, combined sewer overflow, and industrial point source loading data were obtained from USEPA's Permit Compliance System (PCS), Clean Water Needs Survey (CWNS), and the Industrial Facilities Database (IFD).

2.2.6 Non-Point Sources (Non-AFO Manure) Loadings Dataset

Nutrient loads for non-point sources were computed by land-use type by ecoregion based on SPARROW (*SPA*tially *R*eferenced *R*egression *O*n *W*atershed attributes) which is a statistical modeling approach for estimating major nutrient source loadings at a reach scale based on spatially referenced watershed attribute data. An optimization algorithm was developed to estimate non-manure loadings by comparing SPARROW non-manure non-point source estimates for cataloging units with modeled outputs. The optimal coefficient set was determined for both nitrogen and phosphorus for each ecoregion within a hydroregion. This was accomplished by iteratively running an optimization routine using a genetic algorithm to estimate loading coefficients for major land use categories present in the ecoregion. Non-point sources were delivered directly to the RF3Lite reaches for hydrologic routing through the river/stream network.

Non-point source data for fecal coliform, fecal streptococci, and sediments were not readily available at the national scale.

2.3 AFO/CAFOs BENEFITS ANALYSIS MODEL PROCESS

At the national scale, NWPCAM simulates the chemical and physical processes which occur within a watershed and along a hydrologic network. The simulations are performed on a reach-by-reach basis across the United States. As NWPCAM processes each RF3 or RF3Lite reach in accordance with the hydrologic sequencing scheme, various data must be extracted from the correct databases and the appropriate analytical models representing the physical and chemical processes must be applied. Typically, these models are executed to route water (i.e., stream discharge) and solutes (i.e., nutrients/pollutants) down a reach to the subsequent reach. NWPCAM accomplishes this by integrating the analytical and data management processes, listed below, into a coherent river and stream network that can characterize a meaningful "universe" of waters within the continental United States:

1. Distribute spatially-related AFO/CAFOs and associated farm-unit level edge-of-field nutrient/pollutant data (for different farm-unit types and sources) to agricultural lands within a defined watershed or county;

2. Calculate nutrient/pollutant loadings from these AFO/CAFO farm-unit levels to the nearby waterbody (i.e., RF3 reach). This process requires that the farm-unit level loadings be delivered from the farm unit to a waterbody;

3. Deliver nutrient/pollutant loadings from point sources (e.g., municipal wastewater treatment plants, industries) to a waterbody;

4. Deliver nutrient/pollutant loadings from non-point sources (e.g., non-AFO/CAFO agricultural run-off, municipal run-off) to a waterbody;

5. Simulate dilution, transport, and kinetics of the nutrients/pollutants loaded to the waterbody as the nutrients/pollutants are transported along the waterbody;

6. Relate the nutrient/pollutant concentrations along the waterbody course to beneficial use attainment criteria and goals;

7. Compute state and national economic benefits for changes in water quality use-support; and

8. Characterize AFO/CAFO source loadings under different policy scenarios (i.e., no treatment/control of farm-unit loading or limited treatment/control).

All of these elements are integrated into a “modeling system shell” through which NWPCAM is executed. Figure 2 presents a simplified functional-level flowchart of the actual NWPCAM process employed for estimating the benefits of AFO/CAFO regulations. The left-hand column of

Figure 2 represents the main processes with the right-hand columns representing integration of data and analytical modeling modules. The overall process is summarized below. A detailed discussion of the technical foundation of the physical and chemical processes represented in the model is presented in Appendix C.

Step 1 - Sequencing of Hydrologic Networks

The NWPCAM process starts with the RF3 river network as the modeling framework. The RF3 network for an entire hydroregion is hydrologically networked to ensure that the streams and lakes are properly connected. Where the RF3 connectivity is not correct (e.g., at watershed boundaries), a manual correction has been made to join the disconnected reaches. The hydrologic sequencing is essential to ensure that nutrient/pollutant loadings are fully routed down the reaches to represent the entire drainage areas of the reaches and larger watersheds. Hydrologic sequencing is a powerful Reach File-based process for simulating transport through the network

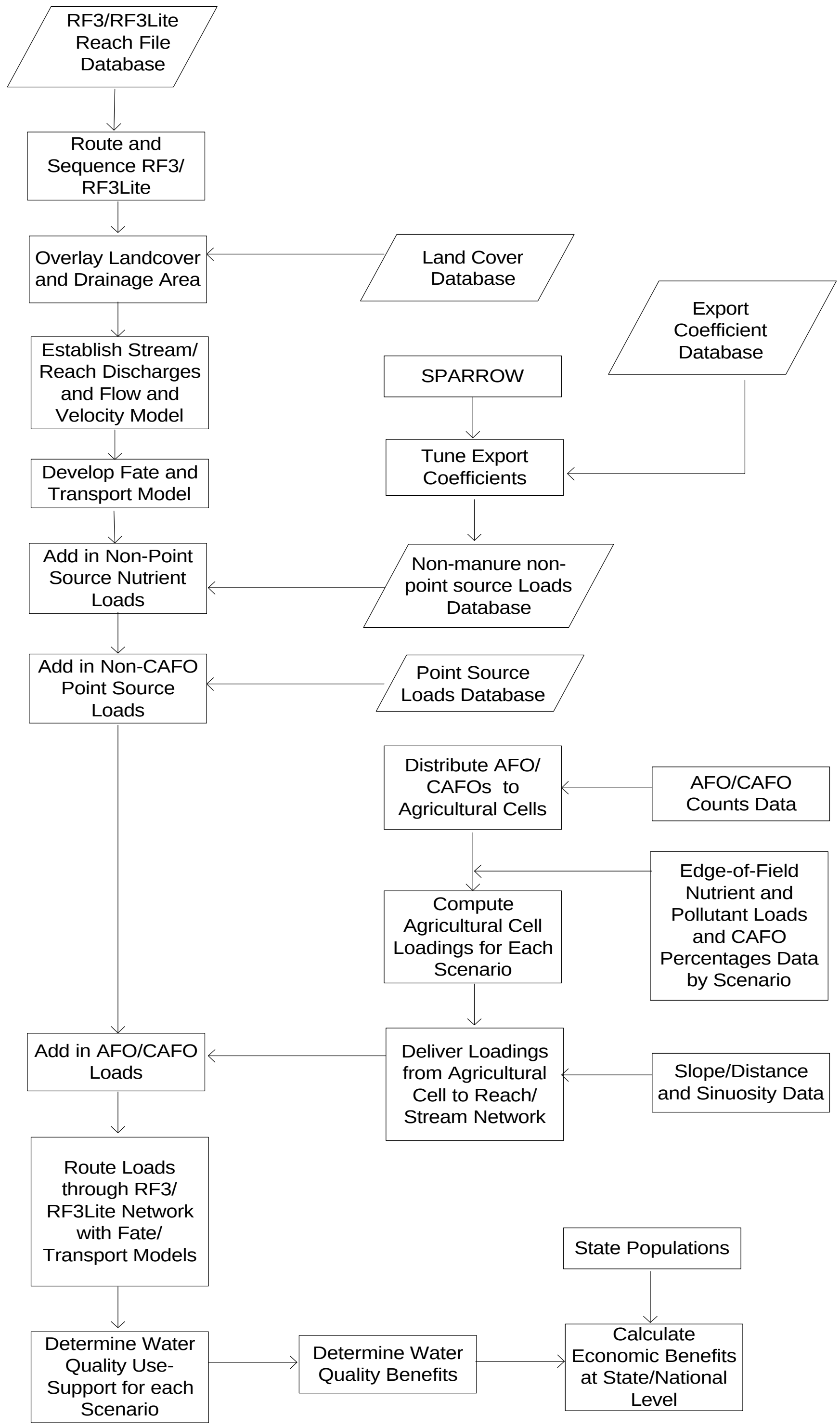
Once the hydrologic sequencing is completed, land-cover data are overlain onto the RF3 network using GIS. This produces an RF3 network that has land-cover distributions and drainage area estimates for each reach within a watershed. Depending on the drainage area estimates, different reach specific discharge/velocity models may be applied for routing purposes. These discharge and velocity estimates are derived from USGS gaging station data and associated drainage area data. Once the hydrologic sequencing and stream flow and velocity models have been established for each river/stream reach, nutrient/pollutant loadings for various source types are integrated into NWPCAM.

Step 2 - AFO/CAFO Distribution and Nutrient/Pollutant Loadings

Several routines are required to integrate AFO/CAFO data into the system. These involve: (1) taking the counts of different types of animal operations on a county level and distributing them and their associated nutrient/pollutant loads to the agricultural lands within the specified county/watershed; (2) taking edge-of-field nutrient/pollutant loading data for each animal operation and modeling the flow from the field-level to the reach/stream; and, (3) then adding these loadings to each reach within the overall NWPCAM framework.

Figure 2

OVERVIEW OF AFO/CAFOs' BENEFITS ANALYSIS PROCESS



AFO/CAFOs and associated edge-of-field nutrient/pollutant loadings were randomly distributed to agricultural land-use cells within the respective county of the AFO/CAFO. Animal manure could be applied to any cell defined as agricultural (Level 1, 2, and 3 categories) within the classification scheme (Appendix A). Agricultural land-use cells could accumulate loadings from several different animal operation types and sizes provided a maximum cell loading amount was not exceeded. The maximum amount for the cells was established based on nitrogen and phosphorus export coefficients for various land uses reported by USEPA (Reckhow et al., 1980). The maximum value represents the amount of nitrogen or phosphorous that can reasonably be exported from an agricultural cell. The random distribution technique was applied county-by-county (and AFO/CAFO by AFO/CAFO) across the United States until all AFO/CAFO assignments had been completed.

In order to be hydrologically routed through the river/stream network, these loadings then are delivered from the agriculture cells to RF3 reaches (RF3Lite for Hydroregions 8 and 17) using a routine to simulate an overland transport process. Overland travel times and associated nutrient decay are based on flow in a natural channel such as may be found on agricultural lands. A unit runoff ($ft^3/sec/km^2$) is derived for each HUC based on data from USGS stream gages in the Hydro-Climatic Data Network (HCDN). The unit runoff therefore represents runoff from each agricultural cell within the HUC and can be used to derive time-of-travel estimates necessary for the routing process as well as for computing nutrient/pollutant decay during the process. Travel distances are from the center of the agricultural cell to the nearest RF3 reach

Non-manure non-point source loadings and point source loadings for nutrients/pollutants then are brought into the system and "loaded" onto each RF3Lite reach from the respective datasets. At this point, a fully developed system has been established that now can perform in-stream water quality modeling.

Step 3 - Hydrologic Routing of Nutrient/Pollutant Loads in RF3 Reaches

Once all nutrient/pollutant loadings have been established, actual model simulations are performed. Loadings delivered to the RF3 reaches are hydraulically routed through the watershed (HUC) following the RF3 hydrologic sequencing schema. As nutrients/pollutants are routed through the hydrologic network from upstream reach to downstream reach in according to the NWPCAM routing schema, nutrient/pollutant decay processes are simulated.

Step 4 - Hydrologic Routing of Nutrient/Pollutant Loads for RF3Lite Reaches

As RF3Lite reaches are encountered during hydrologic routing, all nutrient/pollutant loads to an RF3Lite reach {i.e., AFO/CAFO loads derived from upstream RF3 reaches, point source (non-CAFO) loads, and non-point source (non-manure) loads} are aggregated at the RF3Lite reach level and hydrologic routing continues through the remainder of the HUC and hydroregion. For reaches of Strahler Stream Order 6 or higher (i.e., the larger streams), the discharge for the RF3Lite reach is based on USGS data used in earlier versions of NWPCAM rather than the unit runoffs ($ft^3/sec/km^2$) derived from the HCDN gages. Nutrient/pollutant decay processes are allowed as the nutrients are routed through the RF3Lite reach network. For nutrients, a eutrophication model (BATHTUB) developed for the US Army Corps of Engineers was used to model the response of RF3Lite lakes and reservoirs with a residence time of at least one month to nutrient loadings. The principal output of interest for nutrients was chlorophyll ".

For the CAFO/AFO pollutants (fecal coliform, fecal streptococci, sediments, nitrogenous oxygen demand), all loads were routed with the RF1 reach file to take advantage of earlier work with NWPCAM Version 1.1. The principal outputs of interest for these pollutants were concentrations (or most probable number colony counts for microbiological parameters) of each of these pollutants. In addition, NWPCAM models other fecal coliform sources, instream dissolved oxygen concentrations, and point and NPS loads for biochemical oxygen demand.

Step 5 - Water Quality Assessment Ladder

For nutrients (nitrogen and phosphorous) a regionalized water quality ladder was developed to relate predicted chlorophyll " concentrations in lakes and reservoirs to the ability of the waterbody to support designated uses. This "ladder" is grounded on the NWPCAM water quality ladder approach built into the NWPCAM benefits assessment that focuses on recreational benefits for boating, fishing, and swimming. Values for four (4) project-specific geographic regions were subjectively determined using the available assessment endpoints developed by several States and Region IV. Some geographic regionalization was warranted to account for: trophic gradients across ecoregions (associated with latitude, altitude, climate, land cover, etc.) and judgment regarding public perceptions for major recreational uses in these different ecoregions. The 14 nutrient regions proposed by USEPA's Office of Science and Technology (OST) were collapsed into four regions for assessment purposes.

For biochemical oxygen demand, dissolved oxygen, fecal coliforms, and sediments, water quality conditions were related to beneficial use for recreation activities using the approach developed by Vaughn (Mitchell and Carson, 1986; Bingham et al., 1998). This approach sets a maximum pollutant level that corresponds to boatable, fishable, and swimmable waters. A river/stream reach that fails to meet the boating criterium is classified as a non-support resource.

Step 6 - Economic Benefits Analysis (Mitchell-Carson Model)

Economic benefits associated with the various rule-making scenarios are derived from changes in water quality use-support among the AFO/CAFO rulemaking scenarios and the population benefitting from the changes. The contingent value method (CVM) for estimating the national benefits of freshwater pollution control developed by Mitchell and Carson (1986, 1993) was used in the analysis. Application of the economic benefit analysis model used in NWPCAM, including the general water quality use-support ladder, is discussed in detail in early versions of NWPCAM (e.g., Bingham et al., 1998).

As noted previously, changes in concentration of chlorophyll " among the range of AFO/CAFO rule-making scenarios can be used to develop water quality benefits information which then can be related to economic benefits. This approach was developed for the AFO/CAFO version of NWPCAM and will have greater application for future assessment work. Future work also will evaluate incorporation of a water quality index approach to better assess use-support changes and associated economic benefits compared to the current threshold approach used in NWPCAM.

Based on the water quality assessments for each AFO/CAFO rulemaking scenario and baseline conditions, the RF3/RF3Lite river/stream miles corresponding to each reach are categorized at the State level as swimmable (highest use), fishable, boatable (lowest use), and no-use. The difference in the miles for each use category between baseline conditions and a given AFO/CAFO rulemaking scenario is a measure of the improvement in water quality attributable to the scenario in the given State. These differences in miles then can be converted into economic benefits (dollars) based on the State population and their willingness to pay for improvement in water quality. Benefits are calculated state-by-state at the State (or local) scale as well as at the national scale. For each State, benefits at the local scale represent the value that the State population is willing to pay for improvements to waters within the State or adjoining the State. For each State, benefits at the national scale represent the value that the State population is willing to pay for improvements to waters in all other states in the continental United States.

RESULTS OF AFO/CAFO NWPCAM ANALYSES

This section summarizes the results of the NWPCAM analyses for the AFO/CAFO rulemaking scenarios.

3.1 AFO/CAFO NUTRIENT/POLLUTANT LOADINGS TO NWPCAM

3.1.1 AFO/CAFO Animal Operation Nutrient/Pollutant Loadings to Agricultural Cells

The AFO/CAFO nutrient/pollutant edge-of-field loadings to agricultural cells for baseline conditions and rulemaking scenarios are summarized at the national level in Table 2. These represent the total national edge-of-field loadings actually distributed to the agricultural cells in each hydroregion based on the animal operation types and counts (by county), edge-of-field animal operation loading amounts, and CAFO percentages (by State) provided as input data to the NWPCAM model. A summary of nutrient/pollutant loadings by hydroregion is presented in Appendix D. Note that there are no loadings for dissolved oxygen or biochemical oxygen demand; these constituents do not get modeled until the NWPCAM 1.1/RF3Lite system is used.

Table 2

AFO/CAFO EDGE-OF-FIELD LOADINGS TO AGRICULTURAL CELLS

Rulemaking Scenario	Nitrogen (kg)	Phosphorus (kg)	Fecal Coliforms (colonies)	Fecal Streptococci (colonies)	Sediments (kg)
Baseline Conditions	233,525,745	409,400,420	204,053,884,629	454,905,954,288	724,557,970,319
ELG-N Based + NPDES 1	90,731,921	219,231,299	94,390,795,387	291,361,847,324	724,584,476,131
ELG-N Based + NPDES 2/3	179,626,650	167,235,044	72,522,541,049	259,210,267,437	724,425,952,860
ELG-N Based + NPDES 4	173,597,152	153,896,202	59,588,436,959	250,179,462,734	724,479,970,808
ELG-N Based + NPDES 4A	182,228,654	178,931,923	80,932,229,911	261,059,537,225	724,942,720,312
ELG-P Based + NPDES 1	151,520,135	177,133,826	86,203,154,932	250,661,643,915	564,709,845,139
ELG-P Based + NPDES 2/3	132,438,608	115,189,247	62,601,737,709	210,628,357,908	517,225,861,342
ELG-P Based + NPDES 4	122,727,996	93,171,327	47,757,072,825	190,522,310,519	497,361,824,117
ELG-P Based + NPDES 4A	135,691,107	126,538,544	72,098,401,356	218,157,805,079	519,645,650,360

3.1.2 Nutrient/Pollutant Loadings to RF3 Rivers/Streams

The AFO/CAFO nutrient/pollutant loadings from the agricultural cells to the RF3 rivers/streams for baseline conditions and rulemaking scenarios are summarized at the national level in Table 3. These represent the total national loadings delivered to the RF3 rivers/streams in each hydroregion after overland transport from the agricultural cells to the nearest RF3 river/stream. A summary of nutrient/pollutant loadings delivered to RF3 rivers/streams by hydroregion is presented in Appendix E.

Table 3

AFO/CAFO NUTRIENT/POLLUTANT LOADINGS TO RF3 RIVERS/STREAMS

Rulemaking Scenario	Nitrogen (kg)	Phosphorus (kg)	Fecal Coliforms (colonies)	Fecal Streptococci (colonies)	Sediments (kg)
Baseline Conditions	207,172,103	274,379,073	170,890,941,721	426,097,531,733	496,849,531,724
ELG-N Based + NPDES 1	169,670,489	149,443,526	79,311,777,692	274,619,502,099	496,786,263,333
ELG-N Based + NPDES 2/3	159,481,499	110,314,972	60,519,088,349	243,939,492,896	496,639,130,708
ELG-N Based + NPDES 4	154,021,138	101,508,750	49,184,461,007	235,553,581,393	496,674,058,639
ELG-N Based + NPDES 4A	161,969,422	119,335,737	68,181,585,844	246,021,145,846	496,690,563,064
ELG-P Based + NPDES 1	135,589,770	122,873,183	72,786,585,361	236,436,778,330	387,361,686,699
ELG-P Based + NPDES 2/3	118,085,867	76,670,638	52,513,271,739	198,394,396,915	354,004,956,240
ELG-P Based + NPDES 4	109,297,015	62,002,562	39,492,937,803	179,447,977,975	340,409,785,399
ELG-P Based + NPDES 4A	121,237,778	85,579,407	61,154,656,930	205,893,202,113	356,375,645,300

National nutrient loadings from non-CAFO point sources and non-manure non-point sources to the RF3Lite subset of RF3 rivers/streams for baseline conditions and all rulemaking scenarios are:

- Non-manure non-point sources nitrogen - 4,002,015,576 kg
- Non-manure non-point sources phosphorus - 289,316,930 kg
- Non-CAFO point sources nitrogen - 681,626,859 kg
- Non-CAFO point sources phosphorus - 180,392,329 kg

A summary of these nutrient loadings delivered to the RF3Lite subset of RF3 rivers/streams by hydroregion is presented in Appendix F.

The total nutrient loadings for all sources to the RF3Lite rivers/streams for baseline conditions and rulemaking scenarios are summarized at the national level in Table 4. These represent the total national loadings delivered to the RF3/RF3Lite rivers/streams in each hydroregion for all sources (AFO/CAFO, point sources, non-point sources). A summary of total nutrient loadings delivered to RF3/RF3Lite rivers/streams by hydroregion is presented in Appendix G.

Table 4

TOTAL NUTRIENT LOADINGS FROM ALL SOURCES TO RF3/RF3LITE RIVERS/STREAMS

Rulemaking Scenario	Nitrogen (kg)	Phosphorus (kg)
Baseline Conditions	4,818,474,637	622,021,141
ELG-N Based + NPDES 1	4,804,297,335	587,270,057
ELG-N Based + NPDES 2/3	4,802,610,637	577,057,623
ELG-N Based + NPDES 4	4,800,569,076	573,812,514
ELG-N Based + NPDES 4A	4,736,182,446	503,543,979
ELG-P Based + NPDES 1	4,793,938,472	579,629,078
ELG-P Based + NPDES 2/3	4,788,279,903	257,062,967
ELG-P Based + NPDES 4	4,785,146,081	242,394,891
ELG-P Based + NPDES 4A	4,722,072,825	4,939,748,823

3.1.3 AFO/CAFO Nutrient/Pollutant Loadings to RF3Lite Subset of RF3 Rivers/Streams

The AFO/CAFO nutrient/pollutant loadings to the RF3Lite subset of RF3 rivers/streams for baseline conditions and rulemaking scenarios are summarized at the national level in Table 5. These represent the total national AFO/CAFO loadings delivered to the RF3Lite subset of RF3 rivers/streams in each hydroregion after transport down the RF3 network to the first RF3Lite reach segment encountered. A summary of AFO/CAFO nutrient/pollutant loadings delivered to RF3Lite rivers/streams by hydroregion is presented in Appendix H.

Table 5

AFO/CAFO NUTRIENT/POLLUTANT LOADINGS TO RF3LITE SUBSET OF RF3 RIVERS/STREAMS

Rulemaking Scenario	Nitrogen (kg)	Phosphorus (kg)	Fecal Coliforms (colonies)	Fecal Streptococci (colonies)	Sediments (kg)
Baseline Conditions	67,416,101	76,155,941	49,474,666,517	116,950,342,436	118,052,961,198
ELG-N Based + NPDES 1	53,238,799	41,405,057	23,524,433,633	79,519,233,031	118,054,745,346
ELG-N Based + NPDES 2/3	51,552,101	31,192,423	18,487,988,354	71,842,129,656	118,031,169,594
ELG-N Based + NPDES 4	49,510,540	27,947,314	15,309,272,968	69,907,467,895	118,039,297,764
ELG-N Based + NPDES 4A	52,540,011	33,834,720	20,852,111,289	72,649,447,223	118,039,417,052
ELG-P Based + NPDES 1	42,879,936	33,763,878	20,915,375,036	66,816,096,450	91,666,187,919
ELG-P Based + NPDES 2/3	37,221,367	21,488,232	15,428,542,351	56,802,296,294	83,404,421,054
ELG-P Based + NPDES 4	34,087,545	16,574,249	11,755,865,736	51,825,139,667	80,271,820,096
ELG-P Based + NPDES 4A	38,430,390	24,265,564	18,089,500,824	59,336,357,588	84,225,725,566

3.2 WILLINGNESS-TO-PAY (WTP) ECONOMIC BENEFITS OF AFO/CAFO RULEMAKING SCENARIOS

3.2.1 State WTP Economic Benefits of Proposed AFO/CAFO Rule Making Scenarios

Willingness-to-pay (WTP) benefits were calculated at the State and National level on a State-by-State basis as part of the NWPCAM analyses. Economic benefits are based on improvement in water quality use-support resulting from application of a particular AFO/CAFO rulemaking scenario compared to baseline conditions and the willingness of the population to pay for improvements for different use-support categories. Table 6 provides a National summary of the State WTP economic benefits for each scenario. This summary was computed by summing the State WTP economic benefits for each individual State. A summary of economic benefits by State is presented in Appendix I.

Table 6

NATIONAL SUMMARY OF STATE WTP ECONOMIC BENEFITS FOR AFO/CAFO RULEMAKING SCENARIOS (1999 $)

Rulemaking Scenario	WTP Boatable Waters	WTP Fishable Waters	WTP Swimmable Waters
ELG-N Based + NPDES 1	1,571,871	2,524,541	1,849,672
ELG-N Based + NPDES 2/3	2,716,687	2,825,879	2,440,775
ELG-N Based + NPDES 4	3,563,105	3,342,739	2,619,167
ELG-N Based + NPDES 4A	2,694,501	2,790,265	1,838,272
ELG-P Based + NPDES 1	75,069,157	58,750,666	14,924,114
ELG-P Based + NPDES 2/3	94,895,076	84,402,779	22,280,588
ELG-P Based + NPDES 4	104,256,854	95,400,962	26,790,503
ELG-P Based + NPDES 4	96,095,189	80,863,846	22,065,689

3.2.2 National WTP Economic Benefits of Proposed AFO/CAFO Rule Making Scenarios

Table 7 provides a National summary of the National WTP economic benefits for each scenario. This summary was computed by summing the National WTP economic benefits for each individual State. A summary of economic benefits by State is presented in Appendix J. The total benefits (State WTP plus National WTP) for each scenario are summarized in Table 8.

Table 7 NATIONAL SUMMARY OF NATIONAL WTP ECONOMIC BENEFITS FOR AFO/CAFO RULEMAKING SCENARIOS (1999 $)			
Rulemaking Scenario	**WTP Boatable Waters**	**WTP Fishable Waters**	**WTP Swimmable Waters**
ELG-N Based + NPDES 1	-166,040*	238,868	285,585
ELG-N Based + NPDES 2/3	689,071	402,586	679,442
ELG-N Based + NPDES 4	820,678	502,979	735,642
ELG-N Based + NPDES 4A	636,623	350,724	594,681
ELG-P Based + NPDES 1	21,809,705	12,212,185	1,735,699
ELG-P Based + NPDES 2/3	27,612,255	17,953,473	2,431,599
ELG-P Based + NPDES 4	30,024,109	20,091,405	2,734,999
ELG-P Based + NPDES 4A	27,906,590	16,976,164	2,353,412

* This represents noise/artifacts in summing up river/stream miles of improvement at the national scale upon which economic benefits are based.

Table 8 SUMMARY OF TOTAL NATIONAL WTP ECONOMIC BENEFITS FOR AFO/CAFO RULEMAKING SCENARIOS (1999 $)			
Rulemaking Scenario	**WTP Boatable Waters**	**WTP Fishable Waters**	**WTP Swimmable Waters**
ELG-N Based + NPDES 1	1,405,831	2,763409	2,135,257
ELG-N Based + NPDES 2/3	2,405,758	3,228,465	3,120,217
ELG-N Based + NPDES 4	4,383,783	3,845,718	3,354,809
ELG-N Based + NPDES 4A	3,331,124	3,140,989	2,432,953
ELG-P Based + NPDES 1	96,878,862	70,962,851	16,659,813
ELG-P Based + NPDES 2/3	122,507,331	102,356,252	24,712,187
ELG-P Based + NPDES 4	134,280,963	115,492,367	29,525,502
ELG-P Based + NPDES 4A	124,001,779	84,004,835	24,498,642

REFERENCES

Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. *The Water Quality Analysis Simulation Program, WASP5, Parts A and B, Version 5.10.* Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Bingham, T. H., T. R. Bondelid, B. M. Depro, R. C. Figueroa, A. B. Hauber, S. J. Unger, G. L. Van Houtven, and A. Stoddard. *A Benefits Assessment of Water Pollution Control Programs Since 1972.* Draft. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. June 1998.

Bondelid, T., C. Griffifths, G. Van Houtven. 1999a. *A National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. March 1999.

Bondelid, T., R. Dodd, C. Spoerri, and A. Stoddard. 1999b. *The Nutrients Version of the National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. December 1999.

Brown, L., and T. Barnwell. 1987. *The Enhanced Stream Water Quality Model Qual2E and Qual2e-UNCAS: Documentation and User's Manual*. Athens, GA: U.S. Environmental Protection Agency, Environmental Research Laboratory. EPA/600/3-87/007.

Carson, R.T., and R.C. Mitchell. 1993. The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water. *Water Resources Research*, Vol. 29, No. 7, pp. 2445-2454. July.

Cerco, C., and T. Cole. 1993. *Application of a Three-Dimensional Eutrophication Model CE-QUAL-ICM to Chesapeake Bay*. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station.

Cerco, C., and T. Cole. 1994. *Three-Dimensional Eutrophication Model of Chesapeake Bay*. Vol. 1, Main Report. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station, Tech. Rep. EL-94.4.

Chapra, S.C. 1997. *Surface Water Quality Modeling*. New York: McGraw Hill Publishing.

Clark, M. M.J. Kealy, V. Kibler, and R. Stein. 1995. *Impacts of Municipal Wastewater Treatment: A Retrospective Analysis*. United States Environmental Protection Agency, Office of Water. Washington, DC.

DiToro, D.M., and J.P. Connolly. 1980. *Mathematical Models of Water Quality in Large Lakes: Part 2: Lake Erie*. EPA-600/3-80-6. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Di Toro, D.M., P.R. Paquin, K. Subburamu, and D.A. Gruber. 1990. Sediment Oxygen Demand Model: Methane and Ammonia Oxidation. *Jour. EED, ASCE,* 116(5):945-987.

Dillon, P.J., and F.H. Rigler. 1974. The Phosphorus-Chlorophyll Relationship in Lakes. *Limnology and Oceanography* 19(5):767-773.

Eidenshink, J.E., 1992, The conterminous United States AVHRR data set. In *Photogrammetric Engineering and Remote Sensing*, v. 58, no. 6, p. 809-813.

EnviroTech Associates, Inc. 1992. *Post Audit of the Upper Mississippi River Model Using 1988 Summer Low Flow Water Quality Data*. Final Tech. Report submitted to Metropolitan Waste Control Commission, St. Paul, Minnesota by EnviroTech Associates, Inc., Charlottesville, Virginia, November.

EnviroTech Associates, Inc. 1993. *Water Quality Modeling of the Upper Mississippi River and Lake Pepin. Mississippi River Phosphorous Study, Section 6: Part A*. Tech. Report submitted to Metropolitan Waste Control Commission, St. Paul, Minnesota by EnviroTech Associates, Inc., Charlottesville, Virginia, March.

Hamrick, J.M. 1996. *Users Manual for the Environmental Fluid Dynamic Computer Code*. The College of William and Mary, Virginia Institute of Marine Science, Special Report, 238, 224p.

Henderson, F.M. 1966. *Open Channel Flow*. New York: Macmillian Publishing Co., Inc.

Horner, R.R., and E.B. Welch. 1981. Stream Periphyton Development in Relation to Current Velocity and Nutrients. *Can. Jour. Fish. Aquat. Sci*. 38(4):449-457.

HydroQual. 1999. *Advanced eutrophication model of the Upper Mississippi River, Summary Report.* Draft Tech. Report submitted to Metropolitan Council Environmental Services, St. Paul, Minnesota by HydroQual, Inc., Mahwah, New Jersey, April.

Hydroscience. 1979. Upper Mississippi River 208 Grant Water Quality Modeling Study. Tech. Report submitted to Metropolitan Waste Control Commission, St. Paul, Minnesota by Hydroscience, Inc. Westwood, New Jersey, January.

ICPRB. 1991. *Calibration and Verification of Upper Potomac River Model, Volume I.* ICPRB Report No. 91-XX. Rockville: Interstate Commission on the Potomac River Basin.

Kennedy, Robert H. Application of the BATHTUB Model to Selected Southeastern Reservoirs. Technical Report EL-95-14. US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. April, 1995.

Keup, L.E. 1985. Flowing Water Resources. Prepared for *Water Resources Bulletin*, American Water Resources Association. 21;2. April.

Lovejoy, S.B. 1989. *Changes in cropland loadings to surface waters: Interim report No. 1 for the development of the SCS National Water Quality Model*. Purdue University, West Lafayette, Indiana.

Lovejoy, S.B., and B. Dunkelberg. 1990. *Water quality and agricultural policies in the 1990s: Interim report No. 3 for development of the SCS National Water Quality Model*. Purdue University, West Lafayette, Indiana.

Mancini, J. 1978. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. *Jour. WPCF* 50(11):2477-2484.

Mitchell, R.C., and R.T. Carson. 1986. The Use of Contingent Valuation Data for Benefit/Cost Analysis in Water Pollution Control. CR-810224-02. Prepared for USEPA, Office of Policy Planning and Evaluation. Washington, DC.

Novotny, V., and H. Olem. 1994. *Water Quality Prevention, Identification and Management of Diffuse Pollution*. New York: Van Nostrand Reinhold.

Rast, W., and G.F. Lee. 1978. *Summary Analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading Lake Response Relationships and Trophic State Indices. EPA-600/3-78-008.* U.S. Environmental Protection Agency. p. 453.

Reckhow, Kenneth H. 1990. EUTROMOD spreasheet program-a regional modeling scheme for nutrient runoff and lake trophic state modeling. School of the Environment, Duke University.

Reckhow, K.H., Beaulac, M.N., Simpson, J.T. 1980. *Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients*. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, Washington, DC. EPA 440/5-80-011.

RTI (Research Triangle Institute). 1998. *National Surface Water Nutrient Study: Feasibility Assessment and Recommendations for Expanding the NWPCAM.* Draft Final Report. Prepared for U.S. Environmental Protection Agency Office of Policy and Budget. Research Triangle Institute, September 1998.

Schnoor, J.L., and D.J. O'Connor. 1980. A Steady State Eutrophication Model for Lakes. *Water Research*. 14(11):1651-1665.

Smith, R.A, G.E. Schwarz, and R.B. Alexander. 1997. Regional Interpretation of Water Quality Monitoring Data. *Water Resources Research* 33(12):2781-2798. December.

Tetra Tech 1998. *Progress in Water Quality: An Evaluation of the Benefits of the 1972 Clean Water Act.* Prepared for the U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC. October.

Thomann, R.V., D.M. DiToro, R.P. Winfield, and D.J. O'Connor. 1975. *Mathematical Modeling of Phytoplankton in Lake Onatrio*. EPA-660 3-75-005. Washington, DC: U.S. Environmental Protection Agency.

Thomann, R.V., and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control*. New York: Harper & Row.

Thomann, R.V., and J.P. Fitzpatrick. 1982. *Calibaration and Verification of a Mathematical Model of the Eutrophication of the Potamac Estuary*. Prepared by HydroQual, Inc. for Department of Environmental Services, Government of the District of Columbia.

U.S. EPA 1978. Relationships of Productivity and Problem Condition to Ambient Nutrients: National Eutrophication Survey Findings for 418 Eastern Lakes. EPA-6--/3-78-002. Office of Research and Development, Environmental Monitoring and Support Laboratory. Las Vegas, NV.

USEPA. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition). Environmental Research Laboratory, Office of Research and Development, Athens, Georgia.

USEPA, 1983. Technical Guidance Manual for Performing Wasteload Allocations. Book Two: Streams and Rivers. Chapter 2: Nutrient/Eutrophication Impacts. Office of Water Regulations and Standards, Monitoring and Data Support Division.

USEPA, 1993. Guidelines for Assessing and Predicting Eutrophication Status of Small Southeastern Piedmont Impoundments. Region IV, Environmental Services Division, Athens, GA.

Vollenweider, R.A. 1968. *Scientific Fundamental of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication.* Technical report DAS/CSI/68.27. OECD, Paris, France.

Vollenweider, R.A. 1975. Input-Output Models (with Special Reference to the Phosphorus Loading Model in Limnology). *Schweiz. Z. Hydrol*. 37(1):53-84.

Vollenweider, R.A. 1976. Advances in Defining Critical Loading Levels for Phosphorus in Lake Eutrophication. *Mem. 1st. Ital. Idrobiol*. 33:53-83.

Walker, W.W. 1996. *Simplified Procedures for Eutrophication Assessment and Prediction: User Manual*. Instruction Report W-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Walker, W.W. 1985. Empirical Methods for Predicting Eutrophication in Impoundments. Report 3. Phase II: Model Refinements. U.S. Army Corps of Engineers Technical Report E-81-9. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Additional Information Available at http://www.wes.army.mil/el/elmodels/emiinfo.html.

Welch, E.B., R.R. Horner, and C.R. Patamont. 1989. Prediction of Nuisance Periphytic Biomass: A Management Approach. *Water Res*. 23(4):401-405.

Ziegler, C.K, and B. Nisbet. 1994. Fine-Grained Sediment Transport in Pawtucket River, Rhode Island. *ASCE Jour. Hydraulic Engineering* 120(5):561-576.

Appendix A

Land-Use/Land-Cover File

The USGS conterminous United States Land Cover Characteristics (LCC) Data Set (Version 2) (Table 3) forms the basis for the land-use/land-cover spatial coverage used by the AFO/CAFO version of NWPCAM. The USGS developed the LCC database by classifying 1990 National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite time-series images, with post-classification refinement based on other data-sets, including topography, climate, soils, and eco-regions (Eidenshink, 1992). The database is intended to offer flexibility in tailoring data to specific requirements for regional land-cover information. Land-use/land-cover data are defined at a square kilometer (km^2) cell grid level in LCC. Each land-use cell is assigned to the nearest routed RF3 reach for subsequent drainage area, stream discharge, and hydrologic routing purposes.

The raster image used to assign land-cover cells to a reach has a pixel size of 8-bit (1 byte), representing an area of 1 km^2. (The image contains 2,889 lines and 4,587 samples covering the entire conterminous United States.) The projection of the images is Lambert Azimuthal Equal Area (LAZEA). Based on this information, it was possible to extract a specific area from the image into an ASCII file with an in-house C routine. This approach allowed the importing of only portions of the image, reducing loading and processing time considerably compared to a full image import with a commercial GIS package. The ASCII file was then used to generate a point coverage in ARC/INFO, which was converted to geographic coordinates in order to process it with existing RF3 coverages.

Table 3

MODIFIED ANDERSON LAND COVER CLASSES AND GENERAL EXPORT COEFFICIENTS

Level 1 (derived)	Category (derived)	Level 2	Class	TN_L	TN_M	TN_H	TP_L	TP_M	TP_H
1	Agriculture	1	Dryland Cropland and Pasture	4	15	30	0.4	1.1	4
1	Agriculture	2	Irrigated Cropland and Pasture	4	15	30	0.4	1.1	4
1	Agriculture	3	Mixed Dryland/Irrigated Cropland and Pasture	4	15	30	0.4	1.1	4
2	Agriculture/herbaceous	4	Grassland/Cropland Mosaic	3	12	25	0.4	1	3.5
3	Agriculture/woodland	5	Woodland/Cropland Mosaic	3	10	20	0.2	0.75	2
4	Herbaceous	6	Grassland	3	5	10	0.3	0.6	3
4	Herbaceous	7	Desert Shrubland						
4	Herbaceous	8	Mixed Shrubland/Grassland	3	5	10	0.3	0.6	3
4	Herbaceous	9	Chaparral	3	5	10	0.3	0.6	3

Table 3

MODIFIED ANDERSON LAND COVER CLASSES AND GENERAL EXPORT COEFFICIENTS

Level 1 (derived)	Category (derived)	Level 2	Class	TN_L	TN_M	TN_H	TP_L	TP_M	TP_H
4	Herbaceous	10	Savanna	3	5	10	0.3	0.6	3
5	Forest	11	Northern Deciduous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	12	Southeastern Deciduous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	13	Western Deciduous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	14	Northern Coniferous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	15	Southeastern Coniferous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	16	Western Coniferous Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	17	Western Woodlands	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	18	Northern Mixed Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	19	Southeastern Mixed Forest	1.75	2.5	3.75	0.1	0.2	0.3
5	Forest	20	Western Mixed Forest	1.75	2.5	3.75	0.1	0.2	0.3
6	Water Bodies	21	Water Bodies	4	10	30	0.2	0.3	1
4	Herbaceous	22	Herbaceous Coastal Wetlands	3	5	10	0.3	0.6	3
5	Forest	23	Forested Coastal Wetlands	1.75	2.5	3.75	0.1	0.2	0.3
6	Barren	24	Barren or Sparsely Vegetated	4	10	30	0.2	0.3	1
5	Forest	25	Subalpine Forest	1.75	2.5	3.75	0.1	0.2	0.3
7	Tundra	26	Alpine Tundra						
8	Urban (derived)	30	Urban	2	7.5	20	0.5	1.5	3.5

TN_ = total nitrogen export coefficient (low) TP_L = total phosphorus export coefficient (low)
TN_M = total nitrogen export coefficient (med) TP_M = total phosphorus export coefficient (med)
TN_H = total nitrogen export coefficient (high) TP_H = total phosphorus export coefficient (high)

Information included in the dataset includes the land-use/land-cover code for each cell, the HUC code and FIPS county code in which the cell is located, the RF3 reach associated with the cell, and related information. Each of the several million land-use/land-cover cells in the GIS coverage for the United States is given a unique identification for NWPCAM purposes. Table 4 lists the key fields and field description for the land-use/land-cover data file. The dataset was created in Microsoft Access.

Appendix B

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Beef_M1	CE	1,912.72	370.56	1,680.55	307.68	1,619.55	260.92	1,134.25	187.83
Beef_M2	CE	4,544.62	880.45	3,992.98	731.05	3,848.05	619.95	2,694.98	446.29
Beef_L1	CE	8,309.36	1,855.65	8,309.36	1,855.65	7,574.99	1,236.49	5,199.98	868.63
Beef_L2	CE	134,348.17	24,661.82	134,348.17	24,661.82	128,162.53	19,903.63	88,813.85	14,244.16
Beef_M1	MA	1,498.36	881.12	1,015.75	677.97	936.47	481.27	496.59	224.65
Beef_M2	MA	3,560.10	2,093.54	2,413.41	1,610.86	2,225.06	1,143.50	1,179.89	533.76
Beef_L1	MA	5,494.36	4,956.40	5,494.36	4,956.40	4,379.43	2,321.03	2,227.59	1,053.24
Beef_L2	MA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef_M1	MW	1,174.83	637.66	783.84	531.79	688.72	306.60	487.45	190.79
Beef_M2	MW	2,791.39	1,515.09	1,862.41	1,263.53	1,636.40	728.49	1,158.18	453.31
Beef_L1	MW	3,988.44	3,421.45	3,988.44	3,421.45	3,224.13	1,463.74	2,225.78	904.46
Beef_L2	MW	58,379.16	37,034.91	58,379.16	37,034.91	52,529.63	22,187.93	36,866.18	13,799.19
Beef_M1	PA	3,962.75	2,983.28	3,151.23	2,763.74	2,745.74	2,069.38	1,955.98	1,078.89
Beef_M2	PA	9,415.50	7,088.28	7,487.33	6,566.65	6,523.88	4,916.85	4,647.42	2,563.45
Beef_L1	PA	16,222.73	18,076.56	16,222.73	18,076.56	12,994.06	9,884.23	8,669.97	4,970.01
Beef_L2	PA	244,670.92	219,580.00	244,670.92	219,580.00	211,025.70	153,067.48	147,959.57	79,827.73
Beef_M1	SO	1,538.94	1,490.84	672.60	1,248.99	672.60	1,043.96	546.84	763.96
Beef_M2	SO	3,656.51	3,542.23	1,598.09	2,967.60	1,598.09	2,480.45	1,299.28	1,815.17
Beef_L1	SO	3,155.19	9,453.32	3,155.19	9,453.32	3,155.19	5,000.40	2,456.20	3,539.38
Beef_L2	SO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Broiler_M1a	CE	556.31	1,041.63	490.98	1,023.88	405.24	401.47	233.40	219.81
Broiler_M1b	CE	779.97	1,460.39	688.36	1,435.50	568.16	562.87	327.24	308.17
Broiler_M2	CE	1,088.17	2,305.16	1,009.70	2,283.84	791.97	752.51	447.70	409.14
Broiler_L1	CE	1,738.62	3,870.05	1,738.62	3,870.05	1,275.96	1,142.60	687.19	603.28
Broiler_L2	CE	5,908.49	15,787.28	5,908.49	15,787.28	3,467.71	2,851.28	1,802.58	1,484.15
Broiler_M1a	MA	548.01	1,083.93	412.42	1,026.90	353.88	418.46	232.65	257.57
Broiler_M1b	MA	768.32	1,519.69	578.23	1,439.74	496.15	586.70	326.18	361.13
Broiler_M2	MA	996.09	2,353.69	833.25	2,285.20	690.82	799.23	443.61	484.89
Broiler_L1	MA	1,290.92	3,543.92	1,290.92	3,543.92	1,065.49	1,188.87	646.82	693.54
Broiler_L2	MA	3,584.29	12,228.85	3,584.29	12,228.85	2,692.07	2,873.96	1,559.00	1,626.13
Broiler_M1a	MW	5,561.26	6,517.91	5,451.35	6,488.07	3,867.01	2,240.74	2,495.67	1,420.06
Broiler_M1b	MW	7,797.04	9,138.29	7,642.95	9,096.46	5,421.66	3,141.58	3,499.00	1,990.96
Broiler_M2	MW	10,967.86	13,615.48	10,835.87	13,579.65	7,345.93	4,191.19	4,611.67	2,599.54
Broiler_L1	MW	16,869.10	21,129.69	16,869.10	21,129.69	11,380.18	6,352.11	6,742.65	3,749.39
Broiler_L2	MW	74,910.33	118,089.61	74,910.33	118,089.61	38,785.33	20,908.34	21,886.29	11,878.68

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Broiler_M1a	PA	1,730.50	1,362.27	1,502.39	1,300.71	1,390.22	860.72	690.39	482.67
Broiler_M1b	PA	2,426.22	1,909.94	2,106.39	1,823.63	1,949.13	1,206.75	967.94	676.71
Broiler_M2	PA	3,322.56	2,956.97	3,048.59	2,883.03	2,702.96	1,601.18	1,320.86	887.23
Broiler_L1	PA	5,618.65	5,649.95	5,618.65	5,649.95	4,786.76	2,661.23	2,284.74	1,446.05
Broiler_L2	PA	32,663.64	49,885.18	32,663.64	49,885.18	21,126.97	10,389.99	9,796.24	5,542.45
Broiler_M1a	SO	1,484.64	4,730.37	1,241.04	4,662.39	1,054.09	1,140.20	798.03	765.55
Broiler_M1b	SO	2,081.50	6,632.12	1,739.97	6,536.80	1,477.86	1,598.59	1,118.86	1,073.32
Broiler_M2	SO	2,825.88	10,902.09	2,533.31	10,820.45	2,096.50	2,149.57	1,564.89	1,441.52
Broiler_L1	SO	4,112.27	17,860.20	4,112.27	17,860.20	3,305.33	3,132.96	2,386.35	2,078.81
Broiler_L2	SO	10,623.59	56,048.14	10,623.59	56,048.14	7,768.22	6,727.68	5,488.47	4,445.21
Dairy_M1	CE	2,056.87	2,092.99	1,738.44	2,006.75	1,521.00	1,053.68	893.73	602.21
Dairy_M2	CE	3,006.13	3,058.91	2,540.75	2,932.87	2,222.95	1,539.96	1,306.19	880.13
Dairy_L1	CE	6,071.79	7,640.31	6,071.79	7,640.31	5,030.79	3,422.35	2,834.05	1,889.21
Dairy_M1	MA	3,612.52	3,732.66	2,950.60	3,454.04	2,149.75	1,432.55	1,388.32	853.93
Dairy_M2	MA	5,279.71	5,455.31	4,312.32	5,048.10	3,141.86	2,093.68	2,029.04	1,248.02
Dairy_L1	MA	10,845.39	14,588.44	10,845.39	14,588.44	6,711.35	4,459.72	4,158.08	2,566.88
Dairy_M1	MW	1,021.25	959.33	485.01	814.12	39.07	121.25	202.33	114.62
Dairy_M2	MW	1,492.56	1,402.07	708.84	1,189.85	57.10	177.21	295.71	167.52
Dairy_L1	MW	1,742.25	3,124.80	1,742.25	3,124.80	125.19	391.00	599.20	351.08
Dairy_M1	PA	4,476.76	11,836.31	3,363.74	11,535.21	1,534.64	3,713.50	857.61	1,769.40
Dairy_M2	PA	6,542.81	17,298.83	4,916.13	16,858.77	2,242.88	5,427.30	1,253.41	2,585.99
Dairy_L1	PA	13,651.77	49,746.39	13,651.77	49,746.39	4,646.60	11,425.54	2,530.14	5,352.39
Dairy_M1	SO	1,286.24	1,867.07	98.03	1,535.37	40.54	197.91	35.75	122.73
Dairy_M2	SO	1,879.84	2,728.73	143.28	2,243.96	59.25	289.25	52.25	179.37
Dairy_L1	SO	524.81	11,291.73	524.81	11,291.73	118.84	577.88	99.34	356.52
Swine-FF_M1a	CE	801.23	1,015.69	801.23	1,015.69	798.77	994.24	616.65	749.55
Swine-FF_M1b	CE	1,266.24	1,605.17	1,266.24	1,605.17	1,262.36	1,571.28	974.55	1,184.57
Swine-FF_M2	CE	1,825.26	2,571.87	1,825.26	2,571.87	1,788.06	2,221.70	1,359.87	1,653.34
Swine-FF_L1	CE	2,775.99	4,099.11	2,775.99	4,099.11	2,703.86	3,416.00	2,045.70	2,521.52
Swine-FF_L2	CE	20,092.78	44,024.77	20,092.78	44,024.77	17,665.16	23,972.81	12,984.99	17,045.55
Swine-FF_M1a	MA	286.18	355.79	286.18	355.79	283.01	277.39	205.67	164.89
Swine-FF_M1b	MA	452.27	562.28	452.27	562.28	447.27	438.38	325.03	260.58
Swine-FF_M2	MA	680.84	1,077.74	680.84	1,077.74	663.61	654.99	465.39	378.75
Swine-FF_L1	MA	1,064.58	1,771.73	1,064.58	1,771.73	1,034.64	1,027.39	698.99	576.97
Swine-FF_L2	MA	4,657.49	8,298.47	4,657.49	8,298.47	4,507.35	4,591.26	2,842.66	2,443.05

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Swine-FF_M1a	MW	1,039.95	1,888.64	1,039.95	1,888.64	1,039.95	1,888.64	1,013.58	1,227.68
Swine-FF_M1b	MW	1,643.51	2,984.76	1,643.51	2,984.76	1,643.51	2,984.76	1,601.84	1,940.20
Swine-FF_M2	MW	2,497.48	5,005.39	2,497.48	5,005.39	2,467.54	4,526.40	2,351.42	2,888.48
Swine-FF_L1	MW	3,822.42	8,051.27	3,822.42	8,051.27	3,758.47	7,029.32	3,461.36	4,358.12
Swine-FF_L2	MW	13,294.79	27,768.93	13,294.79	27,768.93	13,173.68	25,857.94	11,320.31	15,123.22
Swine-FF_M1a	PA	1,371.48	1,682.27	1,371.48	1,682.27	1,371.48	1,682.27	902.13	1,131.35
Swine-FF_M1b	PA	2,167.45	2,658.61	2,167.45	2,658.61	2,167.45	2,658.61	1,425.71	1,787.97
Swine-FF_M2	PA	3,004.60	3,722.18	3,004.60	3,722.18	3,004.60	3,722.18	1,971.31	2,486.59
Swine-FF_L1	PA	4,471.06	5,619.10	4,471.06	5,619.10	4,471.06	5,619.10	2,901.18	3,690.43
Swine-FF_L2	PA	26,966.98	38,721.82	26,966.98	38,721.82	26,610.45	35,910.46	16,445.90	21,885.83
Swine-FF_M1a	SO	879.28	671.15	879.28	671.15	879.28	671.15	855.37	452.47
Swine-FF_M1b	SO	1,389.59	1,060.67	1,389.59	1,060.67	1,389.59	1,060.67	1,351.81	715.08
Swine-FF_M2	SO	1,931.85	1,476.90	1,931.85	1,476.90	1,931.85	1,476.90	1,826.16	975.22
Swine-FF_L1	SO	2,928.39	2,280.21	2,928.39	2,280.21	2,928.39	2,280.21	2,692.52	1,467.37
Swine-FF_L2	SO	20,706.95	19,668.67	20,706.95	19,668.67	19,666.41	15,998.66	16,511.22	9,555.38
Swine-GF_M1a	CE	789.28	1,248.43	789.28	1,248.43	759.04	963.30	588.18	726.34
Swine-GF_M1b	CE	1,247.35	1,972.99	1,247.35	1,972.99	1,199.57	1,522.38	929.54	1,147.90
Swine-GF_M2	CE	1,737.26	2,472.99	1,737.26	2,472.99	1,700.52	2,132.34	1,297.73	1,588.48
Swine-GF_L1	CE	2,774.62	4,645.69	2,774.62	4,645.69	2,640.36	3,366.56	1,979.02	2,460.29
Swine-GF_L2	CE	5,560.14	8,696.73	5,560.14	8,696.73	5,383.69	7,033.86	3,835.12	4,895.17
Swine-GF_M1a	MA	290.75	522.43	290.75	522.43	280.90	280.90	206.02	167.00
Swine-GF_M1b	MA	459.49	825.64	459.49	825.64	443.94	443.94	325.59	263.92
Swine-GF_M2	MA	662.24	1,184.33	662.24	1,184.33	639.57	626.41	446.79	361.97
Swine-GF_L1	MA	1,050.07	2,021.66	1,050.07	2,021.66	1,008.34	992.01	659.98	546.13
Swine-GF_L2	MA	2,398.60	3,980.73	2,398.60	3,980.73	2,326.48	2,204.46	1,345.81	1,124.00
Swine-GF_M1a	MW	998.46	2,122.08	998.46	2,122.08	979.48	1,815.16	979.83	1,190.42
Swine-GF_M1b	MW	1,577.94	3,353.69	1,577.94	3,353.69	1,547.94	2,868.64	1,548.50	1,881.31
Swine-GF_M2	MW	2,359.59	5,202.70	2,359.59	5,202.70	2,301.98	4,283.27	2,192.21	2,717.47
Swine-GF_L1	MW	3,655.95	8,276.25	3,655.95	8,276.25	3,551.63	6,608.39	3,153.83	4,012.48
Swine-GF_L2	MW	9,454.23	22,127.14	9,454.23	22,127.14	9,148.51	17,229.71	6,918.19	9,466.02
Swine-GF_M1a	PA	1,235.42	1,543.04	1,235.42	1,543.04	1,235.42	1,543.04	830.41	1,053.31
Swine-GF_M1b	PA	1,952.43	2,438.59	1,952.43	2,438.59	1,952.43	2,438.59	1,312.36	1,664.62
Swine-GF_M2	PA	2,781.43	3,494.02	2,781.43	3,494.02	2,781.43	3,494.02	1,878.33	2,390.43
Swine-GF_L1	PA	4,239.73	5,418.61	4,239.73	5,418.61	4,239.73	5,418.61	2,756.03	3,541.65
Swine-GF_L2	PA	8,607.37	11,328.47	8,607.37	11,328.47	8,607.37	11,328.47	5,611.85	7,343.66

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Swine-GF_M1a	SO	819.86	637.40	819.86	637.40	819.86	637.40	826.19	436.65
Swine-GF_M1b	SO	1,295.69	1,007.33	1,295.69	1,007.33	1,295.69	1,007.33	1,305.69	690.07
Swine-GF_M2	SO	1,842.04	1,442.42	1,842.04	1,442.42	1,832.06	1,420.20	1,750.41	939.84
Swine-GF_L1	SO	2,902.99	2,382.27	2,902.99	2,382.27	2,870.79	2,263.43	2,551.46	1,417.93
Swine-GF_L2	SO	6,010.10	4,901.52	6,010.10	4,901.52	6,010.10	4,901.52	4,678.35	2,790.95
Layer-D_M1a	CE	793.12	1,022.66	656.69	965.27	622.11	601.59	344.31	319.60
Layer-D_M1b	CE	1,100.17	1,418.57	910.92	1,338.97	862.95	834.49	477.60	443.34
Layer-D_M2	CE	1,847.48	2,736.98	1,684.64	2,668.48	1,578.50	1,553.55	910.81	852.30
Layer-D_L1	CE	6,325.35	12,704.22	6,325.35	12,704.22	5,336.06	5,291.16	3,220.96	3,014.58
Layer-D_L2	CE	19,880.05	55,148.22	19,880.05	55,148.22	12,057.39	11,033.64	7,196.24	6,374.79
Layer-D_M1a	MA	667.33	966.41	556.74	936.39	523.68	601.97	327.97	357.61
Layer-D_M1b	MA	925.68	1,340.56	772.28	1,298.91	726.42	835.01	454.94	496.05
Layer-D_M2	MA	1,652.89	2,847.65	1,520.90	2,811.82	1,406.14	1,633.39	918.98	1,005.61
Layer-D_L1	MA	4,450.20	9,582.59	4,450.20	9,582.59	3,977.10	4,715.55	2,759.66	3,041.34
Layer-D_L2	MA	19,926.77	82,560.62	19,926.77	82,560.62	13,521.14	15,418.97	9,423.38	10,134.61
Layer-D_M1a	MW	7,091.35	6,185.36	6,861.81	6,123.41	5,764.67	3,270.91	3,483.35	1,957.91
Layer-D_M1b	MW	9,836.72	8,579.98	9,518.32	8,494.05	7,996.42	4,537.23	4,831.91	2,715.90
Layer-D_M2	MW	18,633.12	17,671.05	18,359.15	17,597.12	14,922.28	8,575.16	9,555.38	5,408.64
Layer-D_L1	MW	54,284.58	57,569.04	54,284.58	57,569.04	41,735.04	24,252.68	28,740.07	16,347.02
Layer-D_L2	MW	431,482.04	776,680.82	431,482.04	776,680.82	181,009.22	102,996.32	123,204.31	69,226.36
Layer-D_M1a	PA	2,450.81	1,449.43	2,205.69	1,381.03	2,205.69	1,381.03	1,076.62	752.84
Layer-D_M1b	PA	3,399.62	2,010.57	3,059.61	1,915.68	3,059.61	1,915.68	1,493.43	1,044.29
Layer-D_M2	PA	6,182.92	4,069.63	5,890.35	3,987.98	5,890.35	3,608.78	2,922.04	2,026.65
Layer-D_L1	PA	15,482.47	11,890.92	15,482.47	11,890.92	14,932.72	9,411.14	7,604.48	5,445.38
Layer-D_L2	PA	52,990.02	63,491.60	52,990.02	63,491.60	41,576.28	23,315.56	21,106.56	13,938.89
Layer-D_M1a	SO	1,478.69	2,884.80	1,412.95	2,866.94	1,331.24	1,385.59	976.30	918.91
Layer-D_M1b	SO	2,051.16	4,001.64	1,959.96	3,976.86	1,846.63	1,922.01	1,354.26	1,274.66
Layer-D_M2	SO	4,520.05	11,468.63	4,441.58	11,447.31	3,991.61	4,245.17	3,000.97	2,846.29
Layer-D_L1	SO	13,131.05	41,295.51	13,131.05	41,295.51	11,710.39	12,872.50	9,179.80	8,786.08
Layer-D_L2	SO	52,870.28	347,201.40	52,870.28	347,201.40	34,866.74	36,384.91	27,661.43	25,157.60
Layer-W_M2	CE	334.75	389.64	171.91	321.14	141.07	114.31	103.87	84.37
Layer-W_L1	CE	2,050.69	5,008.57	2,050.69	5,008.57	1,531.78	1,506.83	877.25	821.00
Layer-W_M2	MA	296.20	327.04	164.20	291.21	150.59	148.78	104.33	102.97
Layer-W_L1	MA	1,524.52	3,942.63	1,524.52	3,942.63	1,291.38	1,507.74	839.15	922.15
Layer-W_M2	MW	1,584.85	1,418.38	1,310.88	1,344.45	1,021.04	571.07	685.38	381.47

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Layer-W_L1	MW	17,880.16	19,726.28	17,880.16	19,726.28	13,381.88	7,716.51	8,456.32	4,799.01
Layer-W_M2	PA	1,244.20	766.12	951.64	684.47	852.30	337.47	439.53	236.32
Layer-W_L1	PA	7,629.42	11,514.90	7,629.42	11,514.90	5,277.09	3,300.79	2,593.19	1,817.54
Layer-W_M2	SO	397.80	959.80	319.33	938.48	282.59	268.53	219.09	185.52
Layer-W_L1	SO	4,152.18	14,272.28	4,152.18	14,272.28	3,582.93	3,848.73	2,701.14	2,581.39
Turkey_M1a	CE	878.96	875.92	820.54	860.05	809.73	742.88	555.47	503.47
Turkey_M1b	CE	1,482.44	1,477.32	1,383.92	1,450.55	1,365.69	1,252.93	936.85	849.15
Turkey_M2	CE	2,145.95	2,448.95	2,067.47	2,427.63	1,991.72	1,694.62	1,376.65	1,167.09
Turkey_L1	CE	7,908.38	12,398.04	7,908.38	12,398.04	6,959.47	5,555.60	4,883.83	3,918.58
Turkey_M1a	MA	1,039.01	1,306.45	917.79	1,255.46	887.40	951.89	521.70	545.68
Turkey_M1b	MA	1,752.39	2,203.45	1,547.94	2,117.45	1,496.68	1,605.46	879.90	920.33
Turkey_M2	MA	2,403.59	3,457.28	2,240.75	3,388.79	2,123.72	2,199.47	1,254.18	1,279.58
Turkey_L1	MA	4,807.63	8,065.78	4,807.63	8,065.78	4,479.22	4,704.66	2,791.86	2,870.33
Turkey_M1a	MW	7,541.54	7,721.86	7,443.28	7,695.18	5,774.51	3,240.29	3,345.64	1,867.66
Turkey_M1b	MW	12,719.52	13,023.64	12,553.79	12,978.65	9,739.26	5,465.06	5,642.74	3,149.98
Turkey_M2	MW	17,887.87	17,076.85	17,755.87	17,041.01	14,294.06	7,799.97	8,361.52	4,578.56
Turkey_L1	MW	58,815.06	54,210.19	58,815.06	54,210.19	48,231.84	25,957.28	29,720.73	16,136.10
Turkey_M1a	PA	1,763.99	786.77	1,560.04	731.73	1,560.04	731.73	771.24	444.37
Turkey_M1b	PA	2,975.14	1,326.97	2,631.15	1,234.14	2,631.15	1,234.14	1,300.77	749.48
Turkey_M2	PA	3,607.42	1,688.72	3,333.45	1,614.79	3,333.45	1,614.79	1,640.19	962.07
Turkey_L1	PA	9,643.83	5,298.41	9,643.83	5,298.41	9,643.83	5,298.41	4,710.10	2,997.79
Turkey_M1a	SO	1,789.32	1,982.13	1,571.52	1,921.35	1,558.69	1,535.05	891.79	746.59
Turkey_M1b	SO	3,017.85	3,343.05	2,650.52	3,240.53	2,628.88	2,589.01	1,504.09	1,259.20
Turkey_M2	SO	3,964.85	5,136.93	3,672.28	5,055.29	3,582.93	3,217.78	2,082.44	1,607.53
Turkey_L1	SO	7,511.94	11,545.29	7,511.94	11,545.29	7,258.39	6,671.44	4,423.43	3,418.73
Veal_M1	CE	729.34	1,566.79	477.58	1,498.60	262.54	556.84	222.33	375.02
Veal_M2	CE	1,541.34	3,311.14	1,009.29	3,167.05	554.83	1,176.79	469.85	792.53
Veal_M1	MA	1,812.72	2,550.80	1,289.39	2,330.51	656.20	732.26	546.64	444.07
Veal_M2	MA	3,830.88	5,390.69	2,724.91	4,925.15	1,386.78	1,547.50	1,155.24	938.48
Veal_M1	MW	733.71	583.36	309.74	468.55	10.20	3.21	59.73	20.98
Veal_M2	MW	1,550.58	1,232.83	654.59	990.20	21.55	6.77	126.24	44.34
Veal_M1	PA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Veal_M2	PA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Veal_M1	SO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Veal_M2	SO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B

ANIMAL OPERATION TYPES AND SIZES AND CORRESPONDING EDGE-OF-FIELD LOADING VALUES FOR VARIOUS RULE-MAKING SCENARIOS

Operation Type	Region	Base SN (kg)	Base SP (kg)	Base SN-R (kg)	Base SP-R (kg)	Opt 1_SN (kg)	Opt 1_SP (kg)	Opt 2 SN (kg)	Opt 2_SP (kg)
Heifer_M1	CE	2,056.87	2,092.99	1,738.44	2,006.75	1,521.00	1,053.68	893.73	602.21
Heifer_M2	CE	3,006.13	3,058.91	2,540.75	2,932.87	2,222.95	1,539.96	1,306.19	880.13
Heifer_L1	CE	6,071.79	7,640.31	6,071.79	7,640.31	5,030.79	3,422.35	2,834.05	1,889.21
Heifer_M1	MA	3,612.52	3,732.66	2,950.60	3,454.04	2,149.75	1,432.55	1,388.32	853.93
Heifer_M2	MA	5,279.71	5,455.31	4,312.32	5,048.10	3,141.86	2,093.68	2,029.04	1,248.02
Heifer_L1	MA	10,845.39	14,588.44	10,845.39	14,588.44	6,711.35	4,459.72	4,158.08	2,566.88
Heifer_M1	MW	1,021.25	959.33	485.01	814.12	39.07	121.25	202.33	114.62
Heifer_M2	MW	1,492.56	1,402.07	708.84	1,189.85	57.10	177.21	295.71	167.52
Heifer_L1	MW	1,742.25	3,124.80	1,742.25	3,124.80	125.19	391.00	599.20	351.08
Heifer_M1	PA	4,476.76	11,836.31	3,363.74	11,535.21	1,534.64	3,713.50	857.61	1,769.40
Heifer_M2	PA	6,542.81	17,298.83	4,916.13	16,858.77	2,242.88	5,427.30	1,253.41	2,585.99
Heifer_L1	PA	13,651.77	49,746.39	13,651.77	49,746.39	4,646.60	11,425.54	2,530.14	5,352.39
Heifer_M1	SO	1,286.24	1,867.07	98.03	1,535.37	40.54	197.91	35.75	122.73
Heifer_M2	SO	1,879.84	2,728.73	143.28	2,243.96	59.25	289.25	52.25	179.37
Heifer_L1	SO	524.81	11,291.73	524.81	11,291.73	118.84	577.88	99.34	356.52
Veal_L1	CE	1,541.34	3,311.14	1,009.29	3,167.05	554.83	1,176.79	469.85	792.53
Veal_L1	MA	3,830.88	5,390.69	2,724.91	4,925.15	1,386.78	1,547.50	1,155.24	938.48
Veal_L1	MW	1,550.58	1,232.83	654.59	990.20	21.55	6.77	126.24	44.34
Veal_L1	PA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Veal_L1	SO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C

NWPCAM Model Formulations

Appendix C

NWPCAM MODEL FORMULATIONS

Appendix C describes the technical foundation of the physical and chemical processes represented in the AFO/CAFO version of NWPCAM.

C1. DATABASES FRAMEWORKS AND INTEGRATION

The AFO/CAFO version of NWPCAM relies on several extensive datasets to support the various analytical routines developed to represent physical and chemical processes occurring within a watershed and along river reaches. Primary databases include: (1) land-use and land-cover information; (2) RF3/RF3Lite hydrologic/reach routing information; (3) AFOs/CAFOs information; (4) watershed and stream discharge information; (5) non-point source pollutant loading information; and, (6) point source pollutant loading information. This section presents details of several of the principal datasets used in the AFO/CAFO version of NWPCAM. Point source and non-point source pollutant loading information used in the model are described in detail in earlier versions of NWPCAM (Bondelid et al., 1999a; Bondelid et al., 1999b).

C1.1 RF3/RF3Lite Hydrologic Routing File

USEPA's Reach File 3 (RF3) forms the national-scale model framework for the hydrologic routing routine upon which NWPCAM is based. The reach file network is discussed in more detail in Section C2.0 which follows. The reach file also is discussed in several earlier reports (Bondelid, et al., 1999a; Bondelid et al., 1999b). Table C-1 lists the key fields and field description of the RF3 routing data file. The dataset was created in Microsoft Access.

Table C-1

KEY FIELDS OF THE RF3/RF3LITE ROUTING DATA FILE

Field	Description
RF3RCHID	RF3 Reach ID
SEQNO	Hydrologic sequence number
STRORDER	Stream order
AU	Accounting Unit
CU	Catalog Unit
N_JUNC	(Networked) stream junction level
N_LEV	(Networked) stream level
SEGL	Segment length
SINU	Sinuosity (RF3 segment length/crow-fly distance)

C1.2 Land-Use/Land-Cover File

The USGS conterminous United States Land Cover Characteristics (LCC) Data Set (Version 2) forms the basis for the land-use/land-cover spatial coverage used by the AFO/CAFO version of NWPCAM. Each land-use cell is assigned to the nearest routed RF3 reach for subsequent drainage area, stream discharge, and hydrologic routing purposes. Information included in the dataset includes the land-use/land-cover code for each cell, the HUC code and FIPS county code in which the cell is located, the RF3 reach associated with the cell, and related information. Each of the several million land-use/land-cover cells in the GIS coverage for the United States is given a unique identification for NWPCAM purposes. Table C-2 lists the key fields and field description for the land-use/land-cover data file. The dataset was created in Microsoft Access.

Table C-2

KEY FIELDS OF THE LAND-USE/LAND-COVER DATA FILE

Field	Description
Cell_ID	Identification number assigned to LULC cell for CAFO NWPCAM study
REG07_ID	Identification number to match cells in table with GIS coverage
LULC_CODE	Code describing type of land-use/land-cover for cell
AGCELL	Marker to designate agricultural land-use/land-cover cell
COFIPS	County FIPS code
DIST_FT	Distance from cell centroid to nearest RF3 reach (feet)
RF3RCHID	Identification number of nearest RF3 reach
CU	Catalog unit where cell is located
AU	Accounting unit where cell is located
SLOPE	Average slope of 1st order streams in accounting unit
UNITQ	Weighted average unit discharge for CU (cfs/km^2)
RND_ID	Random number generated for agricultural cells in CU
N_CELL_LOAD	Total AFO/CAFO N loading for agricultural cell (kg/yr)
P_CELL_LOAD	Total AFO/CAFO P loading for agricultural cell (kg/yr)
N_DELIVER	AFO/CAFO N loading after overland decay (kg/yr)
P_DELIVER	AFO/CAFO P loading after overland decay (kg/yr)

C1.3 AFO/CAFO Dataset Files

AFO/CAFO datasets provided by USEPA, as discussed in the report, were converted to Microsoft Access files for incorporation into the NWPCAM modeling framework. These files provided a county-by-county listing and tabulation of AFOs/CAFOs by animal operation type and size, as well as edge-of-field nutrient/pollutant loading values.

C1.4 Stream Drainage Area, Discharge, and Velocities

Stream drainage area, discharge and velocity data and related hydrologic data at the RF3 reach level were required for hydrologic routing and associated nutrient transport and decay processes simulated by NWPCAM. Several datasets were created in Microsoft Access. Table C-3 lists principal hydrologic data used in the AFO/CAFO version of NWPCAM.

Table C-3

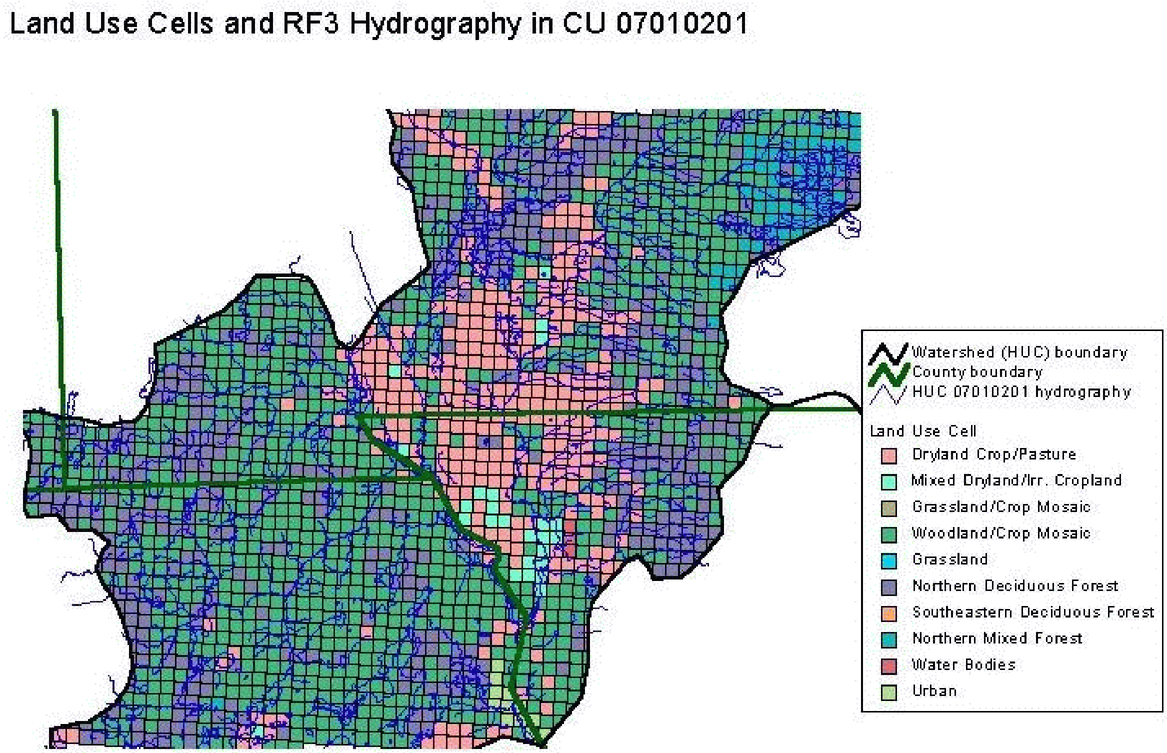
KEY FIELDS OF THE HYDROLOGIC DATA FILE

Field	Description
RF3RCHID	RF3 Reach ID
CU	Catalog unit
AU	Accounting unit
DRAINAGE	Drainage area (km^2)
CUM_DRAIN	Cumulative drainage (includes upstream of reach) (km^2)
UNITQ	Weighted average unit discharge for the CU (cfs/km^2)
Q	Discharge (cfs)
N	Manning's n (min = 0.025, max = 0.040)
SLOPE	If RF1 reach, then slope from RF1 database; if RF3 reach, then average slope of firstorder RF1 reaches in AU
W	Width (ft)
Y_0	Depth (ft)
V	Velocity (ft/s)
TOT	Time of travel (days)

Figure C-1 is a mosaic composite of the RF3, land-use/land-cover, and county/watershed overlay represented at the spatial scale of an eight (8) digit HUC. It is onto this mosaic that AFO/CAFO counts by county/watershed and associated AFO/CAFO edge-of-field nutrient/pollutant loadings are distributed.

Figure C-1

MOSAIC COMPOSITE OF SPATIAL DATA AT THE WATERSHED (HUC) LEVEL



C1.5 <u>Pollutant Loading Data</u>

Both point source and non-point source pollutant loadings are incorporated in the NWPCAM framework. Point source and non-point source loading data used in the model are discussed in discussed in earlier reports (Bondelid et al., 1999a; Bondelid et al., 1999b). This section describes in more detail the AFO/CAFO loading data used in the model as well as the non-point source nutrient loading data at the RF3/RF3Lite scale of the model. Data for AFO/CAFO farm units and nutrient/pollutant loading rates are obtained from USEPA's Office of Water.

AFO/CAFO Loadings

There are several key challenges to be addressed in application of the loading and agriculture modeling framework originally employed in the nutrients version of NWPCAM to the current study of national livestock (i.e., AFOs/CAFOs) waste management scenarios. The first challenge is that principal available data for defining livestock waste have been compiled at the county level scale. These data therefore lack the spatial resolution for directly associating livestock nutrient loadings with land-cover grid cells which provide the geographic foundation for pollutant loadings to NWPCAM. A second challenge is that the existing nutrients version of NWPCAM (NWPCAM 1.1) does not explicitly account for animal manure waste as a separate source category. Rather nutrient loading in the nutrients version of NWPCAM is driven by land-cover patterns and empirical loading data. Therefore, a methodology is required which integrates animal manure loadings into the NWPCAM framework while not compromising the operational integrity of the framework. A third challenge is the need to ensure that the methodology developed for the AFOs/CAFOs version of NWPCAM appropriately delivers field-scale nutrient/ pollutant source inputs derived from animal manure to river reaches. The approaches for addressing these challenges are described below.

To distribute spatially-aggregated county-level farm-unit AFO/CAFO data to cells, a random distribution approach is employed. This approach randomly assigns the spatially aggregated data (total farm-units within a county and associated edge-of-field nutrient/pollutant data) to individual land-cover cells. The assumption used is that edge-of-field loadings could be applied to any cells defined as agricultural (Level 1, 2, and 3 categories) within the classification scheme (Appendix A of the report). Once the farm-unit nutrient/pollutant loadings are distributed to individual land-cover cells and aggregated, actual nutrient/pollutant loadings to HUC reaches can be established. These loadings to the HUC reaches then form the basis for further computations (using the hydraulic routing and fate/transport component) to estimate water quality at the outlet from the HUC.

Initially, the AFO/CAFO dataset provided by USEPA was used to create a Microsoft Access data table of the number of different types of animal operations of different sizes by county. Using a Visual Basic algorithm, this table is used to create a new table which establishes a separate and uniquely identified record for each individual AFO/CAFO in the United States. A second Visual Basic algorithm was developed to establish the numerical range and limits for the random AFO/CAFO distribution process to a county (and therefore by default a HUC). (Initially the process described below was developed to work at the HUC level. The process later was modified to accommodate the actual county-based national AFO/CAFO dataset.) The number of agricultural cells for each county was calculated. Each agricultural cell within a county then was assigned randomly a unique value ranging from one (1) to the number of agricultural cells (n) in the county. Numbers were assigned randomly to each agricultural cell without replacement using the Visual Basic "Randomize" function and saved in the corresponding data field in the AFO/CAFO dataset. This resulted in a random number designation (RNDsgn) for each agricultural cell in each county. The count of agricultural cells for each county also formed the basis for establishing the range of values for randomly distributing individual AFOs/CAFOs (and associated edge-of-field nutrient/pollutant loadings) to the agricultural cells.

A third Visual Basic algorithm was developed using the "Randomize" function to randomly distribute the AFOs/CAFOs within a county to the agricultural cells within that county. For a given AFO/CAFO, a random number was generated ranging from one (1) to the number of agricultural cells (n) in the county. The algorithm then checked to determine if the nutrient loading values associated with that AFO/CAFO could be assigned to the current nutrient load for the agricultural cell identified by the random number (RNDsgn) without exceeding an upper limit criterion. If the criterion was met, then the nutrient/pollutant loading values associated with the AFO/CAFO were assigned to the agricultural cell. If the criterion was exceeded, then a new random number was generated for the same AFO/CAFO and the algorithm repeated. After the AFO/CAFO had been processed and the nutrient/pollutant loading values had been assigned, a new random number was generated for the next AFO/CAFO on the list. Random numbers were generated with replacement so that multiple AFOs/CAFOs and associated loadings could be assigned to a given agricultural cell provided the upper limit for the loading criterion was not exceeded. The process was continued at the county level until all AFOs/CAFOs (and associated nutrient/pollutant loadings) for that county had been assigned to an agricultural cell. The process continued from county to county (and AFO/CAFO to AFO/CAFO) across the United States until all assignments had been completed.

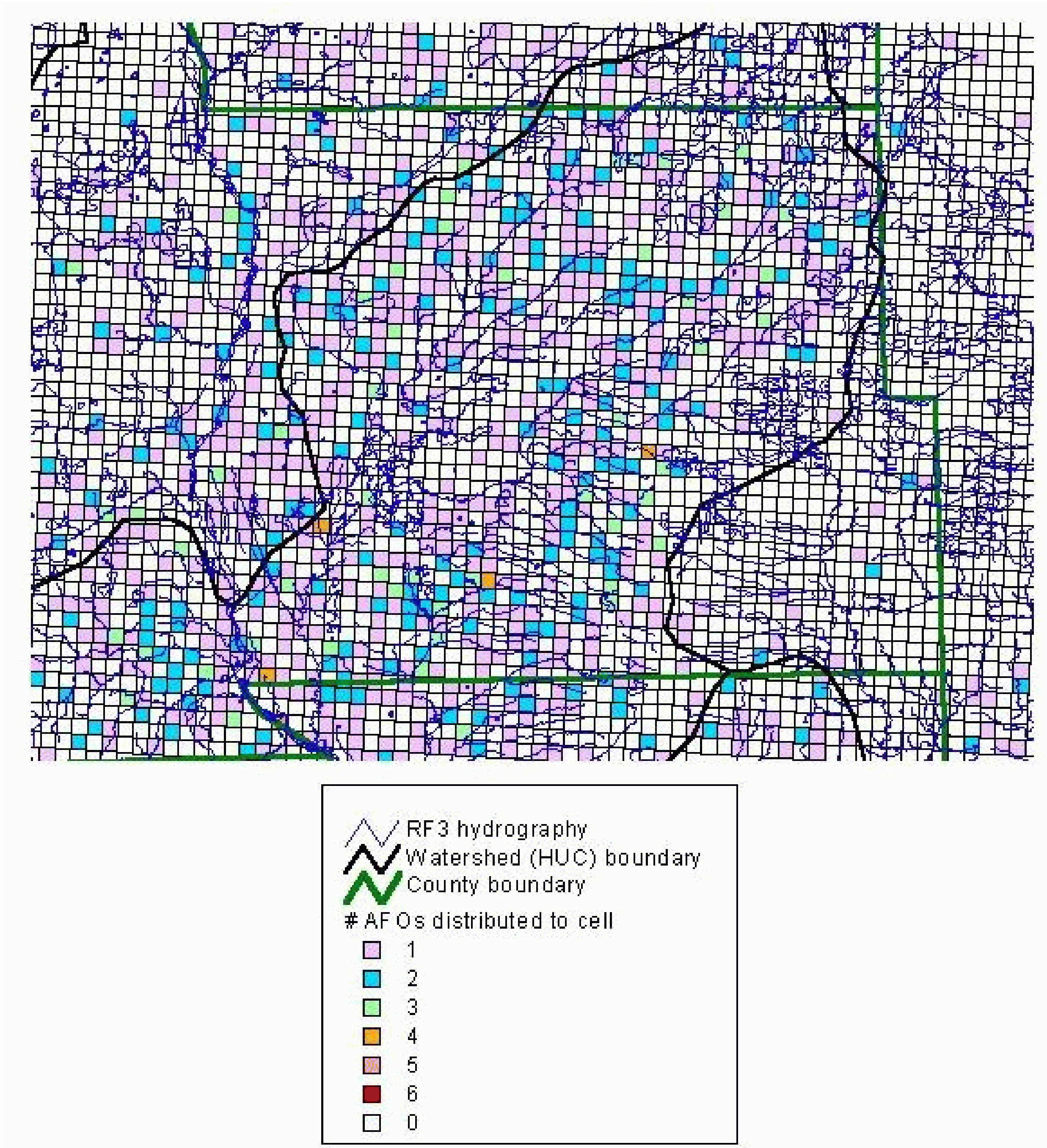
Figure C-2 depicts the spatial mosaic of NWPCAM at the HUC level after the distribution of AFOs/CAFOs to agricultural cells.

Non-Point Source Loadings

The goal of the non-point source loading component is to estimate long term average nutrient (nitrogen and phosphorus) inputs to river reaches (within the RF3/RF3Lite framework) from all contributing non-point sources (excluding AFOs) using a nationally consistent approach. The approach also must work within the constraint of nationally applicable data sources. Traditionally, animal operation loadings to river reaches have been included as part of non-point sources. However, AFOs/CAFOs must be considered a separate source category for purposes of policy evaluation for the AFO/CAFO version of NWPCAM. Consequently, AFO/CAFO source loadings must be removed from the non-point source loading category used in the AFO/CAFO version of NWPCAM. Therefore, the purpose of this effort is to establish non-point source loadings within the RF3/RF3Lite framework which do not include AFO/CAFO loadings for use in the model.

Figure C-2

**MOSAIC COMPOSITE OF SPATIAL DATA AT THE WATERSHED (HUC) LEVEL\
WITH AFOS/CAFOS DISTRIBUTED TO AGRICULTURAL LAND-USE CELLS**



An approach employed based on these objectives has been developed using the framework for NWPCAM (Bondelid et al., 1999b)[1] (nutrients version of NWPCAM). This approach uses a simple export coefficient loading model to deliver nutrients from all sources to a reach. The approach is applied on a watershed level. Export coefficients are empirically based values that describe the loading of a given nutrient expressed in terms of mass per unit time per unit area. The analytical specification for export coefficients, therefore, requires estimates of both the unit loading and the area of land within a catchment described in terms of different types or classes of land use and/or land cover. The analytical model can be summarized as:

$$L = \sum (EC_n \cdot A_n)$$

Where L = loading to a reach (kg/yr)
EC_n = export coefficient for category n (kg/ha/yr)
A_n = area draining to reach in land use category n (ha)
n = land cover or use category

The principal data sources for this model are: (1) the USGS conterminous United States Land Cover Characteristics (LCC) Data Set (Version 2) (Appendix A of the report); (2) empirically based estimates of export coefficients derived from a national study (Reckhow et al., 1980, Table 3); and (3) and model output from a national study of nutrient sources, transport, and instream flux (Smith et al., 1997).

Nutrient loads for non-point sources were computed by land-use type by ecoregion based on SPARROW (*SPA*tially *R*eferenced *R*egression *O*n *W*atershed attributes) which is a statistical modeling approach for estimating major nutrient source loadings at a reach scale based on spatially referenced watershed attribute data (Smith et al., 1997). An optimization algorithm was developed to estimate non-manure loadings by comparing SPARROW non-manure non-point source estimates for cataloging units with NWPCAM modeled outputs. The optimal coefficient set was determined for both nitrogen and phosphorus as described below, and the resulting non-point source loading was delivered directly to the RF1 subset of the RF3Lite reaches for hydrologic routing through the river/stream network.

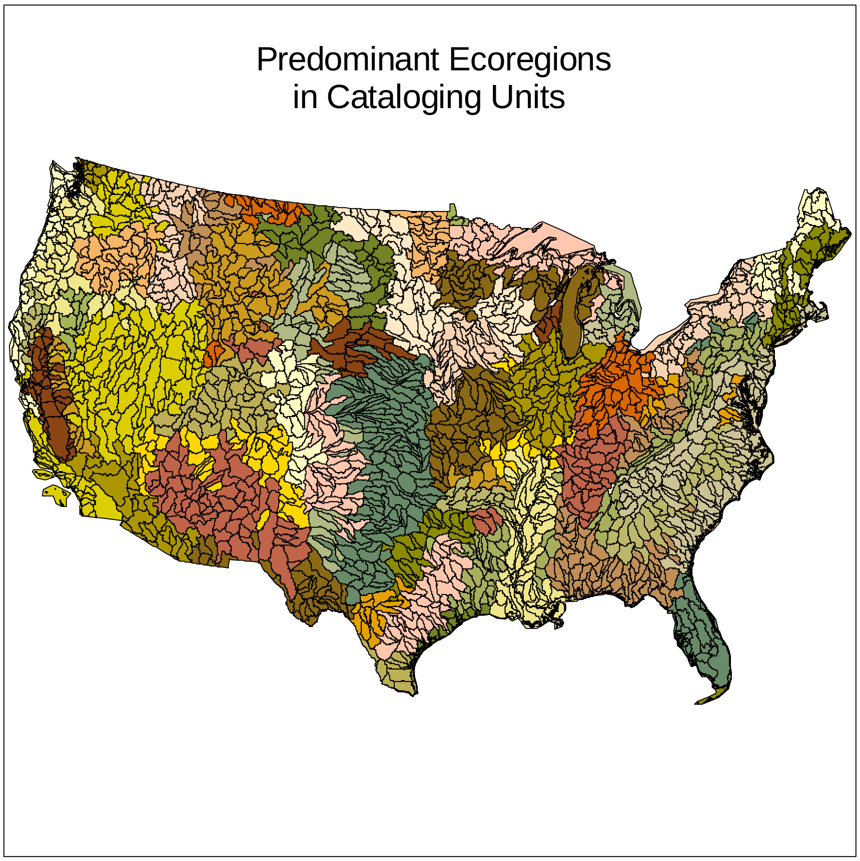
The first step in regional export coefficient estimation was to identify constraints (low and high ranges as shown in Appendix A of the report) on feasible coefficients for different land-cover classes. The next step was to define the system for which estimates of coefficients are desired. The system was defined as all cataloging units sharing the same predominant eco-region (Figure C-3) and the first phase of testing focused on the Upper Mississippi hydroregion. After testing and adjusting genetic algorithm parameters for population size and number of generations, the optimization routine was run for each hydroregion in the conterminous U.S. For each eco-region within a hydroregion,

[1] The reader is referred to Bondelid et al. (1999b) for a more detailed discussion of the non-point source modeling framework. The current study focuses on modifications pursued to address the issue of modeling policy implications of changes in nutrient inputs associated with proposed manure application regulations.

export coefficients were estimated using the optimization routine to find a set of optimal coefficients. The criteria for optimization was minimizing the sum of squared error between predicted (coefficient) and empirically-based (SPARROW) cataloging unit level data.

Figure C-3

PREDOMINANT ECOREGIONS IN CATALOGING UNITS



The modeling framework must appropriately represent the delivery of pollutants from their source area to the receiving waters as well as the transport of pollutants within the watershed. The existing NWPCAM model implicitly accounts for pollutant delivery as a function of the use of an empirically based approach to estimating loading. Export coefficients are not constrained by theoretical descriptions of runoff processes. As such, they conceptually or heuristically can be applied to a wide range of watershed sizes. The empirical data used to determine export coefficient ranges employed by the optimization process were screened to represent data consistent with the 1 km^2 cell size, as the unit loading area. The calibration of the export coefficients to watershed estimates using results from the SPARROW analysis implicitly accounts for all loading to the system. In other words, the loading coefficient assigned to any given cell can be thought of as that loading which is delivered to the outlet of the watershed. Since the routing model incorporates in-stream nutrient assimilation kinetics, a field to stream delivery model is not explicitly required in the model.

C2. HYDROLOGIC ROUTING

Within the contiguous 48 United States, the scope of the physical domain of NWPCAM is primarily limited to free-flowing streams and rivers and run-of-river reservoirs and lakes characterized by inflows and outflows from streams and rivers. The interaction of groundwater and surface water transport processes is not explicitly represented in the model framework.[2] The Great Lakes and other large lakes (e.g., Lake Champlain), tidal rivers, estuaries, embayments, and coastal waters are, for the most part, not included in the current version of NWPCAM, although future versions of the model will expand into these areas.

To support the fate and transport modeling of pollutants in these waters, NWPCAM is built on a sophisticated nationwide surface water routing system. In addition, this system is spatially linked to detailed data on the stream flow and other physical characteristics of these water. These data are used to model the hydrodynamic processes that are critical to NWPCAM's water quality model.

C2.1 National River/Stream Network—The Reach File Routing System

The foundation of the national-scale NWPCAM framework is its surface water routing system, which is based on USEPA's Reach File databases. The USEPA Reach Files are a series of hydrologic databases of the surface waters of the continental United States, which are designed to efficiently route flow and pollutant loads coalescing from headwater streams to tributaries to large rivers. The structure and content of these databases were created expressly to establish hydrologic ordering and to perform hydrologic navigation for modeling applications.

In addition, the Reach Files establish a hierarchy of watersheds that ultimately lead to a unique identifier for each surface water feature (i.e., the reach code). Reach codes uniquely identify, by watershed, the individual components of the nation's rivers and lakes. A series of watershed maps is presented to show the hierarchy of the different spatial scales included in the Reach File databases. Figures C-4 and C-5 present maps of the contiguous United States showing the different spatial scales—from the 18 major river basins to the 2,111 smaller watersheds referred to as catalog units (CU), which are comparable in size to an average county in the United States. Each of the CUs can then be further subdivided into connected surface water segments referred to as reaches.

[2] Summer low-flow conditions that characterize stream flow in free-flowing streams and rivers include a base flow component that essentially accounts for groundwater inflow.

Earlier versions of NWPCAM incorporated the approximately 633,000 miles of rivers and streams in USEPA's Reach File Version 1.0 (RF1), which were grouped into 68,000 reach segments. Approximately 61,000 of these segments were river and stream reaches with an average length of about 10 miles. These were defined as transport reaches, that is, water flows down them. The remaining approximately 7,000 reaches were nontransport reaches (e.g., lake shorelines).

Figure C-4

MAP OF 18 RIVER BASINS

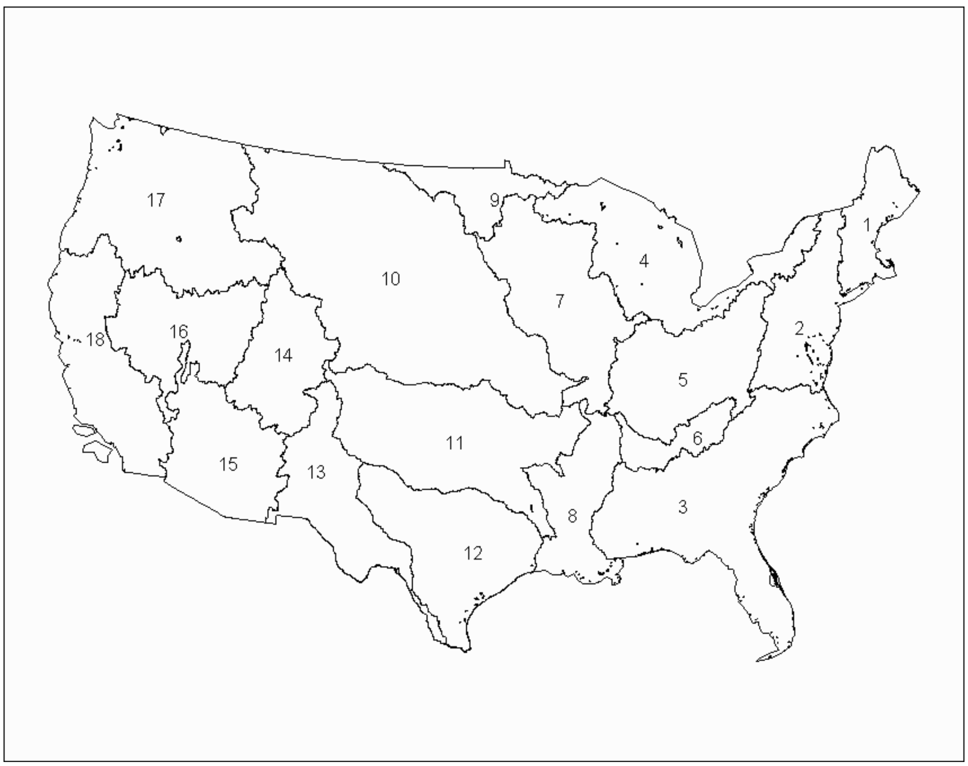
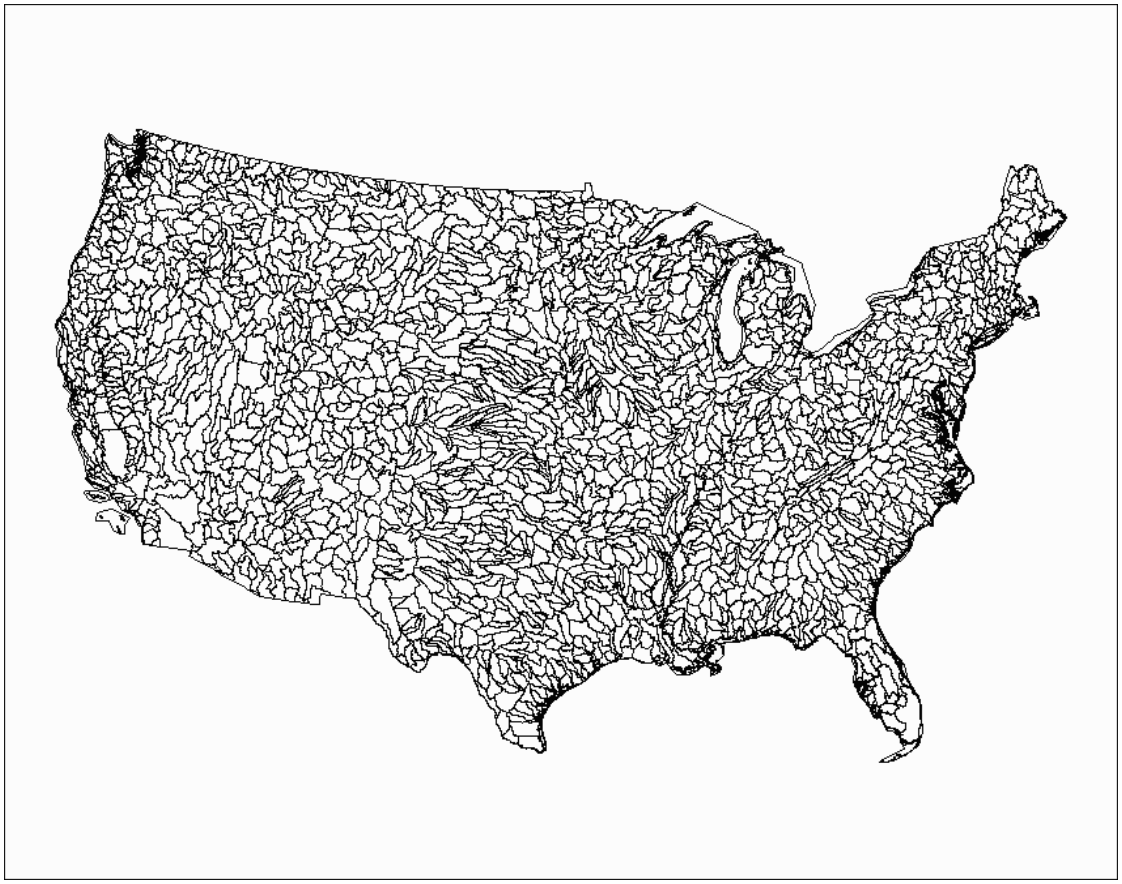


Figure C-5

MAP OF 2,100 CATALOG UNITS



Subsequently, USEPA has developed the more comprehensive database based on Reach File Version 3.0 (RF3), which includes virtually all of the three million miles of rivers and streams in the United States, including smaller intermittent streams.[3] RF3 has a much better characterization of open waters (e.g., lakes, reservoirs, tidal rivers), but the density of reaches is too great (at this time) to justify its full use at a national scale. This problem has been addressed by the building of an RF3 subset that is referred to as "RF3Lite."

RF3Lite, a subset of the RF3 system, includes all of RF1, plus a number of additional RF3 reaches not included in RF1. These extra reaches include streams with major point sources that are not part of RF1 and certain lakes, especially headwater lakes. Using RF3Lite, the types of water bodies currently included in NWPCAM are

- free-flowing streams and rivers,
- lakes characterized by inflows and outflows from streams and rivers, and
- run-of-river reservoirs and tidal rivers.

The RF3Lite subset of reaches was established based on four criteria:

- original RF1 reach,
- segment is longer than 10 miles,
- upstream lake or pond exists, and
- major point discharger exists on or upstream of reach (in process).

Large open water systems of estuaries (e.g., Chesapeake Bay), embayments (e.g., Waquoit Bay), coastal waters (e.g., New York Bight, Southern California Bight), the Great Lakes, and other large lakes (e.g., Lake Champlain) are *not* incorporated in the current version of NWPCAM.

[3] The RF3 database and associated hydrologic/reach routing framework at the core of NWPCAM have been developed so that RF3 can be replaced with the next generation reach file, the National Hydrography Dataset (NHD), when NHD is released in early 2001. NHD provides the following advantages: it is available at different scales (1:100,000, 1:24,000, 1:4,000); states can provide updates to the dataset, making it very dynamic; and it contains areal features for lakes, ponds, and large rivers, for example. In contrast, RF1 and RF3 only contain linear features, making an estimation of water body areas inaccurate or impossible, and areal features contain a centerline (or artificial flow paths), making routing simpler. The transition from RF3 to NHD would require only minor changes in NWPCAM's modeling framework and would increase the power of NWPCAM by taking advantage of NHD's features. For example, model accuracy for water body calculations would increase through use of NHD's area features.

C2.2 Model Hydrology and Hydrodynamics

After the RF3/RF3Lite routing system is established, information regarding the hydrologic (how much water is flowing through the system) and the hydrodynamic (how deep and wide are the rivers/streams and how fast is the water flowing) characteristics of each reach are then incorporated into the model framework. The fate of a water quality parameter routed along a hydrologic network is largely driven by the time-of-travel from one reach to the next reach down the network and the kinetic interactions characteristic of the parameter. Time-of-travel is based on the velocity of water along the reach and the length of the reach. In turn, the velocity depends on the discharge (i.e., volume of flow) in the reach and the channel geometry of the reach. Consequently, the hydraulic routing process of the water quality model largely becomes a system of accounting for discharges, stream geometry, velocity, and travel distances to derive the time-of-travel.

An overland transport module has been developed to move AFO/CAFO loadings from the agricultural cell in which they have been randomly distributed to the nearest RF3 reach. The hydraulic routing and transport processes incorporated in the overland transport module are very similar to the corresponding processes for RF3/RF3Lite reaches discussed in this section.

Among the many challenges of the hydrologic routing is being able to characterize stream discharges and velocities and related stream channel characteristics (length, cross-sectional width, and depth) as accurately as possible. Channel geometry of a reach is determined based on several reach-specific parameters, such as stream slope, open water (lakes/wide rivers) areas, flow data, and reach length, and connectivity. In addition, flow information from upstream modeling units are fed into the channel geometry as initial flow for cross-boundary reaches. Substantial testing of this issue was conducted in the Upper Mississippi Basin (Hydroregion 7) during development of NWPCAM. The stream channel flow and geometry techniques applied in the AFO/CAFOs version of NWPCAM are summarized below:

1. For single-line rivers/streams in the RF3 routing network, drainage area is used to derive discharge or flow estimates for RF3 reaches. Drainage area estimates come from the land-cover/land-use data-set. These drainage area estimates have been compared to drainage area estimates for USGS gaging stations for RF3 reaches. A database that includes an analysis of mean annual flow for these USGS gauging stations has been created to develop these drainage area estimates.

2. For single-line rivers/streams in the RF3 routing network, an estimate of the stream width is based on a summary of stream channel characteristics (Keup, 1985) in which a log-log relationship between stream discharge and stream width is derived. While this approach is based on a national-level summary, it is being used until more geographically specific data are available.

3. For the RF1 reaches subset of RF3Lite, discharge estimates are derived from published data.

4. For open waters (i.e., wide rivers and lakes) in the RF3Lite subset of RF3, stream widths are estimated by taking the open water area and dividing by one-half the total circumference, which provides a measure of the average width along the open water lake or river channel. The open water areas come from previous analyses done for the EMAP program (Bondelid et al., 1999b).

C2.2.1 RF3 River/Stream Drainage Areas and Discharges

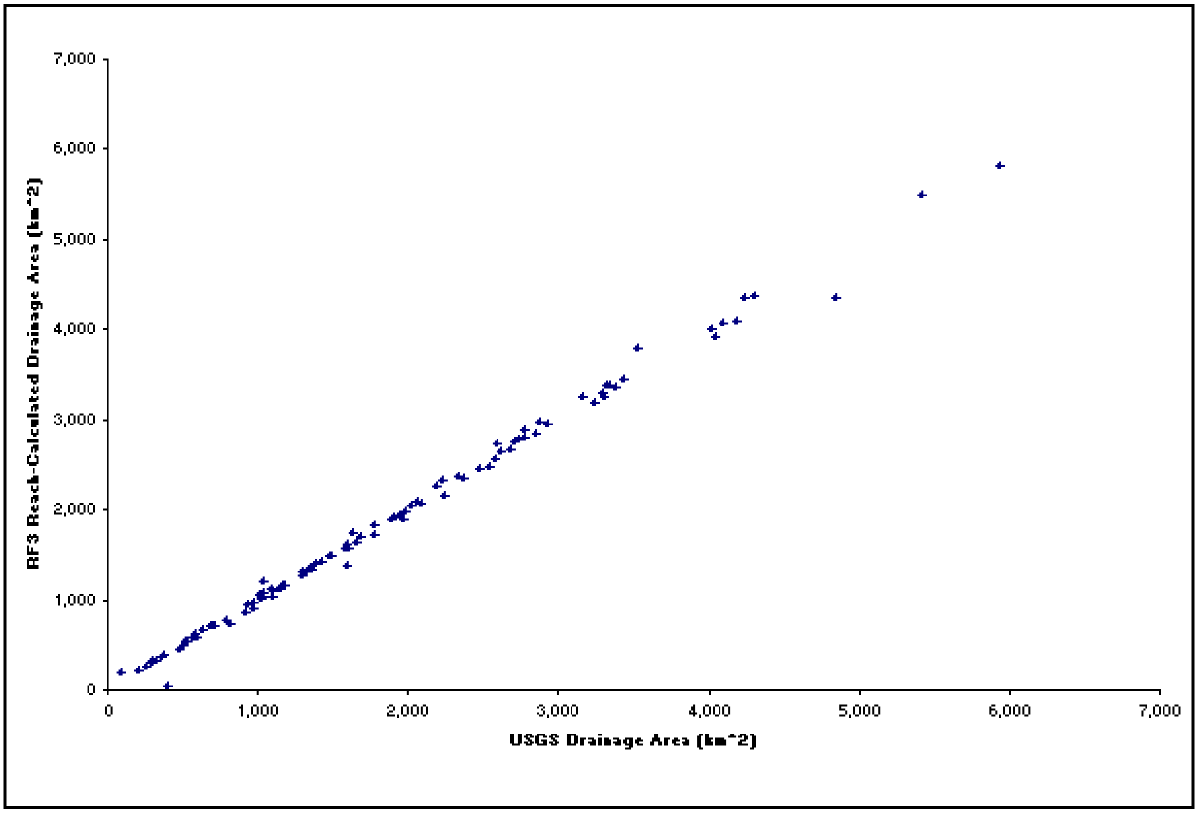
Stream discharge characteristics for each RF3 reach (RF3Lite subset of RF3 in Hydroregions 8 and 17 because RF3 reaches have not been established for these hydroregions) in the AFO/CAFO version of NWPCAM are based on the drainage area for each RF3 reach and the associated land-use cell (1 km^2 unit) runoff determined on a watershed basis (HUC). Land uses are determined from the USGS conterminous U.S. Land Cover Characteristics (LCC) Data Set (Version 2.0). The land-use coverage is overlain on the RF3 hydrologic routing framework to associate each land-use cell (1 km^2 cell) with a specific RF3 reach. The coverage for the 18 hydroregions comprises approximately 7,686,100 land-use cells at the square kilometer cell grid scale. Each land-use cell is assigned to the nearest RF3 reach. The number of cells assigned to each RF3 provides the approximate drainage area in square kilometers (km^2) for the specific RF3 reach. This value represents the land that actually contributes direct runoff to the reach versus the runoff received from the immediate upstream reach (i.e., the hydrologically routed runoff).

Therefore, the cumulative drainage area for an RF3 reach represents the land area associated with the reach itself plus the land area of upstream reaches. The cumulative drainage area for a given RF3 reach is calculated by hydrologically routing all reaches in the RF3 file for each hydroregion according to the routing sequence number and summing the reach-specific drainage areas as they are routed through the system. For example, the cumulative drainage area of the most headwater reach of a stream simply would be calculated from the land-use cells that are directly associated with that reach. As the routing algorithm moves downstream in the system, the cumulative drainage area for a specific reach would be calculated as the area of the land-use cells that are directly associated with that reach plus the drainage areas of each reach that is hydrologically upstream of the specific reach.

Testing of the drainage area calculations to verify the reasonableness of the methodology was completed for Hydroregion 7. Once the drainage areas for all RF3 reaches in Hydroregion 7 had been calculated, these drainage areas were compared with estimates of drainage area for USGS stream gauges in Hydroregion 7. The USGS stream gauges in the Hydro-Climatic Data Network (HCDN) were selected for data comparisons because their predominant characteristic is that they represent relatively natural hydrologic conditions and are not influenced by controlled releases from reservoirs. Further, only gauges with a drainage area less than the drainage area of the cataloging unit where the gauge is located were selected so that the discharge data from the same set of HCDN gauges could be used for future discharge comparisons. At the national level, a total of 1,391 HCDN gauges were identified for this dataset. A subset of these HCDN gauges (103 gauges) for Hydroregion 7 was used to test the comparisons.

Figure C-6

COMPARISON OF USGS VS. RF3 REACH-CALCULATED DRAINAGE AREA FOR HYDROREGION 7 (CORRECTED)



Each of these HCDN gauges in Hydroregion 7 was assigned to the nearest RF3 reach based on geographic coordinate information, and the estimate of the drainage area for the USGS gauge was compared with the drainage area estimate for the RF3 reach derived by overlaying the land-use/land-cover coverage with the RF3 routing coverage. The results of the analysis indicated close agreement between the two drainage area estimates. Figure C-6 presents a regression analysis graphic of the comparison. Initially several outliers were observed. However, further review of the datasets showed either that the nearest RF3 reach to which the HCDN gauge had been assigned was incorrect (i.e., the gauge was assigned to the wrong reach) or, in one case, that the RF3 reach had been removed from the RF3 dataset because of incomplete data. Once these errors were corrected, the regression analysis gave an “r-squared” of 0.995. Based on this analysis, we concluded that the drainage area estimate calculated for each RF3 reach through the overlay of the land-use/land-cover coverage and the RF3 coverage was suitable for use in the model.

The dataset of 1,391 HCDN gauges then were selected to derive a mean annual unit runoff ($ft^3/sec/km^2$) for each cataloging unit. Using a 200-mile maximum search radius from the centroid of the cataloging unit, the five nearest HCDN gauges were identified. In some cases, less than five gauges were available within the 200-mile search radius. Mean annual unit runoffs were calculated using a weighted-average technique based on the distance of the HCDN gauge from the centroid of the cataloging unit. For each cataloging unit, a mean annual unit runoff was calculated based on mean annual discharge for the HCDN gauges. Aggregation of the unit runoffs for each land-use cell in each RF3 reach would represent the total discharge originating from the land-use cells associated with the reach. Total discharge for a reach would equal the sum of the discharge for the reach-associated land-use cells plus the discharge originating from upstream reaches. The resulting unit runoffs for each cataloging unit then were converted to inches of runoff and compared to the USGS runoff contour map for the conterminous United States. Figures C-7 and C-8 present these comparisons and generally indicate close agreement between the two sets of data.

Figure C-7

RF3 REACH—CALCULATED RUNOFF (INCHES) FOR THE UNITED STATES

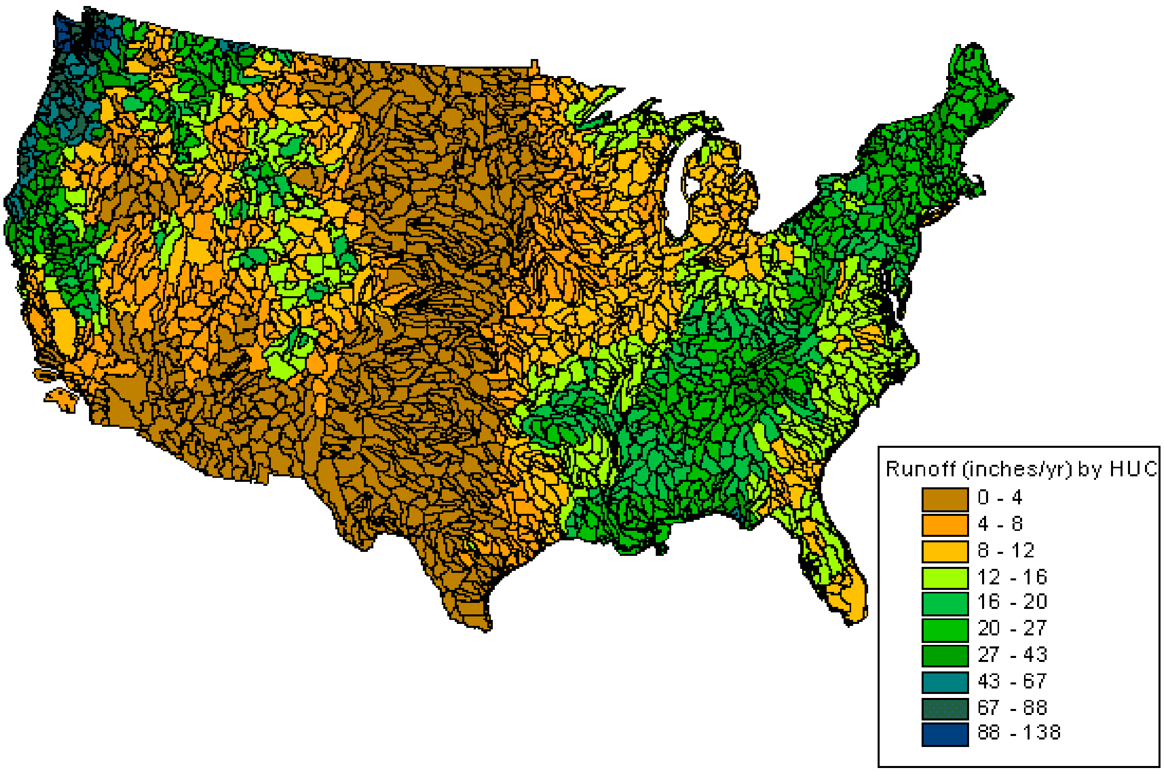
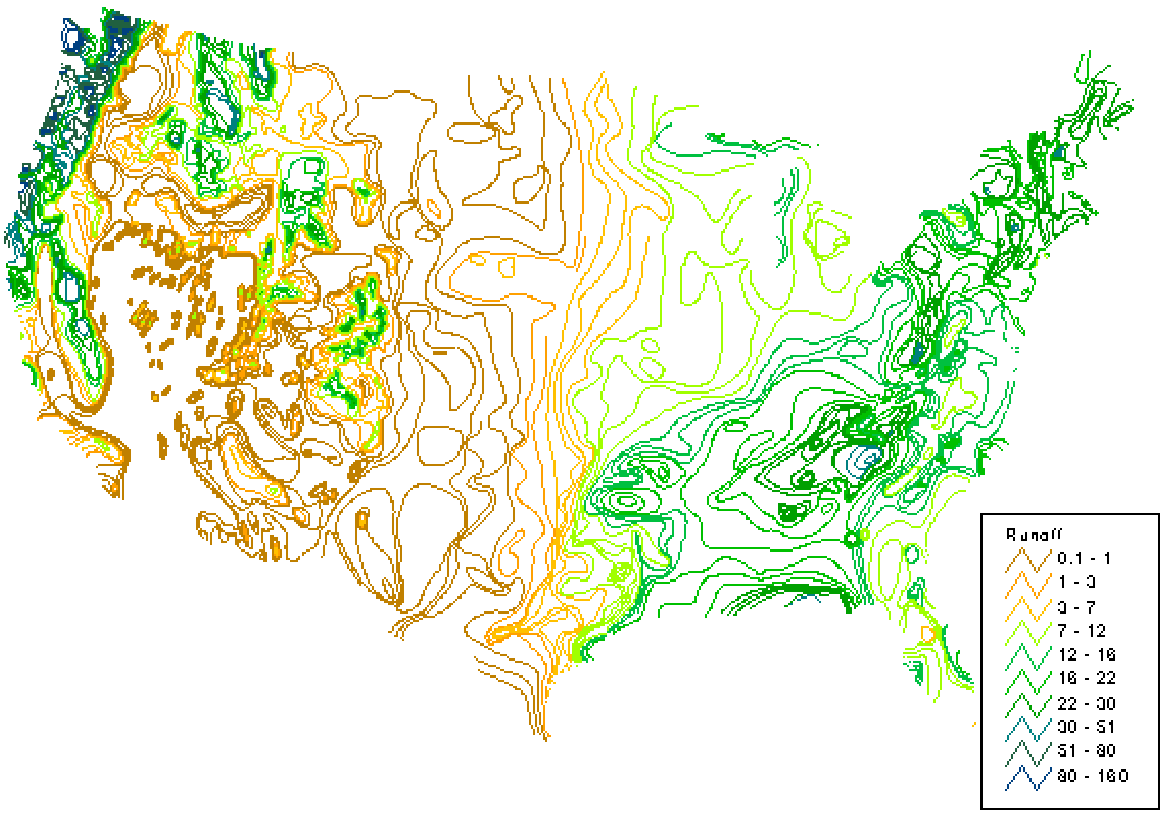


Figure C-8

USGS AVERAGE ANNUAL RUNOFF (INCHES) FOR THE UNITED STATES



C2.2.2 RF3 River/Stream Channel Properties

Once stream discharge characteristics have been defined for a HUC, then Keup's (1985) methodology is used to derive stream channel characteristics and time-of-travel estimates for RF3 reaches. The log-log relationship between stream flow and channel depth developed from these data is:

$$W = 5.27 * Q^{0.459}$$

where:

W	=	channel width (ft) and
Q	=	discharge (stream flow in cubic feet per second [cfs]).

Channel width is set at a maximum of 200 feet, because the digitizing standards for the RF3 source data (USGS 1:100,000 Digital Line Graph Files) require that channel widths greater than 200 feet (e.g., wide rivers) be digitized as double-wide channels, which translates in RF3 as wide rivers or lakes. Channel depths are calculated based on the classic Manning's "n" formulation for channel resistance analysis. Assuming a rectangular channel cross-section, the following formula can be used to calculate stream depth:

$$y_0 = 0.79\ (Q*n/(W*\ (S_0)^{0.5}\ )^{0.6}$$

where:

y_0 = channel depth (ft),
Q = discharge (stream flow in cfs),
n = Manning's "n" roughness coefficient,
W = channel width (ft) calculated above, and
S_0 = channel slope (ft/ft) (for RF3Lite reaches). Otherwise, S_0 = average slope of first-order streams in the accounting unit (equivalent to a six-digit HUC).

Manning's "n" values are assigned depending on whether the stream segment is a lake, wide river, or single-line stream, and they are based on best professional judgment using typical values (Henderson, 1966). For lakes, an "n" of 0.025 is used. For wide rivers, an "n" of 0.030 is used. For single-line streams, Manning's "n" can vary by how "winding" a stream is. RF3 contains enough coordinate detail that the "windiness," or "sinuosity," of a stream segment can be seen on the maps. The basic requirement is to measure the "sinuosity" and then for single-line streams vary Manning's "n" based on the "sinuosity." For this study, sinuosity (S) is calculated as

$$S = SEGL/DIST$$

where:

S = "sinuosity" measure,
SEGL = segment length of the reach (mi), and
DIST = straight-line distance between upstream and downstream nodes of the reach (mi).

Sinuosity (S) was calculated for each reach in the RF3 Reach File using spatial data associated with the reach and GIS techniques.

Without specific available information regarding how Manning's "n" varies as a function of S, a linear relationship was used in the study. The standard tables for Manning's "n" (Henderson, 1966) were used for the study. For an earlier version of NWPCAM, a statistical analysis of the sinuosity of 1,884,096 single-line reaches in RF3 was completed. The analysis indicated a mean value of S of 1.21, a median of 1.13, a 10th percentile value of 1.03, and a 95th percentile value of 1.64. Therefore, the minimum Manning's "n" corresponding to S = 1 is set at the lower limit of "clean and straight" channels, which is Manning's "n" = 0.025. The upper limit for the Manning's "n" corresponding to S at the 95th percentile (S = 1.64) is set at the upper limit of "winding with pools and shoals" ("n" = 0.040). Assuming a linear relationship, Manning's "n" for single-line streams is

$$\text{Manning's ``n''} = 0.0016 + 0.0234 * S,$$

with a lower limit of Manning's "n" = 0.025 and an upper limit of Manning's "n" = 0.040.

C2.2.3 RF3 Water Velocities

Stream velocity for RF3 reaches therefore is calculated as

$$V = Q/(W*y_0)$$

where:

- V = velocity (ft/sec),
- Q = discharge (streamflow in cubic feet per second, cfs),
- y_0 = channel depth (ft) calculated above, and
- W = channel width (ft) calculated above.

Time-of-travel along a stream reach corrected to units of days is calculated as

$$Tt = SL/(V*86{,}400)$$

where:

- Tt = time-of-travel along stream reach (days),
- V = velocity (ft/sec) calculated above, and
- SL = stream length or segment length of reach (ft).

C2.2.4 Agricultural Land-Use Cell to RF3 Reach Routing

AFO/CAFO nutrient loadings to agricultural land-use cells must be delivered to RF3 reaches in order to be hydrologically routed through the RF3 network. The modeling process is based on a time-of-travel analysis with nutrient/pollutant decay from the center of the cell to the nearest reach. Time-of-travel calculations are described above with minor modifications, as listed below.

Modifications to the time-of-travel calculations include:

Q = the discharge (per km^2) for the HUC calculated from analyses of USGS data as presented above
SL = D*S (where D = distance from cell center to nearest reach and S = sinuosity)
S = average sinuosity for the hydroregion
S_0 = channel slope (ft/ft) = ½ average slope of first-order streams in the accounting unit (equivalent to a 6-digit HUC).
n = 0.10

The sinuosity varied on a hydroregion basis and was calculated as the 75th percentile value of the sinuosities for the first-order stream RF3 reaches in the given hydroregion. A Manning's "n" of 0.10 was selected to represent weedy, windy, overgrown channels such as might be found on agricultural lands.

C2.2.5 RF1 River/Stream Discharges, Channel Properties, and Velocities

Drainage areas are not critical to the performance of NWPCAM at the RF1 reach subset of RF3Lite; rather discharge estimates are based on available data. For RF1 reaches, NWPCAM can be run using mean annual, 7-day 10-year low flow, or mean summer flow conditions. The mean annual and low flow conditions are directly extracted from Grayman's (1982) estimates for each RF1 reach. Consistent with the occurrence of worst case water quality conditions during summer and the selection of the summer as the critical time period used for designing wastewater treatment plants, mean summer stream flow data are based on estimates of mean summer (July to September) flow conditions within each RF1 stream reach. Mean summer flows for USGS gauging stations are based on the ratio of July to September average flows divided by the respective gauge mean. The summer flow then is computed by multiplying the ratio by the Grayman mean. Summer velocities are estimated as a function of the summer flow based on the Grayman velocities for mean and low flows. Grayman's (1982) estimates of mean summer velocities for each RF1 reach are based on an analysis of a compilation of time-of-travel studies and a log-log regression of mean flow and mean velocity with the data compiled by major river basin.

Under the assumption of steady-state flow and one-dimensional transport in free-flowing streams and rivers, channel velocity and geometry (depth, width, cross-sectional area, and wetted perimeter) for each RF1 reach are estimated using the mean summer flow balance and velocity data estimated for each RF1 reach and the "stable channel analysis" developed by the U.S. Bureau of Reclamation (Henderson, 1966). A reach is represented in the stable channel analysis with a 35E side slope trapezoidal cross-section with mean channel depth (H), channel depth at the center of the reach (H_o), cross-sectional area (A_c), wetted perimeter (P), and velocity (U) assumed uniform over the downstream length of the laterally and depth-averaged RF1 reach. The stable channel analysis, based on bed shear and local depth, provides a methodology to estimate the mean depth and wetted perimeter of a reach as a function of reach cross-sectional area. With Grayman's (1982) stream flow and velocity data assigned to each RF1 reach, the cross-sectional area (A_c) and mean depth (H) in the reach were estimated from summer mean stream flow (Q) and velocity (U) as follows:

$$A_c = Q/U,$$
$$H_o = A_c/2.86,$$
$$H = H_o * 0.445,$$
$$P = H_o * 4.99,$$

where

A_c = cross-sectional area of reach (ft^2),
Q = mean summer reach stream flow (cfs),
U = mean summer reach velocity (ft/sec),
P = wetted perimeter of reach (ft),
H_o = channel depth at center of reach (ft), and
H = mean channel depth of reach (ft).

C2.2.6 Stream Reach Routing

The USEPA Reach Files are a series of hydrologic databases of the surface waters of the continental United States. The structure and content of the Reach File databases were created expressly to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature (i.e., the reach code). Reach codes uniquely identify, by watershed, the individual components of the nation's rivers and lakes. RF3 has a very powerful routing design ideal for upstream and downstream orientations. This routing design works reach by reach, requiring no more than one "reach" database record to be "in memory" at a time. The routing design can be set up to run quite rapidly and is discussed in detail in Bondelid et al. (1999a, 1999b).

C3 WATER QUALITY AND EUTROPHICATION ASSESSMENT COMPONENT

For the AFO/CAFO version of NWPCAM, several models are used to assess the fate of water quality parameters within the hydrologic framework. First, nutrients and pollutants are routed overland from the agricultural cell in which AFO/CAFO edge-of-field loadings have been distributed to the nearest RF3 reach. Next, nutrients and pollutants are routed within the RF3 hydrologic framework to the RF1 subset of the RF3Lite hydrologic framework. For both overland transport and the RF3 hydrologic framework, the fate of these parameters is considered to be driven by a first-order decay process. For lakes within the RF1 subset of the RF3Lite framework, nutrient related water quality changes are evaluated using a eutrophication model. Lastly, dissolved oxygen (DO), nitrogenous biochemical oxygen demand (N-BOD), total suspended solids (TSS), and fecal coliforms (FC) are modeled within the RF1 subset of the RF3Lite hydrologic framework based on the kinetics used in the nutrients version of NWPCAM (version 1.1).

C.3.1 <u>RF3/Overland Water Quality Kinetics</u>

Within the RF3 hydrologic framework and for overland flow, the fate of nutrients and pollutants distributed to agricultural cells from AFO/CAFO operations is driven by first-order decay kinetics based on the following equation:

$$\frac{dc}{dt} = -K * c$$

where

dc/dt	=	the instantaneous change in pollutant concentration
K	=	decay rate (1/d)
c	=	pollutant concentration (mg/L).

The closed-form solution of this simple differential equation is

$$C_t = C_0 * e^{(-Kt)}$$

where

C_0	=	concentration (mg/L) at time zero
C_t	=	concentration (mg/L) at time t.

Extensive experience from a large number of studies has shown that the first-order decay process can be adequate for modeling many of the complex physical and biological processes that take place with many constituents in water. A difficulty with this approach, however, is in selecting the appropriate decay rate (K) which generally is based on field measurements, other modeling studies, and/or calibration of the model for a particular river system. For biological processes, K has been found to be temperature dependent. For NWPCAM, temperature adjustments to K have been adopted from USEPA (1985). For phosphorus, K is considered related to the deposition rate of sediments because phosphorus generally is bound to sediments. The kinetic expressions used to represent decay for overland flow transport and within the RF3 hydrologic framework of the AFO/CAFO version of NWPCAM include:

Total Nitrogen - $C_t = C_0 * e^{(-Kn*t)}$ where Kn = 0.3842 for discharges < 1,000 cfs
Kn = 0.1227 for discharges > 1,000 cfs and <10,000 cfs
Kn = 0.0408 for discharges > 10,000 cfs
(Smith et al., 1997)

Total Phosphorus - $C_t = C_0 * e^{(-Kpsed*t)}$ where Kpsed = (0.3/reach depth (y))

Fecal Coliform - $C_t = C_0 * e^{(-0.8*1.07\wedge(Temperature-20)*t)}$ where Temperature (°C)

Fecal Streptococci - $C_t = C_0 * e^{(-0.168*t)}$

Sediments - $C_t = C_0 * e^{(-Ksed*t)}$ where Ksed = (0.3/reach depth (y))

To support evaluation of nitrogenous biochemical oxygen demand (N-BOD) based on the kinetics used in the nutrients version of NWPCAM (version 1.1), nitrogen speciation also is modeled during overland flow transport and within the RF3 hydrologic framework. The kinetic expressions used for nitrogen species include (where temperature (temp) in °C) :

Nitrate-Nitrogen (NO_3_N)- $C_t = C_o$ * (Exp(-0.1 * 1.045 ^ (temp - 20) * t))

Soluble Ammonium-Nitrogen (NH_4S_N)- $C_t = C_o$ * (Exp(-0.12 * 1.08 ^ (temp - 20) * t))

Insoluble Ammonium-Nitrogen (NH_4I_N)- $C_t = C_o$ * (Exp(-0.12 * 1.08 ^ (temp - 20) * t))

Organic-Nitrogen (ORGNI_N)- $C_t = C_o$ * (Exp(-0.075 * 1.08 ^ (temp - 20) * t))

Transformation of nitrogen species resulting from these kinetics include:

NO_3_N from NH_4S_N (NO_3_NH_4S)- NO_3_NH_4S = NH_4SN (at C_o) - NH_4S_N (at C_t)
NO_3_N from NH_4I_N (NO_3_NH_4I)- NO_3_NH_4I = NH_4I_N (at C_o) - NH_4I_N (at C_t)
NH_4S_N from ORGNI-N (NH_4S_ORGNI)- NH_4S_ORGNI = ORGNI_N (at C_o) - ORGNI_N (at C_t)

Total fluxes of nitrogen species at a given time (C_t) therefore become:

Total NO_3_N (C_t) = NO_3_N + NO_3_NH_4S + NO_3_NH_4I
Total NH_4S_N (C_t) = NH_4S_N + NH_4S_ORGNI
Total NH_4I_N (C_t) = NH_4I_N
Total ORGNI_N (C_t) = ORGNI_N

C3.2 Nutrient Water Quality Assessment

Nutrient related water quality and eutrophication changes resulting from the various rule-making scenarios are evaluated using an eutrophication model (BATHTUB) developed for the US Army Corps of Engineers. Nutrient loads evaluated using the eutrophication model represent the combined nutrient loadings of AFO/CAFO operations as well as the SPARROW generated non-point source nutrient loadings to the RF1 subset of the RF3Lite hydrologic framework. BATHTUB was used to model the response of RF1 lakes and reservoirs with a residence time of at least one month to nutrient loadings (Walker, 1985). BATHTUB was chosen because of its strong empirical foundation, use of an extensive national database, and general acceptance and use by lake and reservoir modelers. Major inputs required for BATHTUB include lake morphometry (surface area and depth), flow, latitude, and nutrient loads. Several of these BATHTUB series models ranging from the very simple to the most complex were evaluated in the NWPCAM analyses. While each model may show slightly different water quality results, the bottom line change in water quality use-support was not affected by model selection. The principal output of interest for this study was chlorophyll ". Changes in concentration of chlorophyll " among the range of AFO/CAFO rule-making scenarios can be used to develop water quality benefits information which then can be related to economic benefits.

The model equations used and described below predict reservoir concentrations of total phosphorus, total nitrogen, chlorophyll ", organic nitrogen, particulate phosphorus, and hypolimnetic oxygen depletion rate as functions of reservoir mean depth, hydraulic residence time, and inflow concentrations of total phosphorus, ortho-phosphorus, total nitrogen, and inorganic nitrogen. Major inputs required for the eutrophication response model include lake morphometry (surface area and depth), flow, latitude, and nutrient loads, delivered to the lake. The relationships are:

log (chl") = log(Xpn) - .33 -.57 log(a) - .39 log(Z) -.0041/Ts

where

chl" = reservoir chlorophyll " concentration (mg/m^3)
Xpn= composite nutrient concentration variable (mg/m^3), and
$Xpn=(P^{-2} + ((N-150)/12)^{-2})^{-.5}$

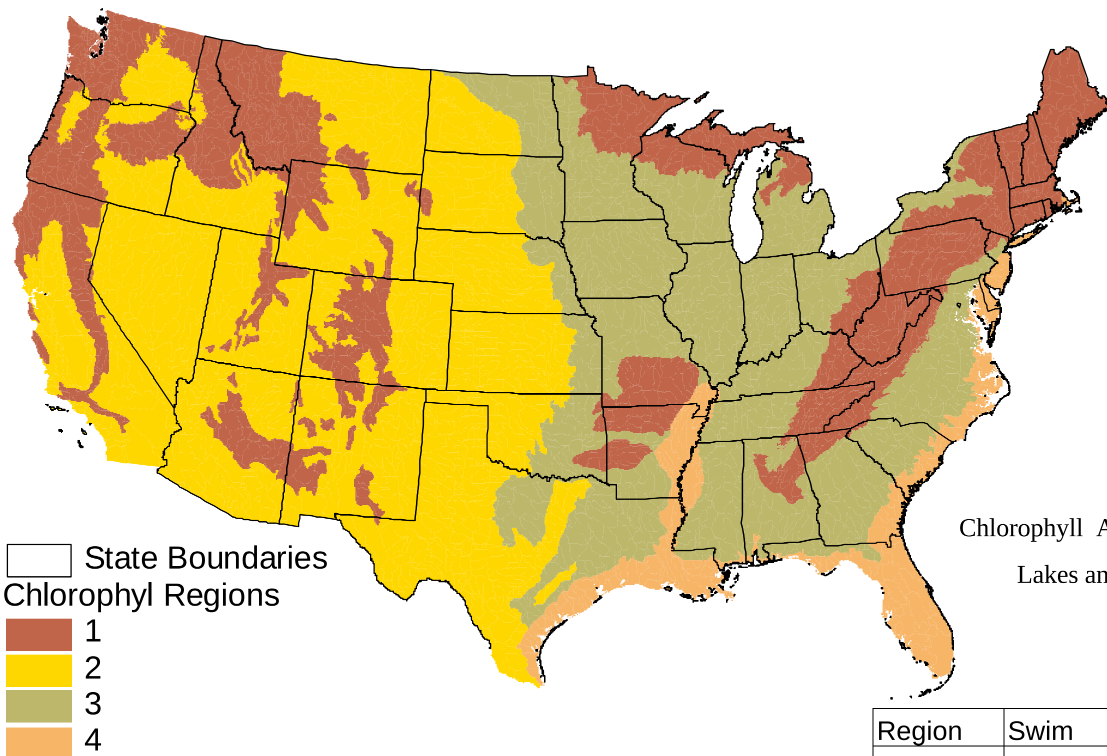
P = reservoir total phosphorus concentration (mg/m^3)
N = reservoir total nitrogen concentration (mg/m^3)

a = nonalgal turbidity (1/m)
log(a) = .23 - .28 log(Z) - .20 log (Ts) + .36 log(P) - 0.027 LAT
Z = mean reservoir depth (m)
Ts = summer hydraulic residence time (years), and
LAT = latitude (deg-N)

Figure C-9 presents the regionalizing water quality use-support ladder based on chlorophyll " concentrations used to assess breakpoints among different types of water use.

Figure C-9

REGIONALIZING USE SUPPORT LADDER USING CHLOROPHYLL "



Chlorophyll Assessment Breakpoints

Lakes and Reservoirs (ug/l)

Region	Swim	Fish	Boat
1	10	15	15
2	20	25	25
3	30	35	35
4	35	40	40

C3.3 NWPCAM 1.1 KINETICS FOR RF1 SUBSET OF RF3LITE REACHES

Nutrients/pollutants from AFO/CAFO operations are transported within the RF3/RF3Lite system as discussed in Sections C3.2 and C3.3. Pollutants from point sources (e.g., industrial, municipal, combined sewer overflows) and non-point sources (SPARROW generated data) are brought into the NWPCAM framework at the RF1 subset of the RF3Lite framework. At this point, the combined pollutant loads from AFO/CAFO operations, point sources, and non-point sources are evaluated based on the kinetics used in the nutrients version of NWPCAM (version 1.1). For the AFO/CAFO version of NWPCAM, these kinetics model dissolved oxygen (DO), nitrogenous biochemical oxygen demand (N-BOD), total suspended solids (TSS), and fecal coliforms (FC). The kinetics for the nutrients version of NWPCAM (version 1.1) have been discussed in detail in Bondelid et al. (1999b).

The following discussion presents the kinetic interactions, equations used for solution of the model, kinetic coefficients, and forcing functions used to simulate each state variable.

C3.3.1 Steady-State, One-Dimensional Model of a Non-conservative Constituent

For a constituent (C) that reacts with simple first-order kinetics (non-conservative) described by a reaction rate (K), the steady-state, one-dimensional (1-D) differential Equation C-1 describes how the material changes along the length of a uniform reach of a stream or river in response to advection and inputs from point sources and uniformly distributed nonpoint sources.

$$U\,dC/dx = -KC + S_d \qquad \text{(C-1)}$$

where the terms and units as mass (M), length (L), and time (T) are defined as follows:

U	=	constant velocity component within reach along longitudinal (x-axis) .	(ML^{-3})
C	=	concentration of water quality constituent	(LT^{-1})
x	=	longitudinal coordinate (x-axis)	(L)
K	=	first-order kinetic reaction rate	(T^{-1})
S_d	=	uniformly distributed source (+) or sink (-) of constituent	$(ML^{-3}T^{-1})$

Assuming a constant depth and cross-sectional area and no change of stream flow within a reach in the downstream direction of stream flow, the constant velocity (U) is given in Equation C-2:

$$U = Q/A_c \qquad \text{(C-2)}$$

where the terms in the velocity relationship are:

Q	=	constant stream flow in reach	(L^3T^{-1})
A_c	=	constant cross-sectional area of reach [(depth) (width)]	(L^2)

Solution to Steady-State, 1-D Model

The simplified model framework adopted for NWPCAM Version 1.1 incorporates only linear terms. With steady-state conditions and linear terms and constant hydraulic and kinetic parameters defined for a river reach, an exact analytical solution can be written for Equation C-1. The closed-form, analytical solution for the model (Chapra, 1997; Thomann and Mueller, 1987) describes the steady-state, spatial distribution of a constituent, C(x), along the length of a river reach (x) in Equation C-3:

$$C(x) = C_o e^{(-Kx/U)} + (Sd/K) [1 - e^{(-Kx/U)}] \qquad \text{(C-3)}$$

where:

x	=	longitudinal coordinate (x-axis)	(L)
C_o	=	upstream boundary concentration	(ML^{-3})
K	=	first-order kinetic reaction rate	(T^{-1})
U	=	constant velocity within reach	(ML^{-3})
S_d	=	uniformly distributed source (+) or sink (-) of constituent	($ML^{-3}T^{-1}$)

The first term in the solution is the spatial distribution resulting from the tributary load or wastewater point source load input at the upstream boundary of the reach. The second term of the solution gives the spatial response to the uniformly distributed, or nonpoint source, load input.

The upstream boundary concentration (C_o) accounts for the mixing and dilution of the inflowing upstream mass load [(upstream stream flow) x (upstream concentration)] of the constituent with the sum of the lateral mass load(s) contributed by either a tributary [(tributary flow) x (tributary concentration)] and/or a point source discharge [(effluent flow) x (effluent concentration)] at the upstream boundary. The upstream boundary of the reach is defined by the location of the confluence of the river with a tributary and/or wastewater discharge(s). The upstream boundary concentration (C_o) is obtained from a steady-state mass balance dilution calculation in Equation C-4:

$$C_o = [(Q_u C_u) + (Q_e C_e) + (Q_t C_t)] / [(Q_u + Q_e + Q_t)] \qquad \text{(C-4)}$$

where:

Q_u	=	upstream stream flow entering reach	(L^3T^{-1})
C_u	=	upstream boundary concentration of constituent	(ML^{-3})
Q_e	=	effluent flow of point source	(L^3T^{-1})
C_e	=	effluent concentration of point source constituent	(ML^{-3})
Q_t	=	tributary flow of point source	(L^3T^{-1})
C_t	=	tributary concentration of constituent	(ML^{-3})

The uniformly distributed source term (S_d) defines the input of a uniform mass load normalized to a unit volume of the river with units of mass per volume per time ($ML^{-3}T^{-1}$). Uniform distributions can also be defined as normalized to the length of shoreline as a line source ($ML^{-1}T^{-1}$) or normalized to a unit area of the water column or bottom as an areal source ($ML^{-2}T^{-1}$).

C3.3.2 Carbonaceous Biochemical Oxygen Demand

Ultimate carbonaceous biochemical oxygen demand (CBODU) is defined as the oxygen equivalent needed for the complete stabilization of organic carbon in water and wastewater. Depending on the type of point or nonpoint source load, ratios of CBODU to 5-day biochemical oxygen demand (BOD5) are used to convert effluent loading data compiled as BOD5 to loading data needed for input to the model as ultimate carbonaceous BOD. External sources of CBODU in the model are derived from inputs from point and nonpoint sources. The loss of CBODU from a waterbody is influenced by bacterial decomposition of organic carbon and physical settling of the particulate fraction of the total organic carbon pool from the water column.

Following the general solution given in Equation C-3, the solution for the spatial distribution of CBODU, C(x), as a function of the location (x) on the river is given in Equation C-5

$$C(x) = C_o\, e^{[-K_r\, x/U]} \qquad \text{(C-5)}$$

where:

C_o	=	upstream boundary concentration of CBODU	(mg/L)
K_r	=	CBODU removal rate	(day^{-1})
x	=	longitudinal coordinate (x-axis)	(m)
U	=	constant velocity component along longitudinal (x-axis)	($m\ day^{1}$)

The solution is determined by the upstream boundary condition and the removal rate of CBODU from the water column which, in turn, is defined by bacterial decomposition and settling of the particulate fraction of oxidizable organic matter (CBODU).

<u>Upstream Boundary Condition</u>

The upstream boundary concentration (C_o) is computed from Equation C-4 for mass balance dilution. The effluent concentration of CBODU (C_e) in the dilution calculations is computed using values of the ultimate BOD to 5-day BOD ratio assigned for each type of effluent, tributary input, or nonpoint source load as shown in Equation C-6:

$$C_e = \text{CBOD5e (CBODU/CBOD5)} \qquad \text{(C-6)}$$

where:

CBOD5e	=	carbonaceous 5-day effluent biochemical oxygen demand
CBODU	=	ultimate carbonaceous biochemical oxygen demand
CBOD5	=	carbonaceous 5-day biochemical oxygen demand

Decomposition Rate

The kinetic rate for bacterial decay (K_d) is represented as a simple first-order reaction that accounts for the overall decomposition of both the labile/refractory and dissolved/particulate fractions of total organic carbon. Assignment of the CBODU decay rate depends on the level of wastewater treatment, with higher decay rates used to account for discharges of raw and primary effluent (more labile, more particulate, easier to decompose). Lower decay rates are characteristic of discharges of secondary and better than secondary effluent (more refractory, more dissolved, more difficult to decompose) (Chapra, 1997; Lung, 1998).

In the data compiled by Hydroscience (1971; 1972) and Wright and McDonnell (1979), K_d (min) was defined by a value of 0.3 day^{-1}. Note that the field data used by Hydroscience (1971; 1972) in this relationship were collected during the 1960s when many treatment plants achieved less than secondary treatment; 72 percent of publicly owned treatment works (POTW) facilities were discharging raw or primary effluent in 1968 (U.S. Department of the Interior or DOI, 1970). The value of K_d (min) = 0.3 day^{-1} is consistent with decay rates ranging from 0.1 to 0.3 day^{-1} typical of waterways receiving primary effluent (Chapra, 1997; Lung, 1998).

For the baseline scenario in which contemporary (ca. 1995) effluent loading rates are represented in the model, the decomposition rate [K_d(min)] is assigned a lower value of 0.2 day^{-1} reflecting more refractory secondary and better than secondary effluent (Chapra, 1997; Lung, 1998). As documented in the 1996 Clean Water Needs Survey, 86 percent of the nation's POTW facilities discharged secondary or better effluent in 1996 (U.S. EPA, 1997).

The functional relationship of Equation C-7 is used to assign K_d as the decomposition rate, with the parameter value for K_d (min) assigned different values to represent the (a) baseline “with Clean Water Act (CWA) ca. 1995 effluent loads” and (b) “without CWA primary effluent only loads” policy scenarios.

The decomposition rate (K_d) is also adjusted for water temperature (T) according to the relationship shown in Equation C-8:

$$K_d\,(T) \quad = \quad K_d\,(20)\; 2_d^{(T-20)} \qquad \text{(C-8)}$$

where:

T	=	water temperature	(EC)
$K_d(20)$	=	reaction rate at 20 EC	(day^{-1})
2_d	=	temperature coefficient	(1.047)

Settling Loss

The loss rate of the particulate fraction of CBODU by settling is given by the term W_{sc}/H where W_{sc} is the settling velocity for particulate organic matter and H is water column depth. As municipal treatment levels increase from raw and primary to secondary and better than secondary, the suspended solids load and the corresponding particulate fraction of organic matter in the effluent is considerably reduced. Facilities whose treatment level is less than secondary typically remove about 50 to 70 percent of influent suspended solids and better than secondary treatment level plants can remove about 95-99 percent of solids (Association of Metropolitan Sewerage Agencies or AMSA, 1997; Gunnerson et al., 1982; Metcalf and Eddy et al., 1991). Assuming that 40 percent of effluent suspended solids are composed of particulate organic carbon (HydroQual, 1987), the particulate fraction of effluent CBODU is reduced from 40 to 51 percent for less than secondary effluent to 37 percent for secondary effluent and only 7 to 19 percent for better than secondary effluent. The load of settleable organic solids discharged by municipal wastewater thus decreases as the treatment efficiency is improved. As the dissolved fraction of organic matter in the effluent increases with better than secondary treatment levels, the settling loss rate (W_{sc}/H) diminishes and the in-stream removal rate ($K_r = K_d + W_{sc}/H$) is effectively lowered to approach the in-stream decomposition rate ($K_r \sim K_d$) (Lung, 1998).

Based on the range of values reported for the settling velocity (W_{sc}) of particulate organic matter (~0.2-2 m day^{-1}) (Chapra, 1997), the deposition loss of organic matter (CBODU) from the water column is parameterized in the model with a settling velocity of 0.5 m.day^{-1}.

Removal Rate

Calculation of the CBODU removal rate (K_r) is determined by the decomposition rate (K_d), the settling velocity (W_{sc}), depth (H), and a "policy scenario multiplier" (M_p) as shown in Equation C-9:

$$K_r = K_d + (W_{sc}/H)(M_p - 1) \quad \text{(C-9)}$$

where

K_d = CBODU decomposition rate . . . . (day^{-1})
W_{sc} = CBODU settling velocity . . . . (m day^{-1})
H = water column depth . . . . (m)
M_p = policy scenario multiplier . . 1 = with CWA; 2 = without CWA, primary only)

Assignment of the CBODU removal rate (K_r) for the without CWA primary effluent only policy scenario is computed using a value of M_p= 2 for the policy scenario multiplier. Particulate deposition of settleable solids are thus represented in the without CWA scenario.

Based on population-served data compiled from the 1996 Clean Water Needs Survey (U.S. EPA, 1997), it is estimated that about 89 percent of the national influent load of total suspended solids (TSS) and the corresponding influent load of particulate organic carbon has been removed from secondary and better than secondary effluent discharged to surface waters. Under the contemporary (ca. 1995) effluent with CWA load scenario, the particulate fraction of the effluent is assumed sufficiently small that the settling loss term can be ignored in Equation C-9. A value of M_p = 1 is assigned for the policy scenario multiplier to effectively define the removal rate (K_r) as equivalent to the decomposition rate (K_d) (Chapra, 1997; Lung, 1998). Particulate deposition of settleable solids are thus considered negligible in the with CWA scenario.

Version 1.1 of the NWPCAM is to be used to assess the water quality benefits attained by upgrading wastewater treatment from primary only (without CWA policy scenario) to secondary and better than secondary (with CWA ca. 1995 policy scenario). The model framework must therefore assign different reaction rates for CBODU removal by decomposition and settling. The kinetic formulations used to define CBODU removal are summarized below for each policy scenario.

Baseline Scenario: With CWA Secondary and Better Than Secondary Effluent

K_d (T,H) = [Equations C-7 and C-8]
K_d (min) = 0.2 day^{-1}
M_p = 1
K_r = Equation C-9

Policy Scenario: Without CWA Primary Effluent Only

K_d (T,H) = [Equations C-7 and C-8]
K_d (min) = 0.3 day^{-1}
M_p = 2
K_r = Equation C-9

C3.3.3 Oxidizable Nitrogen

In the sequential nitrification reactions for the oxidation of ammonia to nitrite and nitrite to nitrate, oxygen is consumed. In the breakdown of organic matter, organic nitrogen is hydrolyzed to ammonia. The total amount of oxidizable nitrogen in water and wastewater is given as total Kjeldahl nitrogen (TKN) and is the sum of organic nitrogen and ammonia nitrogen. The amount of oxygen required for nitrification is considered as the nitrogenous biochemical oxygen demand (NBOD). External sources of TKN in the model are derived from inputs from point and nonpoint sources. The loss of TKN from a waterbody is determined by the complete bacterial oxidation of ammonia to nitrate, hydrolysis of organic nitrogen, and physical settling of the particulate fraction of organic nitrogen. As a product of sediment diagenesis, regeneration of ammonia in the sediment bed serves as a source term for oxidizable nitrogen by the mass transfer of ammonia from the sediment bed back into the water column.

Upstream Boundary Concentration

The upstream boundary condition (C_o) is computed from Equation C-4 for mass balance dilution.

NBOD Oxidation Rate

The kinetic rate for oxidation of NBOD (K_n) is represented as a simple first-order reaction that accounts for the overall loss of oxidizable nitrogen (TKN) via hydrolysis of organic nitrogen, settling of the particulate fraction of organic nitrogen, and the oxidation reactions transforming ammonia to nitrite and nitrate. Several environmental factors have been shown to influence the overall loss rate of oxidizable nitrogen from the water column including pH, water temperature, suspended solids concentration, dissolved oxygen concentration, the benthos and substrate of the waterbody, depth, velocity, and other hydraulic characteristics (Zison et al., 1978; Bowie et al., 1985).

The loss rate (K_n) for TKN, at 20 EC, is adjusted for ambient water temperature (10 C <T< 30 C) according to the following relationship:

$$K_n (T) = K_n (20)\ 2^{(T-20)} \tag{C-12}$$

where:

T	=	water temperature	(EC)
K_n (20)	=	oxidation rate at 20 EC	(day^{-1})
2_n	=	temperature coefficient	(1.08)

C3.3.4 Dissolved Oxygen

Dissolved oxygen (DO) is included in the model framework as a key indicator of water quality for the protection of aquatic biota. DO levels are also directly related to policy scenarios that drive municipal and industrial effluent loading rates of carbonaceous (CBODU) and nitrogenous (TKN) oxygen-demanding materials. Sources of DO that add oxygen to surface waters include atmospheric reaeration and photosynthetic oxygen production from algae, macrophytes, and periphyton. DO is lost from surface waters by respiration of algae, macrophytes, and periphyton; biochemical decomposition of organic carbon (i.e., CBODU); nitrification of ammonia; and consumption of oxygen in the sediment bed. In Version 1.1 of the model framework, the photosynthetic gains (P) and respiratory losses (R) from aquatic plants, assumed to be balanced (i.e., P - R = 0 or P = R), are not included.

In contrast to the straightforward solutions for the other state variables, the solution for DO is coupled with the solutions obtained for CBODU and TKN because these solutions account for the carbonaceous and nitrogenous oxygen demands. The solution for DO is also given in terms of the DO deficit, or departure from the oxygen saturation concentration.

The solution for the spatial distribution of oxygen deficit, D(x), is taken from Thomann and Mueller (1987) and given in Equation C-15, for oxygen balance:

The components of the oxygen balance equation (C-15) are as follows:

(a) the initial value of the oxygen deficit
(b) point source of CBODU
(c) point source of TKN
(d) distributed source of TKN load with no significant addition to river flow
(e) deficit due to distributed source from algal gross photosynthesis
(f) deficit due to distributed sink from algal respiration
(g) deficit due to distributed sink from sediment oxygen demand

$$D(x) = D_o \exp\left(-K_a \frac{x}{U}\right) \qquad \text{(C-15a)}$$

$$+ \left(\frac{K_d}{K_a - K_r}\left[\exp\left(-K_r \frac{x}{U}\right) - \exp\left(-K_a \frac{X}{U}\right)\right]\right) L_o \qquad \text{(C-15b)}$$

$$+ \left(\frac{K_n}{K_a - K_n}\left[\exp\left(-K_n \frac{x}{U}\right) - \exp\left(-K_a \frac{x}{U}\right)\right]\right) N_o a \qquad \text{(C-15c)}$$

$$+ \left(\frac{K_n}{K_a K_n}\left[1 - \exp\left(-K_a \frac{x}{U}\right)\right] - \left(\frac{K_n}{(K_a - K_n) K_n}\left[\exp\left(-K_n \frac{x}{U}\right) - \exp\left(-K_a \frac{x}{U}\right)\right]\right)\right) S_{an} \qquad \text{(C-15d)}$$

$$- \left[1 - \exp\left(-K_a \frac{x}{U}\right)\right]\left(\frac{P_a}{K_a}\right) \qquad \text{(C-15e)}$$

$$+ \left[1 - \exp\left(-K_a \frac{x}{U}\right)\right]\left(\frac{R_a}{K_a}\right) \qquad \text{(C-15 f)}$$

$$+ \left[1 - \exp\left(-K_a \frac{x}{U}\right)\right]\left(\frac{S_B}{K_a H}\right) \qquad \text{(C-15g)}$$

where:

D(x)	=	oxygen deficit along longitudinal distance of river	(ML^{-3})
D_o	=	initial oxygen deficit at upstream end of a segment	(ML^{-3})
K_a	=	atmospheric reaeration coefficient	(T^{-1})
x	=	longitudinal distance in direction of flow	(L)
U	=	freshwater stream velocity	(LT^{-1})
K_d	=	CBOD decomposition rate	(T^{-1})
K_r	=	CBOD removal rate	(T^{-1})
L_o	=	initial CBODU concentration at upstream end of segment	(ML^{-3})
N_o	=	initial TKN concentration at upstream end of segment	(ML^{-3})
K_n	=	nitrification rate	(?)
S_{dn}	=	distributed source of ammonia from sediments	$(ML^{-3}T^{-1})$
P_a	=	daily average gross photosynthetic oxygen production ($P_a = R_a$)	$(ML^{-3}T^{-1})$
R_a	=	algal respiration rate ($R_a = P_a$)	$(ML^{-3}T^{-1})$
S_B	=	sediment oxygen demand	$(ML^{-3}T^{-1})$
H	=	depth of river segment	(L)

All reaction rates are computed for the ambient water temperature (T, EC). Note that in NWPCAM Version 1.1, it is assumed that $P_a = R_a$ so that $P_a - R_a = 0$; net algal production of oxygen = 0.

After computation of the oxygen deficit, D(x), the DO concentration is computed using Equation C-16:

$$DO(x) = [C_s - D(x)] \qquad \text{(C-16)}$$

where:

C_s	=	dissolved oxygen saturation concentration	(ML^{-3})
D(x)	=	oxygen deficit along longitudinal distance of rivers	(ML^{-3})

The DO saturation concentration, (C_s [S,T, E_{msl}]) depends on water temperature, salt concentration, and elevation above mean sea level, and is computed from relationships given by Thomann and Mueller (1987) and Chapra (1997).

The effect of water temperature on oxygen saturation (O_{sf}) is computed with Equation C-17:

$$\ln O_{sf} = -139.34411 + \frac{1.5757\text{-}01 \times 10^5}{T_a} - \frac{6.642308 \times 10^7}{T_a^2} + \frac{1.243800 \times 10^{10}}{T_a^3} - \frac{86.621949 \times 10^{11}}{T_a^4} \qquad \text{(C-17)}$$

where:

T_a	=	absolute temperature	(degrees K)
T	=	temperature	(EC)

where T_a is computed from Equation C-18:

$$T_a = T + 273.15 \tag{C-18}$$

The effect of salt on oxygen saturation (O_{ss}) is computed using Equation C-19:

$$\ln O_{sf} = \ln O_{sf} - S\left(1.7674 \times 10^{-2} - \frac{1.0754 \times 10^{1}}{T_a} + \frac{2.1407 \times 10^{3}}{T_a^{2}}\right) \tag{C-19}$$

where:

S	=	salinity	($g\ L^{-1}$ = parts per thousand, ppt, sometimes given as $^{0}/00$)

Using data extracted from STORET, the spatial distribution of chlorides is represented in Version 1.1 of the model framework as a mean summer forcing function with summary statistics of chlorides assigned to RF1 reaches as catalog unit mean values. Chloride levels (as mg/L) are converted to salinity (S, as g/L) to estimate oxygen saturation using Equation C-20:

$$S = 0.03 + 1.80655 \times 10^{-3}\,[Cl^{-}] \tag{C-20}$$

The effect of elevation on the temperature (T) and salt-dependent DO saturation (O_{sp}) is computed from a formulation given by Chapra (1997) using Equation C-21:

$$O_{sp} = (O_{sf} + O_{ss})\,[1 - 114.8\,E_{MSL})] \tag{C-21}$$

where:

O_{sf}	=	temperature-dependent oxygen saturation (Equation C-17)	(mg/L)
O_{ss}	=	salt-dependent oxygen saturation (Equation C-19)	(mg/L)
E_{MSL}	=	mean elevation above sea level	(m)

Upstream Boundary Concentration

After transforming the DO concentrations of the upstream inflow, tributary inflows, and point and nonpoint sources to the deficit concentration, the upstream boundary condition of the oxygen deficit (D_o) is computed from the mass balance dilution equation (Equation C-4). For headwater start reaches, 100 percent oxygen saturation is assumed so that the initial deficit is zero. For inflows across the upstream boundary and tributary inflows, the oxygen deficit is computed, stored, and assigned from upstream solutions of the model. For point sources and nonpoint source runoff, characteristic oxygen concentrations, and hence deficits, are assigned to each type of load input. Municipal and industrial discharges assume a water temperature of 25 EC, and the deficit from urban and rural runoff is based on the water temperature assigned to an RF1 reach. Spatially dependent water temperature, chlorides, and elevation data are used with Equations C-17, C-19, C-20, and C-21 to assign the oxygen saturation concentration and oxygen deficits (Equation C-16) for each type of source.

Atmospheric Reaeration

Oxygen transfer from the air to the surface layer of a waterbody depends on water temperature and turbulence due to velocity in the river, wind mixing, and any turbulence contributed by water falling over waterfalls and dams. For this simplified model, the atmospheric contributions from wind mixing, waterfalls, and dams are not considered. The atmospheric reaeration coefficient (K_a) is determined using the method of Covar (1976) presented in Bowie et al. (1985) and adopted for the Wasp5-Eutro5 model (Ambrose et al., 1993). The method computes reaeration as a function of velocity and depth using formulations developed by Owens et al. (1964), Churchill et al. (1962), and O'Connor and Dobbins (1958) for different categories of streams and rivers. The selection of the specific formulation is governed by the paired depth and velocity assigned to the RF1 reach (see Table C-4). The computation of K_a is given in Equation C-22:

$$K_a = a\,U^b\,H^c \qquad \text{(C-22)}$$

where:

a, b, c	=	coefficients for depth and velocity	(see table C-2)
U	=	velocity	(ms^{-1} or ft s^{-1})
H	=	depth	(m or ft)

The lower and upper ranges for depth (H) and velocity (U) and the numerical values of the coefficients (a, b, and c) for the three formulations are given for both metric and English units in Table C-2.

The atmospheric reaeration rate (K_a) is determined from Equation 4-23 at 20 EC, and adjusted for ambient water temperature according to the following relationship:

$$K_a(T) = K_a(20)\,2_o^{(T-20)} \qquad \text{(C-23)}$$

where:

T	=	water temperature	(EC)
$K_a(20)$	=	atmospheric reaeration rate at 20 EC	(day^{-1})
2_o	=	temperature coefficient	(1.024)

Table C-4

DEPTH (H) AND VELOCITIES (U) RANGES REAERATION FORMULATIONS AND COEFFICIENTS FOR OWENS ET AL., CHURCHILL, AND O'CONNOR-DOBBINS (Chapra, 1997; Ambrose et al., 1993)

		Metric Units (U as m s^{-1}, H as m)	English Units (U as ft s^{-1}, H as ft)
Owens et al. (1964)			
(Depth: Shallow streams)			
H	=	0.12< H < 3.3	0.4< H < 11
U	=	0.03< U < 1.52	0.1< U < 5
			(continued)
a	=	5.32	21.6
b	=	0.67	0.67
c	=	-1.85	-1.85
Churchill (1962)			
(Depth: Moderate to deep; fast velocity)			
H	=	0.61 < H < 3.3	2 < H < 11
U	=	0.55 < U < 1.52	1.8 < U <5
a	=	5.026	11.6
b	=	1.0	1.0
c	=	-1.67	-1.67
O'Connor and Dobbins (1958)			
(Depth: Moderate to deep; low to moderate velocity)			
H	=	0.3 < H < 9.1	1 < H < 30
U	=	0.15< U < 0.49	0.5 < U < 1.6
a	=	3.93	12.9
b	=	0.5	0.5
c	=	-1.5	-1.5

Sediment Oxygen Demand

Organic matter in the aquatic ecosystem is derived from the external loading from wastewater discharges, watershed runoff, and in situ biological production processes. The dissolved and particulate fractions of organic matter are then removed from the water column by bacterial decomposition, with the particulate fraction subject to additional removal from the water column by settling of particulate organic matter to the bottom. Under aerobic conditions, bacterial decomposition of organic matter, occurring in the water column and on the sediment bed, consumes DO. The rates of consumption of oxygen in both the water column and the sediment bed are clearly correlated with the rates of external point and nonpoint source loading and in situ biological production of organic matter. In the water quality model, the water column consumption of oxygen is described by the decay of the amount of CBODU remaining in the water column after the initial dilution and transport of external point and nonpoint source loads. The water column consumption of oxygen is thus directly coupled to the magnitude of external point and nonpoint source loads. Any increase in the loads will increase water column oxygen consumption and decrease DO. Any decreases in loads will have the opposite effect, increasing levels of oxygen.

The importance of the decomposition of organic matter deposited in the sediment bed has been understood since oxygen balance models were first developed during the 1960s. Water quality models built since the 1960s and even into the 1990s typically defined spatially dependent rates of SOD as a zero-order, external forcing function specified as input data to a model (e.g., Qual2E, Brown and Barnwell, 1987; Wasp5-Eutro5, Ambrose et al., 1993). Field measurements of SOD or the literature, were typically used to assign model input values for existing loading conditions for calibration and validation of a model. To prepare model projections of future conditions simulated under reduced loading conditions as a result of control alternatives, the specification of future SOD conditions was problematic since no reliable methodologies were available to provide a link between changes in organic matter deposition to the bottom and changes in SOD. Future SOD values were either unchanged or reduced assuming a linear proportionality with reduced external loads. Where the control alternatives were not expected to greatly alter the loading of particulate organic matter to the sediments, the assumption of no change in only the SOD was reasonable. Where control alternatives were intended to reduced particulate organic matter loads, the assumption of linear proportionality was based only on best professional judgement. Most control alternatives, however, such as upgrading primary facilities to secondary and better than secondary treatment, controlling combined sewer overflows or reducing the loading of nutrients, either directly or indirectly, reduce the amount of particulate organic matter supplied to the sediment bed and thus directly influence SOD.

In the NWPCAM, the primary objective of the model framework is to couple changes in water quality and beneficial uses that can be expected through implementation of policy scenarios for point and nonpoint source controls. Development of a technically credible model framework for the NWPCAM, therefore, requires that a link between external loads and SOD be incorporated into the model.

Contemporary state-of-the-art water quality models for the Chesapeake Bay (Cerco and Cole, 1993) and the Upper Mississippi River (HydroQual, 1999; 199a; 1996b), for example, incorporate a mechanistic relationship between deposition and decomposition of particulate organic matter and SOD based on the landmark work of Di Toro et al. (1990). Incorporating the full complexity of the state-of-the-art models cited above is far beyond the scope of the simplified model framework adopted for Version 1.1 of the NWPCAM. The key finding in the analysis of Di Toro et al. (1990), however, is that the SOD that can be exerted by decomposition of particulate organic carbon in the sediments is not linearly proportional but rather is dependent on the square root of the loading of particulate organic carbon to the sediments. Thus, if the external point and nonpoint source loading rate is controlled by regulatory policy so that the flux of organic carbon to the sediments is reduced by 50 percent, the maximum SOD is reduced by the square root of 0.5 ($0.5^{0.5} = 0.707$) or only a 30 percent reduction. This surprising theoretical result of the SOD model has been confirmed in analyses of published data sets and contemporary field measurements (Di Toro et al., 1990).

In an analysis of organic carbon loading and SOD measured in the tidal Potomac River from the late 1960s and into the 1970s and during 1986, HydroQual (1987) concluded that changes in external and in situ particulate organic carbon loads could be directly related to the observed changes in SOD. Particulate organic carbon loads considered in the analysis accounted for the upstream boundary load, municipal wastewater and combined sewer overflow (CSO) loads, and in situ algal production. Using the model of Di Toro et al. (1990), SOD estimates were in the range of observed field data measured under the loading conditions of the late 1960s and 1970s (2.3-2.5 g O_2 $m^{-2}day^{-1}$) and 1986 (1.4 g O_2 $m^{-2}day^{-1}$).

Following the approach employed by HydroQual (1987) to couple changes in organic carbon loads with changes in SOD in the tidal Potomac River, the key finding from the model of Di Toro et al. (1990) is used in the NWPCAM framework. The square root dependency of SOD with the external organic carbon loading rate is used as a conceptual framework to modify SOD rates assigned as input data for the baseline (ca. 1995) contemporary effluent loading scenario for simulation of the without CWA primary effluent loading policy scenario.

As a national-scale model, estimates of nationally aggregated point source loading rates for particulate organic carbon (POC) are compiled for contemporary after-CWA (ca. 1995) conditions and pre-CWA conditions (ca. 1960s). The assumption was made that reach level assignments of SOD rates for the without CWA primary effluent scenario can be derived by increasing the with CWA baseline conditions (ca. 1995) for SOD in proportion to the square root of the ratio of pre-CWA (ca. 1960s) and post-CWA (ca. 1995) effluent POC loads. The proposed methodology, although using the key finding of Di Toro et al. (1990), is far from ideal since the baseline condition (ca. 1995) assignments of SOD rates are not explicitly coupled with the magnitude of external organic carbon loading to a reach as done, for example, for a state-of-the art water quality model of the Upper Mississippi River (HydroQual, 1999a; 199b). Baseline conditions for SOD are assigned using best professional judgement drawn from a review of the literature.

Based on a review of the literature, (Bowie et al., 1985; Zison et al., 1978; Thomann and Mueller, 1987; Hatcher, 1986), SOD rates can range from ~1 to 10 g O_2 $m^{-2}day^{-1}$. As a result of settling out of solids from effluent discharges, higher rates are typically observed in the vicinity of an outfall, with the rate diminishing with distance downstream of a point source discharge. SOD measurements near a CSO discharge in the Pardegat Basin in New York City show a clear trend of high rates (~5-10 g O_2 $m^{-2}day^{-1}$) within about 0.2 miles of the CSO discharge. After the bulk of settleable solids have been deposited in the vicinity of the outfall, the SOD measurements drop to lower rates (~1-3 g O_2 $m^{-2}day^{-1}$) at a distance of ~0.5 mile to 2 miles from the CSO discharge (HydroQual, 1991). A similar spatial pattern of high SOD rates within about 0.25 miles of a heavy waste load are presented by Bowie et al. (1985) in a survey of the Passaic River in New Jersey (Hunter et al., 1973).

Using the type of pollutant source(s) defined as input loads to a reach, SOD rates (at a reference temperature of 20 EC) are assigned to RF1 reaches for the with CWA ca. 1995 baseline loading conditions as follows:

With CWA Baseline Conditions, ca. 1995

RF1 Reaches Not Impacted by Point Sources

- Rural Nonpoint Source (NPS) . . . . 0.5 g O_2 $m^{-2}day^{-1}$

RF1 Reaches Assigned Point Source Load(s)

- Urban NPS/ Municipal/Industrial Point Source (PS) . . . . 1.5 g O_2 $m^{-2}day^{-1}$

Inventories of the population served by different types of municipal wastewater treatment plants have been compiled in Tetra Tech and Stoddard (2000) from U.S. Public Health Service (PHS) municipal wastewater inventories for 1940, 1950, 1962, and 1968 and U.S. EPA Clean Water Needs Surveys for 1976 through 1996. Using the population served data, estimates of national effluent loading rates for total suspended solids (TSS) and POC was based on the following assumptions:

- Per capita wastewater flow rate based on average of U.S. EPA Clean Water Needs Survey data (1978-1986) includes residential, commercial, and industrial components of wastewater flow (Tetra Tech and Stoddard, 2000; Metcalf Eddy et al., 1991):

$$q = 165 \text{ gallons (person-day)}^{-1}$$

- Influent TSS wastewater concentration based on mean influent data extracted from the U.S. EPA Permit Compliance System (PCS) database for records submitted during 1993-1996 (Tetra Tech and Stoddard, 2000):

$$\text{Influent TSS} = 213.5 \text{ mg/L}$$

C Removal efficiency and effluent concentrations for TSS in municipal wastewater treatment plants (Metcalf Eddy et al., 1991; Gunnerson et al., 1982):

Raw	=	0%	213.5 mg/L
Primary	=	50%	106.7 mg/L
Adv-Primary	=	70%	64.1 mg/L
Secondary	=	85%	32.0 mg/L
Adv-Secondary	=	95%	10.7 mg/L
AWT	=	99%	0.85 mg/L
<Secondary	=	60%	34.1 mg/L
>Secondary	=	97.5%	2.1 mg/L

C Carbon (C) to dry weight (DW) ratio of POC in TSS in wastewater effluent (Metcalf Eddy et al., 1991):

POC:TSS = 0.44 g C (g DW)$^{-1}$

The results of the nationally aggregated estimates of POC loading from municipal wastewater discharges are presented for 1968 (68 percent removal, 2400 mt day^{-1}) and 1996 (89 percent removal, 1133 mt day^{-1}) in Table C-5. Using the ratio of the national estimates of POC loading pre-CWA and post-CWA (2.1 = 2400/1133) to determine the square root dependency (1.45 = 2.1$^{0.5}$) of SOD with municipal POC loads, the baseline SOD assumptions were increased by a factor of ~1.5. Data are not available to define CSO loading rates before and after the CWA. It was assumed that the same factor of 1.5 can be used to describe an increase of SOD rates in reaches characterized by CSO discharges that were not subject to any types of controls before the CWA.

Crude national estimates of the contribution of industrial POC loading before and after the CWA were also derived using effluent BOD5 data from Luken et al. (1976) for pre-CWA (ca. 1973) and the NWPCAM for post-CWA (ca. 1995). Assuming that CBODU:BOD5 ratios for industrial loading could be described with values of 1.6 for pre-CWA and 2.8 for post-CWA and the particulate fraction of total organic carbon declined from ~50 percent pre-CWA to ~20 percent post-CWA, industrial BOD5 loads of 5406 mt day^{-1} (ca.1973) and 1806 mt day^{-1} (ca. 1995) could account for POC loads of ~1620 mt day^{-1} (ca. 1973) and ~379 mt day^{-1} (ca. 1995). If the industrial component of the pre-CWA and post-CWA POC loads are added to the municipal component, the ratio of pre-CWA to post-CWA POC loads increases to 2.66 = 4020/1512 and the square root dependency increases to 1.6. A factor of 1.5 is therefore a reasonable parameter value to define increased rates of SOD for the without CWA policy scenario.

Table C-5

NATIONAL ESTIMATE OF MUNICIPAL EFFLUENT POC, TSS, AND CBODU LOADING PRE-CWA (1968) AND AFTER-CWA (1996) (ADAPTED FROM TETRA TECH AND STODDARD, 2000)[a]

Year	Facility	Population Served (millions)	POC Load (as mt day^{-1})	TSS Load (as mt day^{-1})	CBODU (as mt day^{-1})
1968	Raw	10.1	538.7	1346.8	1628
1968	<Secondary	44.1			6159
1968	Secondary	85.6			4897
1968	>Secondary	0.3			6
1968	No discharge	n/a	n/a	n/a	n/a
1968	Total	140.1	2399.9 (89% R)	599.8 (68% R)	12689 (44% R)

Year	Facility	Population Served (millions)	POC Load (as mt day^{-1})	TSS Load (as mt day^{-1})	CBODU (as mt day^{-1})
1996	Raw	0	0	0	0
1996	<Secondary	17.2	366.5	916.2	2122
1996	Secondary	81.9	655.6	1639.2	4688
1996	>Secondary	82.9	110.6	276.5	2422
1996	NoDischarge	7.7	0	0	0
1996	Total	140.1	1132.7	2831.8	9232

[a] Assumptions used in POC, TSS, and CBODU load calculations
< secondary = average of primary and advanced primary
> secondary = average of advanced secondary and advanced treatment
Flow rate as gallons per person per day . . . . 165 gpcd
n/a = not applicable
Influent BOD5 . . . . 215 mg/L
BOD5 removal for raw 0%
BOD5 removal for primary 35%
BOD5 removal for advanced primary 50%
BOD5 removal for secondary 85%
BOD5 removal for advanced secondary 90%
BOD5 removal for advanced treatment 95%
CBODU:BOD5 for raw effluent 1.2
CBODU:BOD5 for primary and advanced primary effluent 1.6
CBODU:BOD5 for secondary and advanced secondary effluent 2.84
CBODU:BOD5 for advanced treatment effluent 3.0
O_2:C conversion of POC (as C) and CBODU (as O_2) . . . . 2.67 g O_2 (g C)$^{-1}$

Influent TSS . . . . 213.5 mg/L
TSS removal for raw 0%
TSS removal for primary 50%
TSS removal for advanced primary 70%
TSS removal for secondary 85%
TSS removal for advanced secondary 95%
TSS removal for advanced treatment 99%
POC:TSS as carbon:dry weight ratio 40%

Without CWA Primary Effluent Scenario

RF1 Background Reaches Not Impacted by Point Sources

C Rural NPS . . . . 0.5 g O_2 $m^{-2}day^{-1}$

RF1 Reaches Assigned Point Source Load(s)

C Urban NPS/Municipal/Industrial PS . . . . 2.25 g O_2 $m^{-2}day^{-1}$

C CSO . . . . 7.5 g O_2 $m^{-2}day^{-1}$

For both the baseline with CWA and without CWA policy scenarios, SOD values, assigned at a reference temperature of 20 EC, are adjusted for water temperature (T) in Equation C-24:

$$SOD(T) = SOD(20)\ 2_{sod}^{\ (T-20)} \qquad (C\text{-}24)$$

where:

T	=	water temperature	(EC)
SOD(20)	=	sediment oxygen demand at 20 EC	(day^{-1})
2_{sod}	=	temperature coefficient	(1.065)

C3.3.5 Total Suspended Solids

Suspended solids are included in the model framework as an indicator of water clarity. Solids are introduced into surface waters by naturally occurring geomorphological processes and anthropogenic loading from point sources and land use-influenced nonpoint sources. In streams and rivers, the distribution of solids suspended in the water column is determined by the particle size characteristics of cohesive and noncohesive solids, hydrodynamics, and the particle size-dependent balance between deposition and bottom shear-induced resuspension.

The representation of suspended solids in Version 1.1 of the model framework is highly simplified. A single size class of solids is used to define both the inorganic and organic components of TSS with no distinction made between cohesive and noncohesive solids. No attempt was made to account for the solids content of a sediment bed that can be resuspended back into the water column under high-flow conditions of erosion for two key reasons: (1) national-scale data are not available to characterize the spatial distribution of solids in the sediment bed much less to distinguish between cohesive and noncohesive size classes either in the water column or the bed; and (2) any representation of resuspension based on bottom shear stresses and velocities computed from the simplified flow balance would introduce an enormous amount of uncertainty into the model framework. The low-flow, summer condition of the model framework assumes that resuspension is most likely a minor component of a summer mean solids balance in streams and rivers. The simplified model for TSS, based on no interaction of solids between the water column and the sediment bed, assumes a “one-way loss of solids to the bed” (Chapra, 1997).

Sources of suspended solids in the model are derived from external inputs from point and nonpoint sources. The balance between deposition and resuspension is represented in the model as a simple, first-order loss term governed by the settling velocity assigned to the single size class of solids and the depth of the water column.

Following Equation C-3, the solution for the spatial distribution of TSS, C(x), as a function of the location (x) on the river is given in Equation C-25:

$$C(x) = C_o\, e^{[-(K_{ss})\, x/U]} \tag{C-25}$$

where:

C_o = upstream boundary concentration of TSS . . . . (mg/L)
K_{ss} = TSS removal rate . . . . (day^{-1})
x = longitudinal coordinate (x-axis) . . . . (m)
U = constant velocity component along longitudinal (x-axis) . . . . ($m\ day^{1}$)

Upstream Boundary Concentration

The upstream boundary condition (C_o) for TSS is computed using Equation C-4 for mass balance dilution.

Removal Rate

The removal rate of suspended solids from the water column (K_{ss}) is governed by the solids settling velocity and depth according to Equation C-26:

$$K_{ss} = W_{ss}/H \tag{C-26}$$

where:

W_{ss} = TSS settling velocity . . . . ($m\ day^{-1}$)
H = depth of water column . . . . (m)

Based on the range of values reported for the settling velocity (W_{ss}) of particulate organic matter (~0.2-2 m day^{-1}), clays (~0.3-1 m day^{-1}) and silts (~3-30 m day^{-1}) (Chapra, 1997), the loss of solids from the water column is parameterized in the model using a settling velocity of 0.3 m day^{-1}.

C3.3.6 Fecal Coliform Bacteria

Fecal coliform bacteria (FCB), used as an indicator for the public health risk of exposure to waterborne pathogens, are present in surface waters primarily from sources accounted for by direct discharges from municipal and industrial wastewater facilities, CSOs, and watershed runoff from urban and rural land uses. Bacteria are lost from the water column primarily by mortality. Settling and/or resuspension of bacteria sorbed onto particles are also processes that can influence the density of bacteria. The loss of FCB is represented in the model as a simple, first-order lumped mortality term.

Following Equation C-3, the solution for the spatial distribution of FCB, C(x), as a function of the location (x) on the river is given in Equation C-27:

$$C(x) \quad = \quad C_o \, e^{[-(K_b)\, x/U]} \qquad \text{(C-26)}$$

where:

$C(x)$	=	spatial distribution of FCB	(No./100 mL)
C_o	=	upstream boundary concentration of FCB	(No./100 mL)
K_b	=	coliform bacteria mortality rate	(day^{-1})
x	=	longitudinal coordinate (x-axis)	(m)
U	=	constant velocity component along longitudinal (x-axis)	(m.day^{1})

<u>Upstream Boundary Concentration</u>

The upstream boundary condition (C_o) for FCB is computed from the mass balance dilution equation, Equation C-4.

<u>Mortality Rate</u>

The mortality rate for total coliform bacteria (K_b) depends on water temperature, salt concentration (chlorides), and incident solar radiation (Mancini, 1978). In contrast to a more complex modeling approach where the loss of bacteria from partitioning to solids and settling is coupled with suspended solids (Chapra, 1997), the mortality rate is implicitly defined to include the loss of bacteria via settling on particles in NWPCAM Version 1.1. Assuming that FCB mortality coliforms is similar to total coliforms bacteria and neglecting the effect of sunlight, the temperature and salt dependent mortality rate for total coliform bacteria (Mancini, 1978; Chapra, 1997) is given in Equation C-28:

$$K_b \quad = \quad [0.8 + 0.006\ (S/S_o)(100\%)]\ 2_b^{\ (T-20)} \qquad \text{(C-28)}$$

where

S	=	ambient salt concentration (as salinity)	(g/L)
S_o	=	reference seawater salt concentration (as salinity)	(35 g/L)
2_b	=	temperature dependence coefficient	(1.07)
T	=	water temperature	(EC)

For fresh water (S = 0), the mortality rate is 0.8 day^{-1} (at T = 20 EC) with an additional component of bacterial mortality accounted for by the linear dependence on salinity (or chlorides) concentration. Chloride levels (Cl^- as mg/L) are converted to salinity (S as g/L) to estimate the coliform bacteria mortality rate using Equation C-20. The reference seawater salinity of 35 g/L used by Mancini (1978) is equivalent to a chloride concentration of 19,357 mg/L. If salt concentration is expressed as chlorides, then the terms for S and S_o are as follows:

S	=	ambient salt concentration (as chlorides)	(mg/L)
S_o	=	reference seawater salt concentration (as chlorides)	(19,357 mg/L)

Tables C-6 through C-10 present summaries of model coefficients, parameter values, units, and formulations used in Version 1.1 of the NWPCAM.

Table C-11 summarizes the dependency of model parameters assigned as a function of spatial scale (RF1 reach; global) and policy scenario (without CWA and with CWA).

Table C-6

MODEL COEFFICIENTS AND KINETIC FORMULATIONS: CBODU

K_d	CBODU decomposition rate	from Hydroscience (1971)
K_d (min)	Minimum CBODU decomposition rate	day^{-1}
	K_d = K_d (min) $(H_f/8)^{-0.434}$ H_f # 8 ft	day^{-1}
	K_d = K_d (min) H_f > 8 ft	day^{-1}
	H_f = depth	feet
	K_d (T) = K_d (20) $Theta_d^{(T-20)}$	day^{-1}
K_r	CBODU removal rate	day^{-1}
W_{sc}	CBODU particle settling velocity	0.5 m day^{-1}
M_p	Policy scenario multiplier	(1,2)
Baseline Scenario: With CWA Secondary and Better Than Secondary Effluent		
	K_d (min) = 0.075 M_p = 1	day^{-1}
Policy Scenario: Without CWA Primary Effluent Only		
	K_d (min) = 0.3 M_p = 2	day^{-1}
	K_r = K_d (T,H_f) + (W_{sc}/H) $(M_{p.}$-1)	day^{-1}
H	RF1 reach depth	m
T	RF1 reach water temperature	C
2_d	Temperature dependence for CBODU decomposition	1.047

Table C-7

MODEL COEFFICIENTS AND KINETIC FORMULATIONS: TKN

Parameter	**Description**	**Unit**
K_n	Nitrogen oxidation and loss rate	day^{-1}
	$K_n (T) = K_n (20)\, 2_n^{(T-20)}$	day^{-1}
H	RF1 reach depth	m
U	RF1 reach velocity	$m\ s^{-1}$
T	RF1 reach water temperature	EC
2_n	Temperature dependence for TKN oxidation	1.08
	$S_{dn} (20) = SOD(20) [(a_{cn}) (a_{oc})]^{-1}$	
	$S_{dn} (T) = S_{dn} (20)\, 2_{dn}^{(T-20)}$	
SOD(20)	sediment oxygen demand at 20 EC	$g\ O_2\ m^{-2}\ day^{-1}$
a_{oc}	stoichiometric ratio of O_2:C	$2.67\ g\ O_2\ (g\ C)^{-1}$

Table C-8

MODEL COEFFICIENTS AND KINETIC FORMULATIONS: DO

Parameter	**Description**	**Unit**
C_s	Saturation concentration of dissolved oxygen as f (T,S, E_{MSL})	mg/L
T	RF1 reach water temperature	EC
S	RF1 reach salt as chlorides	mg/L
E_{MSL}	RF1 reach elevation above mean sea level	m
K_a	Atmospheric reaeration rate as f (U,H)	from Covar (1976)
	$K_a = a\, U^b\, H^c\, C$	day^{-1}
	$K_a (T) = K_a (20)\, 2_o^{(T-20)} C$	day^{-1}
$K_a(20)$	Atmospheric reaeration rate at 20 EC	day^{-1}
$K_a(T)$	Atmospheric reaeration rate at water temperature T	day^{-1}
a,b,c	Reaeration formulation coefficients	see Table C-2
U	RF1 reach velocity	($ft\ s^{-1}$; $m\ s^{-1}$)
H	RF1 reach depth	(ft; m)
2_o	Reaeration temperature dependence coefficient	1.024

Table C-9

MODEL COEFFICIENTS AND KINETIC FORMULATIONS: SOD

Parameter	Description	Unit
SOD	Sediment oxygen demand as f (T, PS, NPS, policy scenario)	g O_2 m^{-2} day^{-1}
	With CWA Baseline Conditions ca. 1995	**SOD (20 °C)**
	RF1 “background” reaches not impacted by point sources	
	• Rural NPS	0.5 g O_2 $m^{-2}day^{-1}$
	RF1 reaches assigned point source load(s)	
	• Urban NPS/Municipal/Industrial PS	1.5 g O_2 $m^{-2}day^{-1}$
	Without CWA Primary Effluent Scenario	**SOD (20 °C)**
	RF1 “background” reaches not impacted by point sources	
	• Rural NPS	0.5 g O_2 $m^{-2}day^{-1}$
	RF1 reaches assigned point source load(s)	
	• Urban NPS/Municipal/Industrial PS	2.25 g O_2 $m^{-2}day^{-1}$
	$SOD(T) = SOD(20)\,\theta_{sod}^{(T-20)}$	g O_2 $m^{-2}day^{-1}$
SOD(20)	Sediment oxygen demand at 20 °C	g O_2 $m^{-2}day^{-1}$
SOD(T)	Sediment oxygen demand at water temperature, T (°C)	g O_2 $m^{-2}day^{-1}$
θ_{sod}	Temperature dependence coefficient for SOD	1.065

Table C-10

MODEL COEFFICIENTS AND KINETIC FORMULATIONS: TSS AND FECAL COLIFORM BACTERIA

Parameter	Description	Unit
K_{ss}	TSS removal rate	day^{-1}
	$K_{ss} = W_{ss}/H$	day^{-1}
W_{ss}	TSS particle settling velocity	0.3 m day^{-1}
H	Depth	m
K_b	Total coliform mortality rate as f (T,S)	from Mancini (1978)
	$K_b = [0.8 + 0.006\ (S/S_o)100]\ 2_b\ ^{(T-20)}$	day^{-1}
T	RF1 reach water temperature	EC
S	RF1 reach salt as chlorides	mg/L
S_o	Reference seawater salt as chlorides (salinity = 35 g/L)	19,357 mg/L
2_b	Temperature dependence coefficient for bacterial mortality	1.07

Table C-11

SPATIAL SCALE AND POLICY SCENARIO DEPENDENCY OF MODEL PARAMETERS

Parameter	Description	RF1	Policy	Global
	Hydraulics			
T	Water temperature	/		
Q	Stream flow	/		
H	Water column depth	/		
U	Velocity	/		
A_c	Cross-sectional area	/		
	Carbonaceous Biochemical Oxygen Demand (CBODU)			
K_d	CBODU decomposition rate	/	/	
K_d (min)	Minimum CBODU decomposition rate		/	
K_r	CBODU removal rate	/	/	
W_{sc}	CBODU particle settling velocity		/	
M_p	Policy scenario multiplier		/	
2_d	Temperature coefficient for decomposition			/
	Oxidizable Nitrogen (TKN)			
K_n	NBOD oxidation rate	/		
2_n	Temperature dependence for TKN oxidation			/
S_{dn}	Benthic regeneration rate of ammonia-N	/		
a_{cn}	Stoichiometric ratio of C:N			/
a_{oc}	Stoichiometric ratio of O_2:C			/
2_{dn}	Temperature dependence for benthic regeneration			/
	Dissolved Oxygen (DO)			
C_s	Oxygen saturation concentration	/		
S	Ambient reach salt as chlorides	/		

Parameter	Description	RF1	Policy	Global
E_{MSL}	Reach elevation above mean sea level		/	
K_a	Atmospheric reaeration rate	/		
a,b,c	Reaeration formulation coefficients			/
2_o	Temperature dependence coefficient for reaeration			/
SOD	Sediment oxygen demand	/	/	
2_{sod}	Temperature dependence coefficient for SOD			/
Total Suspended Solids (TSS)				
K_{ss}	TSS removal rate	/		
W_{ss}	TSS particle settling velocity			/
Fecal Coliform Bacteria (FCB)				
$K_b(20,0)$	Coliform mortality rate at 20 EC and salt = 0			/
K_b (T,S)	Coliform mortality rate as f (T,S)	/		
S	Ambient salt as chlorides	/		
S_o	Reference seawater salt as chlorides			/
2_b	Temperature dependence coefficient			/

C4 ECONOMIC BENEFIT ANALYSES

The economic benefit analysis model used in the AFO/CAFO version of NWPCAM, including the general water quality use-support ladder, is discussed in detail in early versions of NWPCAM (e.g., Bingham et al., 1998).

C4.1 Water Quality Ladder

The application of recreational use-support categories to characterize water quality corresponds with the defined objectives of the Clean Water Act (CWA)—to attain "fishable and swimmable" conditions in all of the nation's waters—and it is also roughly consistent with the "beneficial use" designations that many states have adopted to report on the status of their water resources, as required under Section 305(b) of the CWA. More importantly for NWPCAM, defining the estimated impacts of water pollution control policies in terms of use-support changes provides a useful basis for assessing the benefits of these policies.

NWPCAM uses the water quality ladder described in Table C-12 to translate in-stream concentration estimates for BOD, TSS, DO, and FC into corresponding use-support categories using an approach developed by Vaughn for Resources for the Future (Mitchell and Carson, 1986). This approach involves choosing a maximum pollutant level for BOD, TSS, DO, and FC that corresponds to boatable, fishable, and swimmable waters. A water resource that fails to meet the boating criteria is classified as a "nonsupport" resource. Vaughn's original water quality ladder included BOD, turbidity, DO, pH, and FC. In the AFO/CAFO version of NWPCAM, TSS is used as a surrogate for turbidity.

Table C-12

WATER QUALITY LADDER VALUES

Beneficial Use	Biological Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	Dissolved Oxygen (% saturated)	Fecal Coliforms (MPN/100 mL)
Swimming	1.5	10	0.83	200
Fishing	2.4	50	0.64	1,000
Boating	4.0	100	0.45	2,000

Using the water quality ladder shown in Table C-12, NWPCAM water quality outputs for several constituents can be described in terms of a single index. That is, the model output can be expressed as the number or percentage of inland reach (RF1 subset of RF3Lite) miles in the continental United States that fall into each of the use-support categories.

As noted above in Section C3.2, changes in concentration of chlorophyll " among the range of AFO/CAFO rule-making scenarios can be used to develop water quality benefits information[4] which then can be related to economic benefits. This approach was developed for the AFO/CAFO version of NWPCAM and will have greater application for future assessment work. Future work also will evaluate incorporation of a water quality index approach to better assess use-support changes and associated economic benefits compared to the current threshold approach used in NWPCAM.

C4.2 Economic Benefits Calculations

Based on the water quality assessments for each AFO/CAFO rulemaking scenario and baseline conditions, the RF3/RF3Lite river/stream miles are categorized as swimmable (highest use), fishable, boatable (lowest use), and no-use. The difference in the miles for each use category between baseline conditions and a given rulemaking scenario is a measure of the improvement in water quality attributable to the scenario. These differences in miles then can be converted into economic benefits (dollars) based on the population and their willingness to pay for improvement in water quality.

For the AFO/CAFO version of NWPCAM, some modifications have been made in the equations for computing willingness-to-pay (WTP) benefits for boatable, fishable, and swimmable waters. Benefits are calculated state-by-state at the state (or local) scale as well as at the national scale. At the state scale, benefits are calculated as:

WTP for boating = (Boat_alt - Boat_base)/statemiles*statepop/2.62*245*2/3
WTP for fishing = (Fish_alt - Fish_base)/statemiles*statepop/2.62*184*2/3
WTP for swimming = (Swim_alt - Swim_base)/statemiles*statepop/2.62*205*2/3

[4] Chlorophyll " assessment breakpoints were qualitatively assigned. Regionalization was based on: proposed USEPA nutrient regions (http://www.epa.gov/OST/standards/nutstra3.pdf); available water quality objectives/guidelines from USEPA wasteload guidance (USEPA, 1983), Region IV (USEPA, 1993), North Carolina,Virginia, Minnesota, Oregon, judgment about trophic gradients across different ecoregions (based on latitude, altitude, climate, land cover); and judgment regarding public perceptions for major recreational uses.

where:

Boat_alt = miles of the State's boatable waters for given rulemaking scenario
Boat_base = miles of the State's boatable waters for baseline conditions
Fish_alt = miles of the State's fishable waters for given rulemaking scenario
Fish_base = miles of the State's fishable waters for baseline conditions
Swim_alt = miles of the State's swimmable waters for given rulemaking scenario
Swim_base = miles of the State's swimmable waters for baseline conditions
Statemiles = total miles of RF3/RF3Lite rivers/streams in the State
Statepop = population of the State

and

2.62 is an adjustment factor to convert State population to State households
245 is the 1999 household willingness to pay for boatable waters
184 is the 1999 household willingness to pay for fishable waters
205 is the 1999 household willingness to pay for swimmable waters
2/3 (or 0.66) is the fraction of the household WTP applied to State waters

At the national scale, benefits are calculated as presented below. For a given State, the miles of National waters do not include the waters for that State.

WTP for boating = (Boat_alt - Boat_base)/natlmiles*statepop/2.62*245*1/3
WTP for fishing = (Fish_alt - Fish_base)/natlmiles*statepop/2.62*184*1/3
WTP for swimming = (Swim_alt - Swim_base)/natlmiles*statepop/2.62*205*1/3

where

Boat_alt = miles of National boatable waters for given rulemaking scenario
Boat_base = miles of National boatable waters for baseline conditions
Fish_alt = miles of National fishable waters for given rulemaking scenario
Fish_base = miles of National fishable waters for baseline conditions
Swim_alt = miles of National swimmable waters for given rulemaking scenario
Swim_base = miles of National swimmable waters for baseline conditions
Natlmiles = total miles of RF3/RF3Lite rivers/streams in the Nation not including the miles for the given State
Statepop = population of the State

and

2.62 is an adjustment factor to convert State population to State households
245 is the 1999 household willingness to pay for boatable waters
184 is the 1999 household willingness to pay for fishable waters
205 is the 1999 household willingness to pay for swimmable waters
1/3 (or 0.33) is the fraction of the household WTP applied to National waters

C5 REFERENCES

Alexander, R.B., R.A. Smith, and G.E. Schwarz. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature*, 403:758-761.

Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. *The Water Quality Analysis Simulation Program, WASP5 Part A: Model Documentation, Version 5.10.* U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

AMSA (American Metropolitan Sewerage Agencies). 1997. *The AMSA Financial Survey 1997: A National Survey of Municipal Wastewater Management Financing*. Washington, DC.

Bondelid, T., C. Griffifths, G. Van Houtven. 1999a. *A National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. March 1999.

Bondelid, T., R. Dodd, C. Spoerri, and A. Stoddard. 1999b. *The Nutrients Version of the National Water Pollution Control Assessment Model*. Draft. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, North Carolina. December 1999.

Bowie, G.L., W.B. Mille, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chen, S.A. Gherini, and C.E. Chamberlin. 1985. *Rates, Constants and Kinetic Formulations in Surface Water Quality Modeling, (Second Edition)*. EPA-600/3-85/040. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA. June.

Brown, L.C., and T.O. Barnwell. 1987. *The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User's Manual*. EPA-600/3-87/007. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

Carson, R.T., and R.C. Mitchell. 1993. The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water. *Water Resources Research*, Vol. 29, No. 7, pp. 2445-2454. July.

Cerco, C.A., and T. Cole. 1993. Three-dimensional eutrophication model of Chesapeake Bay. *American Society of Civil Engineers Journal of the Environmental Engineering Division*, 119(6):1006-1025.

Chapra, S.C. 1997. *Surface Water Quality Modeling*. McGraw Hill, Inc., New York, NY. 844 pp.

Churchill, M.A., H.L. Elmore, and R.A. Buckingham. 1962. The prediction of stream reaeration rates. *American Society of Civil Engineers Journal of the Sanitary Engineering Division*, 88(SA4):1-46.

Covar, A.P. 1976. Selecting the proper reaeration coefficient for use in water quality models. Presented at the U.S. Environmental Protection Agency Conference on Environmental Simulation and Modeling, April 19-22, Cincinnati, OH.

Di Toro, D.M. 1986. A diagenetic oxygen equivalents model of sediment oxygen demand. In: Hatcher, K.J. (ed.). *Sediment Oxygen Demand, Processes, Modeling and Measurement*. Institute of Natural Resources, University of Georgia, Athens, GA. pp. 171-208.

Di Toro, D.M., P.R. Paquin, K. Subburamu, and D.A. Gruber. 1990. Sediment oxygen demand model: Methane and ammonia oxidation. *American Society of Civil Engineers Journal of the Environmental Engineering Division*, 116(5):945-987.

Dillon, P.J., and F.H. Rigler. 1974. The Phosphorus-Chlorophyll Relationship in Lakes. *Limnology and Oceanography* 19(5):767-773.

Eidenshink, J.E., 1992, The conterminous United States AVHRR data set. In *Photogrammetric Engineering and Remote Sensing*, v. 58, no. 6, p. 809-813.

Garber, J.H. 1990. *Sediment-Water Flux Measurements in the Peconic Bay Estuarine Ecosystem: July and October 1989*. Data report submitted to Suffolk County Dept. Health Services, Riverhead, NY. Final technical report for Agreement No. 01-4400-456-29-00022.

Gunnerson, C.G., R. Adamski, P.W. Anderson, R.S. Dewling, D.A. Julius, G.S. Kleppel, D.W. Lear, A.J. Mearns, J.T. Miller, E.P. Myers, J. J. Roswell, S. Schroeder, D.A. Segar, C.J. Sindermann, and C.M. Stern. 1982. Management of Domestic Waste. In: *Ecological Stress and the New York Bight: Science and Management*, G. F. Mayer (ed.) Estuarine Research Foundation, Columbia, SC. pp. 91-112.

Hatcher, K.J. (ed.). 1986. *Sediment Oxygen Demand, Processes, Modeling and Measurement*. Institute Natural Resources, University of Georgia, Athens, GA.

Henderson, F.M. 1966. *Open Channel Flow*. New York: Macmillian Publishing Co., Inc.

Hunter, J.V., M.A. Harnett, and A.P. Cryan. 1973. *A Study of the Factors Determining the Oxygen Uptake of Benthal Stream Deposits*. NTIS PB-226-238. Water Resources Research Inst., Rutgers University, New Brunswick, NJ. 28 pp.

HydroQual. 1987. *Evaluation of Sediment Oxygen Demand in the Upper Potomac Estuary*. Report NCOG0100 prepared by HydroQual, Inc., Mahwah, NJ, for Metropolitan Washington Council of Governments, Washington, DC. July.

HydroQual. 1991. *Water Quality Impact of Combined Sewer Overflows*. Briefing notes prepared by HydroQual, Inc., Mahwah, NJ, for presentation to U.S. Environmental Protection Agency, Office of Water Enforcement and Compliance. July 17.

HydroQual. 1999a. *Advanced eutrophication model of the Upper Mississippi River, Summary Report*. Report MCWS0010 prepared by HydroQual, Inc., Mahwah, NJ, for Metropolitan Council Environmental Services (MCES), St. Paul, MN. April.

HydroQual. 1999b. *Advanced Eutrophication Model of Pools 2 to 4 of the Upper Mississippi River*. Report MCWS0010 prepared by HydroQual, Inc., Mahwah, NJ, for Metropolitan Council Environmental Services (MCES), St. Paul, MN. April.

Hydroscience. 1971. *Simplified Mathematical Modeling of Water Quality*. Prepared by Hydroscience, Inc., Westwood, NJ, under subcontract to The Mitre Corporation for the U.S. Environmental Protection Agency, Water Quality Management Planning, Washington DC. March.

Hydroscience. 1972. *Addendum to Simplified Mathematical Modeling of Water Quality*. Prepared by Hydroscience, Inc., Westwood, NJ, for the U.S. Environmental Protection Agency, Water Quality Management Planning, Washington DC. May.

Kennedy, Robert H. Application of the BATHTUB Model to Selected Southeastern Reservoirs. Technical Report EL-95-14. US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. April, 1995.

Keup, L.E. 1985. Flowing Water Resources. Prepared for *Water Resources Bulletin*, American Water Resources Association. 21;2. April.

Kremer, J.N. and S.W. Nixon. 1978. *A Coastal Marine Ecosystem Simulation and Analysis*. Springer-Verlag Berlin, New York, NY.

Luken, R.A., D.J. Basta, and E.H. Pechan. 1976. *The National Residuals Discharge Inventory. An Analysis of the Generation, Discharge, Cost of Control and Regional Distribution of Liquid Wastes To Be Expected in Achieving the Requirements of Public Law 92-500*. National Commission on Water Quality, Report No. NCWQ 75/104, NTIS No. PB-252-288. Prepared for the Study Committee on Water Quality Policy, Environmental Studies Board, Commission on Natural Resources, National Research Council. Washington, DC. January.

Lung, W. 1998. Trends in BOD/DO modeling for waste load allocations. *American Society of Civil Engineers Journal of the Environmental Engineering Division*, 124(10):1004-1007.

Mancini, J.L. 1978. Numerical estimates of coliform mortality under various conditions. *Journal of the Water Pollution Control Federation*, 50(11): 2477-2484.

Metcalf & Eddy, Inc., G.T. Tchobanoglous, and F.L. Burton. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse* (Third Edition). Irwin McGraw-Hill (Series in Water Resources and Environmental Engineering), Boston, MA.

Mitchell, R.C., and R.T. Carson. 1986. The Use of Contingent Valuation Data for Benefit/Cost Analysis in Water Pollution Control. CR-810224-02. Prepared for USEPA, Office of Policy Planning and Evaluation. Washington, DC.

Novotny, V., and H. Olem. 1994. *Water Quality Prevention, Identification and Management of Diffuse Pollution*. New York: Van Nostrand Reinhold.

O'Connor, D.J., and W.E. Dobbins. 1958. Mechanism of reaeration in natural streams. *Transactions of the American Society of Civil Engineers*, 86(SA3):35-55.

Owens, M., R. Edwards, and J. Gibbs. 1964. Some reaeration studies in streams. *International Journal of Air and Water Pollution*, 8:469-486.

Rast, W., and G.F. Lee. 1978. *Summary Analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading Lake Response Relationships and Trophic State Indices. EPA-600/3-78-008.* U.S. Environmental Protection Agency. p. 453.

Reckhow, Kenneth H. 1990. EUTROMOD spreasheet program-a regional modeling scheme for nutrient runoff and lake trophic state modeling. School of the Environment, Duke University.

Reckhow, K.H., Beaulac, M.N., Simpson, J.T. 1980. *Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients*. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, Washington, DC. EPA 440/5-80-011.

Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The Influence of Organisms on the Composition of Seawater. In: *The Sea, Vol.2,* M.N. Hill (ed.). Wiley-Interscience, New York, NY. pp. 26-77.

Smith, R.A., Schwarz, G.E., and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. Water Resources Research, Vol 33, No. 12, pp 2781-2798. December, 1997.

Tetra Tech and A. Stoddard. 2000. *Progress in Water Quality: An Evaluation of the National Investment in Municipal Wastewater Treatment*. Prepared by Tetra Tech, Inc., Fairfax, VA, under contract to the U.S. Environmental Protection Agency, Office of Water, Office of Wastewater Management, Washington, DC. July.

Thomann, R.V., and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control*. Harper & Row, Inc., New York, NY.

U.S. DOI (Department of the Interior). 1970. *Municipal Waste Facilities in the U.S.: Statistical Summary, 1968 Inventory*. Publication No. CWT-6. U.S. Department of the Interior, Federal Water Quality Administration (FWQA), Washington DC.

U.S. EPA (Environmental Protection Agency). 1995. *Technical Guidance Manual for Developing Total Maximum Daily Loads, Book II: Streams and Rivers, Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication*. EPA 823-B-95-007. Office of Water, Washington, DC. September.

U.S. EPA. (Environmental Protection Agency). 1997. *1996 Clean Water Needs Survey, Conveyance, Treatment, and Control of Municipal Wastewater, Combined Sewer Overflows and Stormwater Runoff. Summaries of Technical Data.* EPA 832-R-97-003. Office of Water Program Operation, Washington, DC.

U.S. EPA 1978. Relationships of Productivity and Problem Condition to Ambient Nutrients: National Eutrophication Survey Findings for 418 Eastern Lakes. EPA-6--/3-78-002. Office of Research and Development, Environmental Monitoring and Support Laboratory. Las Vegas, NV.

USEPA. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition). Environmental Research Laboratory, Office of Research and Development, Athens, Georgia.

USEPA, 1983. Technical Guidance Manual for Performing Wasteload Allocations. Book Two: Streams and Rivers. Chapter 2: Nutrient/Eutrophication Impacts. Office of Water Regulations and Standards, Monitoring and Data Support Division.

USEPA, 1993. Guidelines for Assessing and Predicting Eutrophication Status of Small Southeastern Piedmont Impoundments. Region IV, Environmental Services Division, Athens, GA.

Walker, W.W. 1996. *Simplified Procedures for Eutrophication Assessment and Prediction: User Manual*. Instruction Report W-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Walker, W.W. 1985. Empirical Methods for Predicting Eutrophication in Impoundments. Report 3. Phase II: Model Refinements. U.S. Army Corps of Engineers Technical Report E-81-9. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Additional Information Available at http://www.wes.army.mil/el/elmodels/emiinfo.html.

Wright, R.M., and A.J. McDonnell. 1979. In-stream deoxygenation rate prediction. *American Society of Civil Engineers Journal of the Environmental Engineering Division*. 105:323-335.

Zison, S.W., W.B. Mills, D. Deimer, and C.W. Chen. 1978. *Rates, Constants and Kinetic Formulations in Surface Water Quality Modeling*. EPA-600/3-78-105. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

Appendix D

AFO/CAFO NUTRIENT LOADINGS (KILOGRAMS) TO AGRICULTURAL LANDUSE CELLS BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE 2000 DATASETS)

Scenario	Hydroregion 1		Hydroregion 2		Hydroregion 3	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	911,350	1,243,873	7,410,693	12,620,466	26,168,358	90,779,014
ELG-N Based + NPDES 1	783,504	783,098	6,581,814	7,902,418	23,460,379	44,211,357
ELG-N Based + NPDES 2/3	733,061	677,430	5,932,313	5,815,813	20,891,603	21,974,064
ELG-N Based + NPDES 4	659,830	551,039	5,440,495	4,980,563	20,482,148	20,342,960
ELG-N Based + NPDES 4A	768,789	729,071	6,260,082	6,550,390	21,602,057	26,425,749
ELG-P Based + NPDES 1	654,695	668,968	5,465,234	6,773,211	19,759,627	39,657,073
ELG-P Based + NPDES 2/3	542,383	500,483	4,280,105	4,077,689	15,450,640	15,059,499
ELG-P Based + NPDES 4	417,132	328,125	3,445,759	2,948,694	14,776,221	13,055,190
ELG-P Based + NPDES 4A	559,056	569,054	4,770,486	4,978,343	16,498,276	19,983,166

Scenario	Hydroregion 4		Hydroregion 5		Hydroregion 6	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	14,572,366	20,066,731	21,967,611	32,957,947	2,896,722	9,359,966
ELG-N Based + NPDES 1	10,607,737	9,454,320	15,668,786	15,389,553	2,576,557	5,027,010
ELG-N Based + NPDES 2/3	10,041,362	8,392,651	15,117,087	14,065,751	2,243,297	2,301,133
ELG-N Based + NPDES 4	9,469,696	7,483,769	14,704,032	13,184,699	2,165,146	2,081,544
ELG-N Based + NPDES 4A	10,190,830	8,523,610	15,115,130	13,968,597	2,373,898	3,112,512
ELG-P Based + NPDES 1	8,601,782	7,542,082	12,591,503	11,953,533	2,223,415	4,632,176
ELG-P Based + NPDES 2/3	7,566,232	6,107,217	11,392,454	10,052,973	1,671,131	1,612,793
ELG-P Based + NPDES 4	6,681,908	4,706,456	10,562,736	8,265,349	1,546,702	1,347,381
ELG-P Based + NPDES 4A	7,684,979	6,137,522	11,278,278	9,658,156	1,875,890	2,521,024

Scenario	Hydroregion 7		Hydroregion 8		Hydroregion 9	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	37,891,658	57,881,498	3,237,361	10,025,130	1,904,659	2,602,827
ELG-N Based + NPDES 1	31,490,841	39,149,871	2,792,397	5,020,069	1,363,118	1,140,149
ELG-N Based + NPDES 2/3	30,497,266	37,009,139	2,474,449	2,442,821	1,309,687	1,020,998
ELG-N Based + NPDES 4	29,702,574	35,471,978	2,418,789	2,245,627	1,270,053	947,415
ELG-N Based + NPDES 4A	30,579,430	36,985,477	2,563,274	3,012,676	1,302,878	1,004,867
ELG-P Based + NPDES 1	26,669,570	29,935,816	2,351,606	4,529,574	1,078,904	892,855
ELG-P Based + NPDES 2/3	24,765,269	26,523,474	1,832,342	1,690,984	961,774	727,475
ELG-P Based + NPDES 4	23,444,102	22,015,671	1,751,418	1,451,439	887,507	598,926
ELG-P Based + NPDES 4A	24,738,316	25,464,356	1,964,211	2,317,621	942,930	691,810

(continued)

Scenario	Hydroregion 10		Hydroregion 11		Hydroregion 12	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	40,099,820	40,836,641	25,600,154	36,168,534	8,569,317	7,100,476
ELG-N Based + NPDES 1	35,047,977	27,128,239	22,273,155	19,876,732	7,802,979	3,998,123
ELG-N Based + NPDES 2/3	34,410,642	25,882,539	20,947,428	11,779,173	7,569,115	3,163,090
ELG-N Based + NPDES 4	33,598,475	24,765,940	20,664,903	11,106,648	7,469,689	2,969,936
ELG-N Based + NPDES 4A	34,124,204	25,590,376	21,296,295	14,226,286	7,617,912	3,337,088
ELG-P Based + NPDES 1	27,323,324	20,340,254	17,216,542	17,274,148	5,610,967	3,152,360
ELG-P Based + NPDES 2/3	26,086,138	18,348,563	14,788,358	8,068,736	5,106,571	2,086,846
ELG-P Based + NPDES 4	24,766,996	15,505,759	14,240,820	7,121,974	4,881,911	1,808,279
ELG-P Based + NPDES 4A	25,616,054	17,425,983	15,383,771	10,786,080	5,205,526	2,310,333

Scenario	Hydroregion 13		Hydroregion 14		Hydroregion 15	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	1,148,551	763,080	688,743	299,690	2,742,448	5,032,324
ELG-N Based + NPDES 1	1,041,917	419,431	651,018	213,434	1,946,099	1,815,867
ELG-N Based + NPDES 2/3	1,031,456	399,815	637,941	188,519	1,891,446	1,680,830
ELG-N Based + NPDES 4	1,023,727	387,139	628,745	173,041	1,852,892	1,589,208
ELG-N Based + NPDES 4A	1,029,645	397,448	642,266	197,390	1,888,237	1,677,302
ELG-P Based + NPDES 1	701,710	280,558	476,915	172,853	1,284,145	1,138,142
ELG-P Based + NPDES 2/3	678,132	251,890	447,017	136,100	1,189,314	957,761
ELG-P Based + NPDES 4	660,158	233,162	425,650	113,275	1,119,386	832,792
ELG-P Based + NPDES 4A	673,632	248,325	455,995	148,767	1,172,453	946,797

Scenario	Hydroregion 16		Hydroregion 17		Hydroregion 18	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	1,853,705	1,258,905	12,486,325	20,123,061	23,375,904	60,280,257
ELG-N Based + NPDES 1	1,725,842	837,402	10,121,134	11,535,947	14,796,666	25,328,278
ELG-N Based + NPDES 2/3	1,669,239	727,458	9,183,223	9,092,136	13,046,037	20,621,686
ELG-N Based + NPDES 4	1,632,574	659,580	8,549,937	7,475,812	11,863,447	17,479,302
ELG-N Based + NPDES 4A	1,688,871	765,909	9,559,031	10,146,436	13,625,825	22,280,739
ELG-P Based + NPDES 1	1,287,321	674,598	7,526,058	9,049,975	10,696,818	18,465,649
ELG-P Based + NPDES 2/3	1,161,109	514,372	6,187,177	5,937,347	8,332,462	12,535,045
ELG-P Based + NPDES 4	1,077,434	414,050	5,299,301	3,867,964	6,742,856	8,556,842
ELG-P Based + NPDES 4A	1,201,893	568,396	6,650,052	7,232,496	8,979,309	14,550,317

AFO/CAFO PATHOGENS/SEDIMENT LOADINGS TO AGRICULTURAL LANDUSE CELLS BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE/JULY 2000 DATASETS) (1)

	Hydroregion 1			Hydroregion 2		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	3,130,773,768	4,838,348,570	68,432,266	16,864,949,002	27,337,112,521	649,396,499
ELG-N Based + NPDES 1	1,551,695,235	4,812,894,127	68,886,341	9,334,335,315	26,705,600,974	651,795,695
ELG-N Based + NPDES 2/3	1,313,810,275	4,806,345,639	68,981,189	7,798,561,792	26,364,364,541	652,485,231
ELG-N Based + NPDES 4	834,051,501	4,800,754,841	69,145,877	4,884,244,462	26,222,687,430	653,451,369
ELG-N Based + NPDES 4A	1,709,627,064	4,805,532,744	68,847,891	10,442,301,862	26,413,819,286	651,557,802
ELG-P Based + NPDES 1	1,358,358,619	3,686,202,255	58,255,060	8,295,940,740	21,060,742,684	534,415,721
ELG-P Based + NPDES 2/3	1,085,765,601	3,481,998,892	51,888,259	6,526,672,688	19,530,070,845	478,745,015
ELG-P Based + NPDES 4	534,445,723	3,071,521,367	47,892,851	3,093,828,666	16,902,145,434	455,674,918
ELG-P Based + NPDES 4A	1,540,048,470	3,816,370,906	54,342,624	9,526,969,857	21,777,972,051	498,876,021

	Hydroregion 3			Hydroregion 4		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	15,940,296,932	37,158,331,244	21,773,119,301	26,222,667,666	53,257,503,106	109,059,703,886
ELG-N Based + NPDES 1	8,419,521,721	23,080,000,836	21,315,897,660	10,660,415,924	31,078,165,597	109,166,730,166
ELG-N Based + NPDES 2/3	4,146,000,083	14,221,556,587	21,102,169,921	8,927,892,192	29,363,949,705	109,189,399,445
ELG-N Based + NPDES 4	3,456,491,422	13,541,621,340	21,091,277,906	6,744,474,379	28,040,900,775	109,200,978,626
ELG-N Based + NPDES 4A	5,487,192,820	16,448,363,225	21,138,441,020	9,744,825,197	28,384,082,874	109,192,872,526
ELG-P Based + NPDES 1	8,202,539,149	21,273,798,143	18,244,965,231	9,918,598,922	26,617,485,444	85,273,223,837
ELG-P Based + NPDES 2/3	3,874,762,031	12,095,775,111	16,486,307,441	7,973,346,727	23,993,383,726	78,642,093,304
ELG-P Based + NPDES 4	3,113,258,929	11,032,245,076	16,332,686,726	5,502,326,121	21,100,459,319	75,279,782,502
ELG-P Based + NPDES 4A	5,270,094,417	14,651,370,560	16,852,331,855	8,969,903,554	24,023,833,422	78,417,630,238

(continued)

Scenario	Hydroregion 5			Hydroregion 6		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	30,652,519,535	72,032,681,751	176,151,838,620	3,715,542,529	6,761,917,796	2,165,993,059
ELG-N Based + NPDES 1	11,440,568,299	33,623,228,012	176,340,236,604	2,038,179,495	5,549,980,996	2,124,418,291
ELG-N Based + NPDES 2/3	9,434,416,570	30,318,582,820	176,374,733,317	1,350,460,436	4,482,731,060	2,099,889,822
ELG-N Based + NPDES 4	7,653,125,537	27,978,139,390	176,394,495,037	926,746,616	4,421,534,561	2,098,872,818
ELG-N Based + NPDES 4A	9,338,131,832	28,664,030,038	176,381,404,107	1,874,185,608	4,853,346,404	2,106,413,661
ELG-P Based + NPDES 1	11,046,493,574	30,858,548,212	136,909,476,135	1,886,323,126	4,670,566,370	1,852,570,771
ELG-P Based + NPDES 2/3	8,855,106,820	26,945,229,339	127,793,784,817	1,166,284,733	3,422,302,235	1,647,543,263
ELG-P Based + NPDES 4	6,857,088,532	23,538,157,216	122,813,104,864	678,800,259	3,020,084,529	1,632,900,180
ELG-P Based + NPDES 4A	8,823,765,075	25,668,930,954	126,685,746,080	1,740,864,080	4,096,064,720	1,713,614,614

Scenario	Hydroregion 7			Hydroregion 8		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	31,279,626,159	97,905,938,042	197,290,990,889	2,414,516,015	5,616,814,110	8,241,208,967
ELG-N Based + NPDES 1	13,106,326,913	60,470,478,996	197,469,515,255	1,227,563,008	3,131,862,598	8,200,033,637
ELG-N Based + NPDES 2/3	10,239,650,395	55,180,988,428	197,519,407,046	586,891,624	1,759,568,347	8,177,619,963
ELG-N Based + NPDES 4	8,866,629,075	52,974,953,330	197,538,683,974	516,088,831	1,648,277,517	8,176,443,835
ELG-N Based + NPDES 4A	10,447,816,760	55,053,734,693	197,517,570,151	764,209,041	2,104,193,442	8,182,240,564
ELG-P Based + NPDES 1	12,530,912,916	53,218,075,832	154,808,054,262	1,195,654,080	2,953,938,184	6,084,765,754
ELG-P Based + NPDES 2/3	9,430,038,899	46,996,382,217	141,126,708,001	544,636,113	1,543,226,343	5,486,898,606
ELG-P Based + NPDES 4	7,874,775,956	42,912,340,403	135,122,982,086	466,986,722	1,401,110,042	5,416,726,083
ELG-P Based + NPDES 4A	9,685,667,862	46,653,838,755	142,222,886,126	726,855,502	1,914,772,842	5,595,688,172

(continued)

Scenario	Hydroregion 9 Fecal Coliforms	Hydroregion 9 Fecal Streptococci	Hydroregion 9 Sediment	Hydroregion 10 Fecal Coliforms	Hydroregion 10 Fecal Streptococci	Hydroregion 10 Sediment
Baseline	2,461,367,949	5,631,243,822	16,508,187,152	24,230,347,816	62,433,946,477	111,990,908,542
ELG-N Based + NPDES 1	862,346,770	2,230,583,942	16,524,789,890	11,181,392,740	38,959,703,829	112,093,636,978
ELG-N Based + NPDES 2/3	725,171,884	1,995,416,552	16,528,258,916	9,566,340,466	36,475,942,830	112,120,360,953
ELG-N Based + NPDES 4	622,692,775	1,806,896,758	16,530,078,753	8,654,827,975	35,300,484,519	112,130,875,994
ELG-N Based + NPDES 4A	660,753,551	1,821,273,789	16,528,798,853	9,531,255,343	35,898,279,028	112,120,364,436
ELG-P Based + NPDES 1	844,572,754	2,132,600,376	12,870,499,790	10,056,281,179	33,719,438,798	86,573,801,110
ELG-P Based + NPDES 2/3	693,133,992	1,862,303,902	11,887,952,502	8,273,866,625	30,524,103,847	79,099,657,620
ELG-P Based + NPDES 4	581,584,891	1,634,315,673	11,397,784,347	7,215,463,795	28,166,706,661	75,798,601,410
ELG-P Based + NPDES 4A	629,362,452	1,687,806,757	11,816,823,384	8,262,509,013	29,885,643,046	79,397,933,789

Scenario	Hydroregion 11 Fecal Coliforms	Hydroregion 11 Fecal Streptococci	Hydroregion 11 Sediment	Hydroregion 12 Fecal Coliforms	Hydroregion 12 Fecal Streptococci	Hydroregion 12 Sediment
Baseline	19,760,789,321	40,477,420,482	79,320,534,230	9,051,840,356	14,517,524,334	591,362,170
ELG-N Based + NPDES 1	10,588,963,647	23,557,855,003	79,288,225,204	4,664,615,701	13,720,995,247	591,101,792
ELG-N Based + NPDES 2/3	6,628,516,506	16,211,658,809	79,252,798,938	3,720,511,237	13,607,737,545	590,001,300
ELG-N Based + NPDES 4	5,933,981,706	15,464,714,829	79,255,183,659	3,178,836,215	13,598,303,236	590,255,641
ELG-N Based + NPDES 4A	8,042,318,632	18,562,361,897	79,264,460,402	4,205,825,732	13,639,288,899	590,215,370
ELG-P Based + NPDES 1	9,975,825,165	21,939,560,299	60,450,881,637	4,015,112,589	10,768,445,913	471,393,721
ELG-P Based + NPDES 2/3	5,829,348,502	13,876,282,734	53,534,185,014	2,922,373,592	9,800,227,992	431,765,388
ELG-P Based + NPDES 4	5,052,552,012	12,730,386,511	52,096,973,819	2,290,815,321	9,277,442,922	421,631,660
ELG-P Based + NPDES 4A	7,322,980,054	16,579,977,343	55,379,547,165	3,484,466,777	10,282,250,661	444,125,183

(continued)

Scenario	Hydroregion 13			Hydroregion 14		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	2,298,065,359	3,509,312,488	62,901,756	528,587,304	856,535,243	23,946,920
ELG-N Based + NPDES 1	800,405,941	3,428,458,939	63,507,014	369,771,507	788,304,159	24,046,168
ELG-N Based + NPDES 2/3	735,087,330	3,428,175,391	63,543,227	279,617,004	787,966,922	24,096,567
ELG-N Based + NPDES 4	695,003,374	3,427,437,145	63,565,413	224,930,507	787,088,898	24,127,022
ELG-N Based + NPDES 4A	740,270,470	3,428,002,050	63,540,664	334,181,196	787,950,898	24,067,495
ELG-P Based + NPDES 1	603,132,905	2,382,414,307	45,152,376	337,798,620	690,113,055	20,027,411
ELG-P Based + NPDES 2/3	527,057,945	2,319,893,452	44,186,695	232,808,620	603,868,459	18,624,585
ELG-P Based + NPDES 4	480,210,025	2,281,158,495	43,571,062	168,932,457	551,133,042	17,794,270
ELG-P Based + NPDES 4A	533,038,798	2,324,739,648	44,222,479	296,280,123	655,960,308	19,310,457

Scenario	Hydroregion 15			Hydroregion 16		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	2,574,345,247	3,934,601,954	78,833,236	2,424,621,397	4,157,359,338	98,005,451
ELG-N Based + NPDES 1	935,283,186	3,818,901,927	79,454,053	1,498,032,422	4,017,996,921	98,424,328
ELG-N Based + NPDES 2/3	852,170,887	3,818,263,560	79,498,778	1,098,914,314	4,017,330,259	98,643,767
ELG-N Based + NPDES 4	800,955,150	3,816,805,442	79,524,893	859,368,749	4,015,599,822	98,773,621
ELG-N Based + NPDES 4A	865,866,980	3,817,936,727	79,490,684	1,332,205,475	4,017,272,940	98,517,267
ELG-P Based + NPDES 1	696,919,282	2,660,693,260	57,659,770	1,355,671,173	3,360,300,809	80,810,393
ELG-P Based + NPDES 2/3	599,719,474	2,580,550,972	56,425,400	891,143,989	2,978,902,125	75,058,099
ELG-P Based + NPDES 4	539,062,202	2,529,917,179	55,555,833	611,955,214	2,749,013,965	71,469,805
ELG-P Based + NPDES 4A	615,498,782	2,593,342,794	56,536,050	1,162,511,698	3,201,511,782	77,899,988

(continued)

Scenario	Hydroregion 17			Hydroregion 18		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	7,638,997,788	11,212,041,222	297,575,222	2,864,030,485	3,267,321,728	185,032,155
ELG-N Based + NPDES 1	4,033,375,457	10,099,812,118	298,744,053	1,678,002,107	2,287,023,103	185,033,001
ELG-N Based + NPDES 2/3	3,481,933,166	10,090,753,270	299,031,468	1,636,594,889	2,278,935,171	185,033,012
ELG-N Based + NPDES 4	3,137,725,619	10,071,196,287	299,203,353	1,598,263,065	2,262,066,616	185,033,018
ELG-N Based + NPDES 4A	3,760,245,141	10,086,561,735	298,884,405	1,651,017,206	2,273,506,557	185,033,014
ELG-P Based + NPDES 1	2,984,778,410	7,407,065,060	231,003,732	898,241,727	1,261,654,912	142,888,429
ELG-P Based + NPDES 2/3	2,334,510,290	6,866,902,287	222,853,073	841,161,069	1,206,953,429	141,184,260
ELG-P Based + NPDES 4	1,916,003,199	6,510,958,279	217,243,749	778,982,800	1,143,214,405	139,447,953
ELG-P Based + NPDES 4A	2,654,641,923	7,128,104,490	226,498,471	852,942,918	1,215,314,040	141,637,664

Appendix E

AFO/CAFO NUTRIENT LOADINGS (KILOGRAMS) TO RF3 REACHES BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE 2000 DATASETS) (1)

Scenario	Hydroregion 1		Hydroregion 2		Hydroregion 3	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	**890,115**	**1,069,600**	**7,183,220**	**10,632,164**	24,700,786	73,570,254
ELG-N Based + NPDES 1	765,628	678,706	6,379,560	6,662,171	22,155,459	36,178,638
ELG-N Based + NPDES 2/3	716,251	586,782	5,750,044	4,893,468	19,732,734	17,813,153
ELG-N Based + NPDES 4	644,553	476,342	5,274,116	4,193,663	19,356,601	16,510,307
ELG-N Based + NPDES 4A	751,270	632,211	6,068,869	5,512,523	20,407,169	21,507,004
ELG-P Based + NPDES 1	639,977	580,537	5,295,878	5,711,592	18,660,885	32,518,878
ELG-P Based + NPDES 2/3	530,069	433,968	4,147,942	3,428,766	14,586,578	12,206,350
ELG-P Based + NPDES 4	407,473	283,500	3,340,914	2,483,014	13,958,464	10,601,853
ELG-P Based + NPDES 4A	585,682	494,560	4,624,684	4,187,348	15,582,515	16,294,254

Scenario	Hydroregion 4		Hydroregion 5		Hydroregion 6	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	10,896,247	10,907,718	21,013,228	26,232,617	2,735,316	7,842,110
ELG-N Based + NPDES 1	8,213,845	5,708,785	14,991,390	12,241,366	2,431,383	4,185,303
ELG-N Based + NPDES 2/3	7,728,047	5,031,820	14,462,419	11,177,333	2,118,763	1,921,756
ELG-N Based + NPDES 4	7,222,527	4,414,568	14,065,392	10,464,936	2,046,899	1,739,029
ELG-N Based + NPDES 4A	7,880,845	5,171,975	14,462,515	11,108,108	2,239,900	2,594,150
ELG-P Based + NPDES 1	6,733,721	4,590,487	12,044,239	9,509,322	2,099,248	3,852,961
ELG-P Based + NPDES 2/3	5,870,625	3,683,321	10,894,943	7,985,332	1,581,428	1,348,383
ELG-P Based + NPDES 4	5,113,840	2,757,177	10,098,445	6,559,392	1,466,935	1,127,399
ELG-P Based + NPDES 4A	6,018,675	3,777,776	10,789,039	7,687,559	1,771,346	2,099,620

(continued)

Scenario	Hydroregion 7 Nitrogen	Hydroregion 7 Phosphorus	Hydroregion 8 Nitrogen	Hydroregion 8 Phosphorus	Hydroregion 9 Nitrogen	Hydroregion 9 Phosphorus
Baseline	35,774,260	41,106,268	2,706,627	5,045,067	1,557,243	903,905
ELG-N Based + NPDES 1	29,760,297	28,034,235	2,335,906	2,477,837	1,103,216	374,974
ELG-N Based + NPDES 2/3	28,826,095	26,540,791	2,071,939	1,220,011	1,060,372	334,194
ELG-N Based + NPDES 4	28,075,676	25,450,639	2,026,086	1,123,484	1,029,091	309,283
ELG-N Based + NPDES 4 A	28,904,285	26,534,797	2,148,743	1,503,400	1,053,630	326,524
ELG-P Based + NPDES 1	25,212,619	21,422,966	1,965,791	2,227,592	871,072	297,723
ELG-P Based + NPDES 2/3	23,424,432	19,026,309	1,534,367	842,021	776,256	240,868
ELG-P Based + NPDES 4	22,178,747	15,791,619	1,467,219	725,455	716,591	196,826
ELG-P Based + NPDES 4 A	23,401,130	18,276,195	1,648,366	1,154,614	758,730	225,604

Scenario	Hydroregion 10 Nitrogen	Hydroregion 10 Phosphorus	Hydroregion 11 Nitrogen	Hydroregion 11 Phosphorus	Hydroregion 12 Nitrogen	Hydroregion 12 Phosphorus
Baseline	36,004,483	24,746,479	21,895,647	26,784,616	6,854,107	4,307,310
ELG-N Based + NPDES 1	31,382,488	16,487,082	18,965,925	14,536,057	6,206,892	2,336,955
ELG-N Based + NPDES 2/3	30,794,072	15,632,285	17,761,337	7,968,998	5,989,027	1,728,817
ELG-N Based + NPDES 4	30,066,900	14,964,183	17,530,921	7,493,195	5,899,300	1,607,066
ELG-N Based + NPDES 4 A	30,544,813	15,493,464	18,093,245	9,991,183	6,037,421	1,856,528
ELG-P Based + NPDES 1	24,547,474	12,406,318	14,773,945	12,863,936	4,498,352	1,892,455
ELG-P Based + NPDES 2/3	23,399,112	11,068,206	12,582,962	5,444,484	4,029,089	1,124,539
ELG-P Based + NPDES 4	22,211,677	9,337,710	12,132,187	4,781,920	3,826,963	949,942
ELG-P Based + NPDES 4 A	22,988,192	10,556,436	13,140,816	7,687,125	4,128,372	1,288,270

(continued)

Scenario	Hydroregion 13 Nitrogen	Hydroregion 13 Phosphorus	Hydroregion 14 Nitrogen	Hydroregion 14 Phosphorus	Hydroregion 15 Nitrogen	Hydroregion 15 Phosphorus
Baseline	870,919	187,473	668,128	221,989	2,170,763	1,387,006
ELG-N Based + NPDES 1	785,470	102,923	631,517	157,272	1,546,132	497,999
ELG-N Based + NPDES 2/3	776,304	96,735	618,818	139,283	1,501,215	456,881
ELG-N Based + NPDES 4	769,597	92,727	609,879	128,054	1,469,512	428,719
ELG-N Based + NPDES 4 A	774,852	96,260	622,990	144,861	1,497,575	450,861
ELG-P Based + NPDES 1	526,168	69,745	462,749	127,302	1,022,050	313,412
ELG-P Based + NPDES 2/3	505,592	60,686	433,703	100,707	945,440	259,802
ELG-P Based + NPDES 4	490,193	54,834	412,923	84,103	889,079	222,234
ELG-P Based + NPDES 4 A	502,049	60,026	442,356	108,646	931,310	250,623

Scenario	Hydroregion 16 Nitrogen	Hydroregion 16 Phosphorus	Hydroregion 17 Nitrogen	Hydroregion 17 Phosphorus	Hydroregion 18 Nitrogen	Hydroregion 18 Phosphorus
Baseline	1,555,532	623,984	11,490,376	12,159,860	18,205,107	26,650,655
ELG-N Based + NPDES 1	1,458,651	438,211	9,292,921	6,954,874	11,263,808	11,390,137
ELG-N Based + NPDES 2/3	1,407,528	373,807	8,410,564	5,304,166	9,755,969	9,094,694
ELG-N Based + NPDES 4	1,374,768	334,107	7,816,325	4,217,101	8,742,995	7,561,347
ELG-N Based + NPDES 4 A	1,425,247	396,997	8,770,613	6,044,676	10,285,454	9,970,205
ELG-P Based + NPDES 1	1,096,273	361,679	6,915,098	5,618,262	8,224,230	8,508,015
ELG-P Based + NPDES 2/3	982,003	268,166	5,657,923	3,527,039	6,203,404	5,621,693
ELG-P Based + NPDES 4	907,129	209,718	4,827,693	2,148,573	4,850,541	3,687,293
ELG-P Based + NPDES 4 A	1,019,173	301,133	6,102,615	4,440,602	6,802,720	6,689,010

AFO/CAFO PATHOGENS/SEDIMENT LOADINGS TO RF3 REACHES BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE 2000 DATASETS) (1)

	Hydroregion 1			Hydroregion 2		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	2,987,248,253	4,787,586,856	59,081,807	15,711,719,270	26,901,715,639	547,134,003
ELG-N Based + NPDES 1	1,486,590,478	4,762,420,257	59,473,337	8,697,848,434	26,278,493,182	549,136,301
ELG-N Based + NPDES 2/3	1,258,078,330	4,755,947,956	59,556,411	7,265,814,895	25,942,401,942	549,715,618
ELG-N Based + NPDES 4	797,151,490	4,750,424,752	59,700,935	4,547,922,340	25,804,863,980	550,523,993
ELG-N Based + NPDES 4 A	1,638,205,946	4,755,155,037	59,440,336	9,731,869,730	25,991,577,588	548,942,383
ELG-P Based + NPDES 1	1,302,398,199	3,648,461,824	50,343,513	7,730,252,745	20,726,609,221	450,184,194
ELG-P Based + NPDES 2/3	1,040,546,575	3,446,149,312	44,807,873	6,080,982,488	19,219,280,449	403,224,806
ELG-P Based + NPDES 4	510,879,598	3,039,448,566	41,335,905	2,881,583,006	16,634,541,456	383,884,231
ELG-P Based + NPDES 4 A	1,476,814,122	3,777,438,468	46,998,380	8,879,909,821	21,439,366,681	420,097,500

	Hydroregion 3			Hydroregion 4		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	14,039,033,020	35,753,102,368	17,673,702,680	19,390,846,009	43,097,143,906	53,839,001,254
ELG-N Based + NPDES 1	7,480,356,729	22,396,444,492	17,302,906,569	8,288,074,099	27,294,948,219	53,887,922,182
ELG-N Based + NPDES 2/3	3,690,300,020	13,843,188,130	17,126,261,352	6,936,079,071	26,027,691,382	53,900,321,887
ELG-N Based + NPDES 4	3,061,912,684	13,195,708,961	17,117,435,668	5,107,081,945	25,099,201,457	53,905,865,551
ELG-N Based + NPDES 4 A	4,899,632,113	15,995,524,846	17,156,401,019	7,856,256,789	25,355,464,652	53,901,390,397
ELG-P Based + NPDES 1	7,279,320,973	20,623,083,832	14,824,096,303	7,612,070,719	22,979,159,597	42,301,723,753
ELG-P Based + NPDES 2/3	3,439,500,532	11,757,035,808	13,376,360,450	6,081,054,679	20,849,646,802	38,518,201,587
ELG-P Based + NPDES 4	2,743,461,620	10,730,027,645	13,253,896,337	3,995,715,068	18,415,075,147	36,769,426,808
ELG-P Based + NPDES 4 A	4,699,232,891	14,234,420,207	13,680,568,981	7,171,926,957	21,177,388,281	38,597,403,701

(continued)

Scenario	Hydroregion 5 Fecal Coliforms	Hydroregion 5 Fecal Streptococci	Hydroregion 5 Sediment	Hydroregion 6 Fecal Coliforms	Hydroregion 6 Fecal Streptococci	Hydroregion 6 Sediment
Baseline	27,837,269,197	70,588,993,783	141,187,103,859	3,359,714,938	6,417,744,922	1,832,257,275
ELG-N Based + NPDES 1	10,410,834,680	32,948,069,123	141,337,943,789	1,826,723,744	5,227,840,597	1,797,009,312
ELG-N Based + NPDES 2/3	8,587,902,200	29,714,370,636	141,365,640,019	1,204,526,005	4,182,650,954	1,776,410,197
ELG-N Based + NPDES 4	6,958,193,323	27,425,075,789	141,381,512,024	832,875,613	4,122,492,654	1,775,544,725
ELG-N Based + NPDES 4 A	8,520,727,598	28,098,764,892	141,370,827,737	1,666,050,028	4,545,973,983	1,781,895,006
ELG-P Based + NPDES 1	10,048,729,514	30,236,542,416	109,724,171,734	1,690,402,840	4,406,016,644	1,566,516,929
ELG-P Based + NPDES 2/3	8,056,067,295	26,404,905,850	102,402,649,172	1,039,837,725	3,194,710,145	1,394,708,243
ELG-P Based + NPDES 4	6,226,229,606	23,067,983,967	98,403,109,130	612,208,808	2,823,528,960	1,382,315,055
ELG-P Based + NPDES 4 A	8,049,895,408	25,164,798,806	101,565,725,036	1,545,553,032	3,829,555,972	1,449,908,377

Scenario	Hydroregion 7 Fecal Coliforms	Hydroregion 7 Fecal Streptococci	Hydroregion 7 Sediment	Hydroregion 8 Fecal Coliforms	Hydroregion 8 Fecal Streptococci	Hydroregion 8 Sediment
Baseline	27,421,126,172	95,293,976,612	136,399,945,502	1,471,659,212	5,154,909,341	3,921,192,647
ELG-N Based + NPDES 1	11,504,237,962	58,935,357,752	136,523,097,817	744,242,332	2,877,425,204	3,899,710,517
ELG-N Based + NPDES 2/3	8,998,466,884	53,800,483,028	136,557,405,901	361,517,907	1,623,230,530	3,888,615,528
ELG-N Based + NPDES 4	7,798,589,927	51,663,633,985	136,570,434,524	314,610,636	1,520,157,396	3,888,057,859
ELG-N Based + NPDES 4 A	8,510,545,540	45,479,028,462	98,348,196,974	457,198,001	1,769,982,911	2,692,832,121
ELG-P Based + NPDES 1	10,989,080,775	51,849,404,813	106,906,749,853	724,138,576	2,712,337,503	2,894,258,391
ELG-P Based + NPDES 2/3	8,277,601,144	45,806,364,487	97,468,225,430	335,213,045	1,422,690,547	2,622,034,924
ELG-P Based + NPDES 4	6,916,338,798	41,836,361,434	93,345,938,319	284,018,023	1,290,676,191	2,584,016,214
ELG-P Based + NPDES 4 A	9,188,691,110	53,683,706,583	136,555,757,704	479,555,466	1,944,819,019	3,890,788,952

(continued)

Scenario	Hydroregion 9			Hydroregion 10		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	1,800,030,864	5,143,475,224	6,130,884,752	21,053,037,831	59,844,309,911	76,227,475,134
ELG-N Based + NPDES 1	620,979,796	2,010,162,019	6,137,224,604	9,630,630,124	37,258,049,710	76,295,359,619
ELG-N Based + NPDES 2/3	522,872,295	1,795,010,033	6,138,449,494	8,174,067,858	34,834,621,380	76,314,596,697
ELG-N Based + NPDES 4	448,890,692	1,622,009,826	6,139,121,835	7,374,416,935	33,696,607,052	76,321,874,913
ELG-N Based + NPDES 4 A	472,282,417	1,634,125,937	6,138,753,804	8,148,946,349	34,280,921,744	76,313,691,970
ELG-P Based + NPDES 1	609,522,030	1,927,460,252	4,767,454,716	8,702,993,845	32,276,595,091	58,772,782,843
ELG-P Based + NPDES 2/3	501,539,581	1,681,174,667	4,424,728,544	7,097,971,557	29,173,274,678	53,394,960,138
ELG-P Based + NPDES 4	421,286,026	1,473,649,347	4,247,639,779	6,171,499,227	26,903,958,761	51,144,270,571
ELG-P Based + NPDES 4 A	450,902,095	1,519,545,022	4,370,308,998	7,094,936,223	28,562,481,931	53,811,556,535

Scenario	Hydroregion 11			Hydroregion 12		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	15,598,938,921	36,575,826,127	58,385,155,613	6,227,090,601	12,789,181,562	369,226,752
ELG-N Based + NPDES 1	8,168,749,492	20,636,979,547	58,349,829,970	3,315,980,379	12,112,924,147	368,287,075
ELG-N Based + NPDES 2/3	4,891,175,797	13,553,060,766	58,316,185,124	2,552,383,828	12,002,027,455	367,312,424
ELG-N Based + NPDES 4	4,407,481,809	12,829,063,446	58,317,691,009	2,117,601,467	11,993,362,848	367,457,296
ELG-N Based + NPDES 4 A	6,018,380,722	15,842,421,878	58,326,655,917	2,956,564,539	12,033,308,936	367,506,485
ELG-P Based + NPDES 1	7,766,198,374	19,354,418,225	44,587,842,932	2,897,723,767	9,600,492,069	297,407,075
ELG-P Based + NPDES 2/3	4,362,350,481	11,800,270,561	39,477,395,351	2,014,385,945	8,677,121,710	268,544,737
ELG-P Based + NPDES 4	3,829,019,408	10,826,495,320	38,388,901,880	1,507,700,787	8,181,247,952	262,068,269
ELG-P Based + NPDES 4 A	5,537,863,982	14,291,083,087	40,901,555,219	2,482,631,688	9,147,188,590	277,382,501

(continued)

Scenario	Hydroregion 13 Fecal Coliforms	Hydroregion 13 Fecal Streptococci	Hydroregion 13 Sediment	Hydroregion 14 Fecal Coliforms	Hydroregion 14 Fecal Streptococci	Hydroregion 14 Sediment
Baseline	1,729,911,770	3,226,248,233	15,563,247	504,893,377	842,227,160	17,589,768
ELG-N Based + NPDES 1	594,187,333	3,166,690,382	15,714,577	354,820,446	775,122,097	17,658,383
ELG-N Based + NPDES 2/3	543,133,260	3,166,438,686	15,726,043	268,129,610	774,788,484	17,694,378
ELG-N Based + NPDES 4	511,931,855	3,165,783,371	15,733,157	215,533,321	773,919,894	17,716,174
ELG-N Based + NPDES 4 A	548,633,767	3,166,265,944	15,724,683	320,441,294	774,772,296	17,675,150
ELG-P Based + NPDES 1	446,669,308	2,195,806,116	11,205,782	324,378,538	679,079,337	14,736,001
ELG-P Based + NPDES 2/3	387,210,304	2,136,806,879	10,892,377	223,421,162	593,987,600	13,722,541
ELG-P Based + NPDES 4	350,749,431	2,100,442,941	10,699,420	161,984,430	541,952,345	13,119,474
ELG-P Based + NPDES 4 A	393,576,437	2,141,796,341	10,924,784	284,272,140	645,338,321	14,171,720

Scenario	Hydroregion 15 Fecal Coliforms	Hydroregion 15 Fecal Streptococci	Hydroregion 15 Sediment	Hydroregion 16 Fecal Coliforms	Hydroregion 16 Fecal Streptococci	Hydroregion 16 Sediment
Baseline	1,727,056,001	3,450,500,366	21,502,154	2,022,280,634	3,724,746,558	50,759,430
ELG-N Based + NPDES 1	627,428,127	3,347,336,283	21,664,343	1,292,185,550	3,603,822,297	50,957,088
ELG-N Based + NPDES 2/3	573,162,549	3,346,749,897	21,674,542	933,660,516	3,603,259,473	51,089,470
ELG-N Based + NPDES 4	539,766,362	3,345,410,863	21,680,358	718,750,240	3,601,796,287	51,168,426
ELG-N Based + NPDES 4 A	580,862,182	3,346,443,814	21,675,532	1,138,274,414	3,603,253,946	51,014,351
ELG-P Based + NPDES 1	463,873,008	2,330,149,161	15,729,860	1,179,182,625	3,045,543,959	42,425,506
ELG-P Based + NPDES 2/3	400,398,367	2,259,917,706	15,423,535	761,927,209	2,684,769,173	39,091,897
ELG-P Based + NPDES 4	360,821,383	2,215,494,402	15,186,502	511,508,059	2,467,679,511	36,997,568
ELG-P Based + NPDES 4 A	409,165,025	2,270,213,980	15,352,166	999,948,198	2,890,979,620	40,844,452

(continued)

Scenario	Hydroregion 17			Hydroregion 18		
	Fecal Coliforms	Fecal Streptococci	Sediment	Fecal Coliforms	Fecal Streptococci	Sediment
Baseline	6,637,138,275	10,689,142,845	116,550,819	1,371,947,377	1,816,700,320	55,405,028
ELG-N Based + NPDES 1	3,497,274,929	9,633,406,627	116,962,593	770,633,058	1,354,010,165	55,405,256
ELG-N Based + NPDES 2/3	3,018,823,650	9,624,802,703	117,070,367	738,993,674	1,348,769,462	55,405,256
ELG-N Based + NPDES 4	2,719,904,545	9,606,228,295	117,134,935	711,845,823	1,337,840,538	55,405,256
ELG-N Based + NPDES 4 A	3,262,358,292	9,621,160,429	117,016,380	753,853,085	1,347,484,319	55,405,256
ELG-P Based + NPDES 1	2,588,613,360	7,064,225,371	90,963,745	431,036,167	781,392,900	43,093,568
ELG-P Based + NPDES 2/3	2,024,279,475	6,549,656,868	87,660,215	388,984,174	736,633,673	42,324,421
ELG-P Based + NPDES 4	1,660,597,771	6,210,634,151	85,364,088	347,336,751	688,779,878	41,615,847
ELG-P Based + NPDES 4 A	2,304,880,843	6,800,010,056	89,165,604	405,404,527	752,585,377	42,652,248

(1) AFO/CAFO loadings to RF3 reaches (to RF1 reaches for Hydroregions 8 and 17) (overland routed from agricultural land-use cells to reaches)

Appendix F

NON-POINT SOURCES (NON-MANURE) AND POINT SOURCES (NON-CAFOS) NUTRIENT LOADINGS (KILOGRAMS) TO RF1 SUBSET OF RF3 REACHES FOR AFO/CAFO RULEMAKING SCENARIOS

	Non-Point Sources (non-manure)		Point Sources (non-CAFOs)	
Hydroregion	Nitrogen	Phosphorus	Nitrogen	Phosphorus
1	254,280,226	4,812,221	33,723,111	7,112,369
2	214,896,123	11,986,099	155,225,579	38,267,257
3	303,697,596	23,596,204	62,337,926	17,189,424
4	193,692,210	11,233,342	126,427,955	45,772,516
5	384,692,513	24,858,336	59,641,272	13,084,824
6	55,813,001	4,403,812	16,560,268	2,762,486
7	576,071,151	41,223,038	49,775,590	13,269,766
8	207,364,132	13,722,593	27,833,261	4,807,287
9	69,283,194	5,333,376	1,213,234	231,305
10	573,132,496	49,720,669	32,998,927	12,429,045
11	253,226,368	19,924,910	15,615,096	4,043,503
12	173,333,169	15,991,499	38,236,960	6,795,278
13	76,750,065	7,367,002	3,498,695	684,821
14	85,959,274	7,303,053	1,697,327	536,218
15	96,394,425	9,780,236	3,763,931	651,669
16	61,578,014	5,982,314	4,578,770	1,679,974
17	302,628,732	22,393,322	10,748,949	2,471,298
18	119,222,887	9,684,904	37,750,008	8,603,289
Totals	4,002,015,576	289,316,930	681,626,859	180,392,329

Appendix G

HYDROREGION NUTRIENT LOADINGS (KILOGRAMS) FOR AFO/CAFO RULEMAKING SCENARIOS (1)

Scenario	Hydroregion 1		Hydroregion 2		Hydroregion 3	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	288,793,742	13,120,206	376,873,340	61,314,068	489,359,092	127,619,080
ELG-N Based + NPDES 1	288,708,547	12,765,731	376,324,745	58,125,778	488,493,232	103,359,236
ELG-N Based + NPDES 2/3	288,659,923	12,660,431	375,940,365	57,303,748	488,007,050	100,676,400
ELG-N Based + NPDES 4	288,594,772	12,430,440	375,245,362	54,965,592	486,239,532	85,476,727
ELG-N Based + NPDES 4 A	288,244,776	12,130,840	371,870,472	51,807,205	369,407,294	44,186,293
ELG-P Based + NPDES 1	288,600,360	12,669,025	375,308,512	57,099,085	469,625,888	95,370,998
ELG-P Based + NPDES 2/3	288,517,450	12,533,939	374,657,198	56,048,575	467,591,561	92,001,192
ELG-P Based + NPDES 4	288,377,112	12,224,570	373,357,311	53,031,754	456,018,152	72,457,792
ELG-P Based + NPDES 4 A	288,193,692	12,086,828	371,456,883	51,432,165	368,616,349	43,358,447

Scenario	Hydroregion 4		Hydroregion 5		Hydroregion 6	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	334,126,873	71,264,884	468,404,939	63,953,272	87,041,802	17,375,484
ELG-N Based + NPDES 1	332,475,090	65,785,170	465,304,105	53,716,530	86,918,326	15,119,473
ELG-N Based + NPDES 2/3	332,136,138	65,103,911	465,017,874	53,021,248	86,840,726	14,696,085
ELG-N Based + NPDES 4	331,351,160	62,913,125	463,857,272	49,371,043	86,578,141	12,373,254
ELG-N Based + NPDES 4 A	321,759,164	58,063,044	447,648,492	40,572,351	72,978,966	7,863,399
ELG-P Based + NPDES 1	329,253,315	64,286,497	459,319,495	50,753,083	85,175,260	14,401,578
ELG-P Based + NPDES 2/3	328,538,841	63,442,934	458,591,237	49,845,790	84,854,623	13,866,425
ELG-P Based + NPDES 4	326,303,723	60,588,351	455,009,206	44,952,269	83,136,379	10,914,814
ELG-P Based + NPDES 4 A	321,366,791	57,776,009	446,814,350	39,749,570	72,847,896	7,722,794

Scenario	Hydroregion 7		Hydroregion 8		Hydroregion 9	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	664,941,120	107,612,330	249,547,986	28,308,667	72,570,522	7,573,674
ELG-N Based + NPDES 1	660,864,858	90,587,607	249,365,328	25,791,185	72,304,456	6,750,710
ELG-N Based + NPDES 2/3	660,299,725	89,240,999	249,303,742	25,464,037	72,280,929	6,696,481
ELG-N Based + NPDES 4	658,331,529	81,936,021	249,090,948	23,623,314	72,180,019	6,400,511
ELG-N Based + NPDES 4 A	632,266,970	60,230,365	237,186,131	19,890,264	70,703,405	5,630,073
ELG-P Based + NPDES 1	652,228,002	84,091,677	247,269,388	24,947,903	71,781,635	6,524,437
ELG-P Based + NPDES 2/3	650,889,581	82,313,774	247,003,165	24,535,854	71,720,447	6,454,952
ELG-P Based + NPDES 4	645,024,496	72,190,801	245,449,889	22,137,154	71,411,480	6,479,733
ELG-P Based + NPDES 4 A	631,029,362	58,466,084	236,712,244	19,565,777	70,646,872	5,611,108

(continued)

Scenario	Hydroregion 10		Hydroregion 11		Hydroregion 12	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	646,153,513	101,343,803	329,892,921	64,369,556	219,032,392	29,200,274
ELG-N Based + NPDES 1	642,045,925	87,764,324	327,871,934	54,582,567	218,337,517	26,670,471
ELG-N Based + NPDES 2/3	641,500,487	86,907,174	327,526,919	53,053,149	218,214,475	26,387,195
ELG-N Based + NPDES 4	640,307,357	83,084,297	326,085,402	44,299,578	218,028,464	25,705,862
ELG-N Based + NPDES 4 A	616,248,408	66,287,746	274,328,335	26,045,382	213,828,154	23,197,920
ELG-P Based + NPDES 1	632,206,455	82,170,850	317,935,838	51,082,019	216,659,419	25,915,029
ELG-P Based + NPDES 2/3	631,145,450	80,983,379	316,602,771	49,117,813	216,459,948	25,496,814
ELG-P Based + NPDES 4	627,870,425	75,596,098	309,198,493	37,883,466	215,983,579	24,557,442
ELG-P Based + NPDES 4 A	613,634,649	65,008,394	272,757,147	25,570,627	213,112,148	23,065,338

Scenario	Hydroregion 13		Hydroregion 14		Hydroregion 15	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	80,990,020	8,827,000	88,287,591	8,145,909	102,185,318	14,258,947
ELG-N Based + NPDES 1	80,857,424	8,375,390	88,246,532	8,054,356	101,604,180	12,034,903
ELG-N Based + NPDES 2/3	80,852,090	8,365,814	88,234,617	8,031,448	101,580,689	11,976,330
ELG-N Based + NPDES 4	80,847,696	8,356,019	88,225,706	8,010,264	101,563,018	11,932,941
ELG-N Based + NPDES 4 A	80,813,380	8,117,546	87,835,679	7,877,272	101,165,589	10,753,545
ELG-P Based + NPDES 1	80,687,438	8,258,843	88,082,847	8,014,980	101,100,284	11,346,951
ELG-P Based + NPDES 2/3	80,679,222	8,244,190	88,066,274	7,980,112	101,060,010	11,255,664
ELG-P Based + NPDES 4	80,670,822	8,229,756	88,052,005	7,950,012	101,023,868	11,181,877
ELG-P Based + NPDES 4 A	80,617,949	8,092,986	87,783,262	7,867,341	100,780,129	10,607,044

Scenario	Hydroregion 16		Hydroregion 17		Hydroregion 18	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	67,514,286	8,747,033	326,620,967	43,725,085	175,299,894	62,036,744
ELG-N Based + NPDES 1	67,400,202	8,384,196	324,918,787	36,990,181	169,971,767	40,843,100
ELG-N Based + NPDES 2/3	67,355,094	8,295,482	324,276,601	35,248,730	168,982,552	38,045,507
ELG-N Based + NPDES 4	67,324,874	8,226,881	323,828,724	34,053,392	168,306,909	36,188,241
ELG-N Based + NPDES 4 A	66,651,282	7,775,441	321,869,704	30,730,792	161,376,214	22,384,499
ELG-P Based + NPDES 1	67,085,757	8,254,461	321,583,935	33,981,551	165,859,555	33,802,284
ELG-P Based + NPDES 2/3	67,026,255	8,118,306	320,497,553	31,314,549	164,174,901	29,526,946
ELG-P Based + NPDES 4	66,980,746	8,016,080	319,691,024	29,452,816	162,957,850	26,610,334
ELG-P Based + NPDES 4 A	66,508,301	7,748,533	319,280,143	29,175,049	159,914,657	21,070,727

Appendix H

AFO/CAFO NUTRIENT LOADINGS (KILOGRAMS) TO RF1 REACHES BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE 2000 DATASETS)

Scenario	Hydroregion 1		Hydroregion 2		Hydroregion 3	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	282,987	359,454	2,084,341	2,964,063	4,089,843	11,621,812
ELG-N Based + NPDES 1	242,808	218,578	1,843,178	1,876,151	3,661,546	5,708,809
ELG-N Based + NPDES 2/3	227,816	189,821	1,670,620	1,410,005	3,251,869	2,851,843
ELG-N Based + NPDES 4	205,177	154,142	1,515,117	1,185,295	3,176,032	2,613,884
ELG-N Based + NPDES 4 A	241,439	206,250	1,748,770	1,553,849	3,371,772	3,400,665
ELG-P Based + NPDES 1	201,754	185,293	1,532,870	1,607,805	3,093,743	5,133,293
ELG-P Based + NPDES 2/3	169,343	140,725	1,218,400	1,001,951	2,411,848	1,967,088
ELG-P Based + NPDES 4	130,541	92,256	960,625	702,468	2,291,334	1,675,859
ELG-P Based + NPDES 4 A	190,355	162,238	1,335,180	1,178,809	2,580,827	2,572,819

Scenario	Hydroregion 4		Hydroregion 5		Hydroregion 6	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	2,278,109	2,285,402	4,758,295	5,959,837	747,611	2,184,968
ELG-N Based + NPDES 1	1,708,213	1,173,608	3,448,120	2,909,829	664,736	1,144,393
ELG-N Based + NPDES 2/3	1,603,397	1,031,051	3,323,932	2,661,248	581,886	526,726
ELG-N Based + NPDES 4	1,496,033	899,230	3,228,393	2,491,949	563,943	480,784
ELG-N Based + NPDES 4 A	1,638,999	1,057,186	3,314,707	2,629,191	605,727	697,101
ELG-P Based + NPDES 1	1,406,737	950,152	2,790,800	2,254,352	573,383	1,050,105
ELG-P Based + NPDES 2/3	1,219,125	759,177	2,522,114	1,896,459	435,848	368,009
ELG-P Based + NPDES 4	1,056,293	563,371	2,333,310	1,555,093	407,824	312,392
ELG-P Based + NPDES 4 A	1,246,626	770,151	2,480,564	1,806,410	474,627	556,496

(continued)

Scenario	Hydroregion 7		Hydroregion 8		Hydroregion 9	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	8,037,375	9,105,614	2,520,817	4,677,730	295,724	157,439
ELG-N Based + NPDES 1	6,602,186	6,080,081	2,163,775	2,256,568	216,477	71,513
ELG-N Based + NPDES 2/3	6,377,406	5,709,783	1,921,439	1,121,815	209,121	65,158
ELG-N Based + NPDES 4	6,224,786	5,480,174	1,878,394	1,034,260	202,668	60,813
ELG-N Based + NPDES 4 A	6,420,229	5,737,561	1,988,738	1,360,384	206,977	65,392
ELG-P Based + NPDES 1	5,589,728	4,675,313	1,812,151	2,022,634	169,780	56,471
ELG-P Based + NPDES 2/3	5,154,837	4,098,442	1,415,735	772,375	154,325	47,325
ELG-P Based + NPDES 4	4,896,831	3,404,261	1,353,074	666,824	142,979	38,604
ELG-P Based + NPDES 4 A	5,182,621	3,973,279	1,514,851	1,035,898	150,444	46,427

Scenario	Hydroregion 10		Hydroregion 11		Hydroregion 12	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Baseline	11,593,609	6,382,850	6,479,081	5,596,050	2,490,977	909,624
ELG-N Based + NPDES 1	10,333,454	4,372,292	5,680,765	2,945,868	2,297,062	501,078
ELG-N Based + NPDES 2/3	10,171,953	4,146,212	5,410,427	1,646,340	2,252,733	391,337
ELG-N Based + NPDES 4	9,967,808	3,966,936	5,360,777	1,559,837	2,231,830	368,645
ELG-N Based + NPDES 4 A	10,116,985	4,138,032	5,486,871	2,076,969	2,258,025	411,143
ELG-P Based + NPDES 1	7,922,882	3,300,008	4,270,434	2,592,412	1,630,942	395,075
ELG-P Based + NPDES 2/3	7,595,728	2,943,394	3,784,650	1,119,823	1,533,084	253,723
ELG-P Based + NPDES 4	7,246,507	2,491,889	3,687,662	997,879	1,484,098	220,469
ELG-P Based + NPDES 4 A	7,503,226	2,858,680	3,915,683	1,602,214	1,542,019	278,561

(continued)

Scenario	Hydroregion 13		Hydroregion 14		Hydroregion 15	
	Nitrogen	**Phosphorus**	**Nitrogen**	**Phosphorus**	**Nitrogen**	**Phosphorus**
Baseline	630,737	128,247	191,559	61,671	1,526,269	1,067,146
ELG-N Based + NPDES 1	571,936	70,051	179,993	38,964	1,043,395	360,227
ELG-N Based + NPDES 2/3	565,358	65,772	177,577	35,937	1,010,765	326,920
ELG-N Based + NPDES 4	560,578	63,062	175,716	34,028	987,874	304,145
ELG-N Based + NPDES 4 A	564,620	65,723	179,078	38,001	1,007,233	321,640
ELG-P Based + NPDES 1	385,792	47,454	129,068	29,591	687,980	225,734
ELG-P Based + NPDES 2/3	371,035	41,196	123,559	25,136	633,598	182,976
ELG-P Based + NPDES 4	360,106	37,256	119,220	22,336	593,832	153,194
ELG-P Based + NPDES 4 A	369,190	41,163	126,661	28,071	621,773	175,139

Scenario	Hydroregion 16		Hydroregion 17		Hydroregion 18	
	Nitrogen	**Phosphorus**	**Nitrogen**	**Phosphorus**	**Nitrogen**	**Phosphorus**
Baseline	532,995	174,578	11,118,327	11,782,332	7,757,447	10,737,122
ELG-N Based + NPDES 1	500,227	118,973	9,008,160	6,767,608	4,868,752	4,790,466
ELG-N Based + NPDES 2/3	488,565	104,962	8,147,699	5,155,429	4,159,538	3,752,066
ELG-N Based + NPDES 4	480,993	96,235	7,568,849	4,094,123	3,685,571	3,059,772
ELG-N Based + NPDES 4 A	494,498	113,153	8,492,023	5,866,172	4,403,319	4,096,306
ELG-P Based + NPDES 1	364,814	94,747	6,704,131	5,476,190	3,612,946	3,667,250
ELG-P Based + NPDES 2/3	338,660	74,349	5,476,176	3,433,394	2,663,300	2,362,690
ELG-P Based + NPDES 4	321,310	61,471	4,667,033	2,087,559	2,034,965	1,491,069
ELG-P Based + NPDES 4 A	351,517	86,245	5,902,462	4,310,429	2,941,762	2,782,534

AFO/CAFO PATHOGENS/SEDIMENT LOADINGS TO RF1 REACHES BY HYDROREGION FOR AFO/CAFO RULEMAKING SCENARIOS (JUNE 2000 DATASETS) (1)

	Hydroregion 1			Hydroregion 2		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	939,095,754	1,507,254,235	19,501,885	5,166,081,075	8,863,150,696	152,027,718
ELG-N Based + NPDES 1	469,326,926	1,497,435,254	19,625,437	2,884,739,441	8,729,786,418	152,681,723
ELG-N Based + NPDES 2/3	397,187,390	1,494,715,649	19,651,398	2,404,178,403	8,650,497,068	152,864,148
ELG-N Based + NPDES 4	251,579,784	1,491,989,183	19,697,065	1,473,909,348	8,620,891,064	153,141,254
ELG-N Based + NPDES 4 A	537326838	1,494,254,089	19,609,826	3,132,493,858	8,654,799,787	152,640,897
ELG-P Based + NPDES 1	411,598,457	1,149,716,245	16,500,844	2,576,131,879	6,895,667,894	125,288,133
ELG-P Based + NPDES 2/3	328,851,909	1,085,010,743	14,877,797	2,024,425,242	6,415,371,521	112,481,534
ELG-P Based + NPDES 4	161,196,363	955,160,509	13,756,191	941,155,635	5,554,306,660	106,633,268
ELG-P Based + NPDES 4 A	489812937	1,208,424,370	15,551,628	2,849,420,939	7,059,896,326	116,886,507

	Hydroregion 3			Hydroregion 4		
Scenario	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	2,305,182,710	6,130,507,986	2,752,669,339	4,031,409,465	8,957,603,063	11,535,553,692
ELG-N Based + NPDES 1	1,214,765,879	3,729,291,958	2,695,745,746	1,751,290,890	5,671,448,816	11,545,841,587
ELG-N Based + NPDES 2/3	618,988,572	2,328,173,351	2,668,647,926	1,454,493,228	5,351,412,207	11,548,511,186
ELG-N Based + NPDES 4	507,243,264	2,187,457,888	2,667,027,748	1,059,298,570	5,095,795,125	11,549,864,735
ELG-N Based + NPDES 4 A	826,729,164	2,652,587,971	2,672,714,087	1,658,903,336	5,142,448,451	11,549,231,847
ELG-P Based + NPDES 1	1,174,992,197	3,432,259,028	2,309,084,779	1,616,466,221	4,818,712,002	9,104,711,135
ELG-P Based + NPDES 2/3	571,024,225	1,979,858,701	2,085,991,605	1,282,287,718	4,320,043,515	8,298,606,726
ELG-P Based + NPDES 4	448,140,541	1,776,893,608	2,063,407,682	834,000,904	3,756,051,676	7,885,831,170
ELG-P Based + NPDES 4 A	791,411,998	2,383,526,142	2,125,821,846	1,526,559,037	4,349,887,428	8,200,310,541

(continued)

Scenario	Hydroregion 5			Hydroregion 6		
	Fecal Coliforms	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	6,138,582,042	15,722,380,213	30,073,770,455	829,417,477	1,605,581,428	521,367,462
ELG-N Based + NPDES 1	2,360,976,052	7,782,122,822	30,105,480,949	438,299,983	1,255,845,266	511,202,880
ELG-N Based + NPDES 2/3	1,949,035,456	7,073,860,717	30,111,463,496	278,160,402	964,281,744	505,401,497
ELG-N Based + NPDES 4	1,556,438,944	6,582,025,656	30,114,906,792	200,571,940	947,065,422	505,146,447
ELG-N Based + NPDES 4 A	1,953,401,548	6,688,524,505	30,113,190,086	358,176,763	106,157,284	506,913,318
ELG-P Based + NPDES 1	2,269,595,225	7,047,553,472	23,409,157,508	406,232,514	1,064,718,880	444,520,360
ELG-P Based + NPDES 2/3	1,817,932,237	6,189,538,219	21,797,591,733	240,112,192	738,629,290	396,473,613
ELG-P Based + NPDES 4	1,374,407,042	5,423,350,326	20,922,349,478	150,812,265	658,684,342	392,997,339
ELG-P Based + NPDES 4 A	1,838,049,019	5,916,663,171	21,432,198,504	325,014,557	870,062,507	411,360,657
Scenario	**Hydroregion 7**			**Hydroregion 8**		
	Fecal Coliforms	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	6,457,542,052	22,108,886,435	31,779,448,006	1,398,635,678	4,896,676,034	3,826,353,016
ELG-N Based + NPDES 1	2,664,208,487	13,291,864,538	31,808,492,046	696,138,721	2,694,193,372	3,806,476,810
ELG-N Based + NPDES 2/3	2,034,688,798	11,974,936,005	31,816,900,203	343,536,628	1,527,598,443	3,796,554,230
ELG-N Based + NPDES 4	1,792,216,045	11,547,823,421	31,819,583,007	298,850,013	1,431,470,038	3,796,082,008
ELG-N Based + NPDES 4 A	2,155,317,888	12,114,347,861	31,815,955,154	447,797,837	1,806,896,525	3,798,313,359
ELG-P Based + NPDES 1	2,556,272,481	11,771,855,573	24,950,332,273	676,438,652	2,539,700,540	2,811,413,221
ELG-P Based + NPDES 2/3	1,877,877,679	10,246,467,096	22,650,836,859	317,781,931	1,339,161,092	2,549,105,803
ELG-P Based + NPDES 4	1,600,837,745	9,413,633,734	21,767,978,699	268,844,088	1,214,564,505	2,512,125,127
ELG-P Based + NPDES 4 A	2,011,134,046	10,354,358,745	22,950,031,330	425,877,591	1,643,526,782	2,615,960,125

(continued)

Scenario	Hydroregion 9 Fecal Coliforms	Hydroregion 9 Fecal Streptococci	Hydroregion 9 Sediment	Hydroregion 10 Fecal Coliforms	Hydroregion 10 Fecal Streptococci	Hydroregion 10 Sediment
Baseline	331,833,510	978,655,147	1,076,672,643	6,259,893,628	16,642,398,718	19,970,456,598
ELG-N Based + NPDES 1	110,140,648	389,677,763	1,077,781,200	3,034,800,400	10,696,693,302	19,987,244,899
ELG-N Based + NPDES 2/3	95,169,714	356,167,537	1,077,972,803	2,645,806,734	10,180,546,558	19,992,524,527
ELG-N Based + NPDES 4	83,116,589	326,850,503	1,078,080,005	2,395,513,651	9,869,400,077	19,994,742,076
ELG-N Based + NPDES 4 A	86,868,758	327,045,792	1,077,986,956	2,685,625,500	10,046,865,446	19,991,575,738
ELG-P Based + NPDES 1	107,694,115	367,507,666	822,786,767	2,714,393,568	9,230,664,075	15,525,599,793
ELG-P Based + NPDES 2/3	91,061,911	328,332,576	770,769,084	2,276,002,313	8,476,593,937	13,991,585,038
ELG-P Based + NPDES 4	77,857,914	291,845,537	742,811,152	1,984,782,388	7,829,016,789	13,310,267,229
ELG-P Based + NPDES 4 A	82,776,021	298,726,116	773,925,717	2,330,046,757	8,374,893,664	14,309,100,594

Scenario	Hydroregion 11 Fecal Coliforms	Hydroregion 11 Fecal Streptococci	Hydroregion 11 Sediment	Hydroregion 12 Fecal Coliforms	Hydroregion 12 Fecal Streptococci	Hydroregion 12 Sediment
Baseline	4,207,916,139	9,458,078,496	16,103,642,886	1,547,519,876	3,553,359,285	68,537,109
ELG-N Based + NPDES 1	2,233,344,129	5,332,364,068	16,101,891,589	776,323,327	3,274,864,668	68,652,242
ELG-N Based + NPDES 2/3	1,381,214,925	3,518,551,755	16,098,272,055	647,219,812	3,259,025,209	68,624,445
ELG-N Based + NPDES 4	1,288,201,577	3,412,555,966	16,098,499,163	571,233,115	3,256,128,976	68,654,009
ELG-N Based + NPDES 4 A	1,730,369,829	4,238,014,607	16,098,948,563	704,668,593	3,263,629,438	68,639,275
ELG-P Based + NPDES 1	2,093,549,064	4,969,892,656	11,958,083,884	657,117,683	2,506,743,973	54,168,771
ELG-P Based + NPDES 2/3	1,207,229,174	3,030,466,618	10,556,787,537	507,271,347	2,340,341,342	49,617,804
ELG-P Based + NPDES 4	1,102,697,279	2,860,012,614	10,378,927,839	418,415,127	2,245,202,879	48,390,032
ELG-P Based + NPDES 4 A	1,570,765,935	3,804,058,053	11,091,732,349	573,730,981	2,413,397,418	50,800,773

(continued)

Scenario	Hydroregion 13 Fecal Coliforms	Hydroregion 13 Fecal Streptococci	Hydroregion 13 Sediment	Hydroregion 14 Fecal Coliforms	Hydroregion 14 Fecal Streptococci	Hydroregion 14 Sediment
Baseline	1,160,042,311	2,115,421,333	10,609,466	122,768,541	197,984,089	4,579,210
ELG-N Based + NPDES 1	409,170,715	2,068,356,586	10,711,729	83,120,969	177,096,419	4,596,718
ELG-N Based + NPDES 2/3	372,034,124	2,068,182,819	10,719,765	65,797,133	177,002,011	4,603,234
ELG-N Based + NPDES 4	349,342,113	2,067,730,398	10,724,660	55,143,735	176,756,212	4,607,206
ELG-N Based + NPDES 4 A	378,045,066	2,068,067,204	10,718,225	82,451,379	176,961,295	4,597,413
ELG-P Based + NPDES 1	310,570,161	1,444,236,769	7,644,770	74,765,597	152,463,274	3,716,763
ELG-P Based + NPDES 2/3	267,320,650	1,401,435,078	7,426,851	54,584,366	135,348,515	3,539,848
ELG-P Based + NPDES 4	240,806,111	1,375,073,535	7,298,370	42,121,194	124,706,247	3,437,336
ELG-P Based + NPDES 4 A	274,286,823	1,407,704,741	7,468,190	73,946,527	151,762,658	3,674,618

Scenario	Hydroregion 15 Fecal Coliforms	Hydroregion 15 Fecal Streptococci	Hydroregion 15 Sediment	Hydroregion 16 Fecal Coliforms	Hydroregion 16 Fecal Streptococci	Hydroregion 16 Sediment
Baseline	978,019,458	1,985,529,433	9,867,691	591,748,346	1,044,307,546	14,384,678
ELG-N Based + NPDES 1	352,127,857	1,915,337,577	9,942,078	351,200,202	996,654,649	14,447,519
ELG-N Based + NPDES 2/3	326,453,439	1,915,007,201	9,944,814	267,528,988	996,482,734	14,477,376
ELG-N Based + NPDES 4	310,572,808	1,914,284,513	9,946,356	217,243,978	996,035,892	14,495,051
ELG-N Based + NPDES 4 A	331,024,845	1,914,743,952	9,945,133	327,885,737	996,550,105	14,454,318
ELG-P Based + NPDES 1	256,259,161	1,322,823,347	7,140,345	313,192,981	819,052,942	11,786,407
ELG-P Based + NPDES 2/3	226,188,000	1,287,871,809	7,054,001	215,801,777	734,529,490	11,014,910
ELG-P Based + NPDES 4	207,298,410	1,265,426,956	6,983,561	157,176,434	683,496,284	10,529,027
ELG-P Based + NPDES 4 A	231,289,112	1,294,646,894	7,026,871	286,039,104	794,907,876	11,588,229

(continued)

Scenario	Hydroregion 17			Hydroregion 18		
	Fecal Coliforms	**Fecal Streptococci**	**Sediment**	**Fecal Coliforms**	**Fecal Streptococci**	**Sediment**
Baseline	6,491,176,240	10,488,691,938	113,531,375	517,802,214	693,876,362	19,987,971
ELG-N Based + NPDES 1	3,403,690,631	9,489,962,001	113,942,129	290,768,379	526,238,151	19,988,066
ELG-N Based + NPDES 2/3	2,930,283,373	9,481,671,121	114,048,426	276,211,234	524,017,527	19,988,066
ELG-N Based + NPDES 4	2,634,800,281	9,463,761,953	114,112,116	263,997,212	519,445,606	19,988,066
ELG-N Based + NPDES 4 A	3,171,701,083	9,478,229,309	113,994,791	283,323,268	523,908,062	19,988,066
ELG-P Based + NPDES 1	2,533,635,440	6,973,778,826	88,584,053	166,469,640	308,749,288	15,668,116
ELG-P Based + NPDES 2/3	1,975,469,948	6,465,013,809	85,332,330	147,319,733	288,282,942	15,327,980
ELG-P Based + NPDES 4	1,616,408,402	6,130,625,294	83,076,340	128,907,894	267,088,173	15,020,257
ELG-P Based + NPDES 4 A	2,253,760,659	6,713,067,203	86,818,350	155,578,779	296,847,495	15,468,738

(1) AFO/CAFO loadings to RF1 reaches (sediment in kilograms/year, fecal coliforms and fecal streptococci in colonies per year)

Appendix I

LocalWTP_ELG-N_NPDES-Alt1

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	18,016	-14,818	0
Arizona	0	52,421	29,114
Arkansas	11,864	45,704	10,083
California	461,727	747,927	575,176
Colorado	10,303	7,638	8,456
Connecticut	0	0	121,061
Delaware	232,793	116,730	64,733
Florida	0	310,039	209,913
Georgia	88,965	69,064	48,876
Idaho	0	0	0
Illinois	0	0	0
Indiana	-44,078	0	0
Iowa	-43,924	0	0
Kansas	9,655	7,084	16,029
Kentucky	0	0	0
Louisiana	0	39,113	63,693
Maine	0	0	0
Maryland	0	0	0
Massachusetts	0	163,685	174,077
Michigan	109,632	205,789	183,437
Minnesota	33,787	-13,186	28,207
Mississippi	0	10,910	11,648
Missouri	0	-14,338	0
Montana	1,174	937	1,020
Nebraska	6,344	9,712	5,466
Nevada	0	0	0
New Hampshire	72,666	0	0
New Jersey	0	0	0
New Mexico	6,811	20,341	28,366
New York	0	0	0
North Carolina	180,075	107,721	0
North Dakota	-3,168	0	0
Ohio	-126,443	140,549	0
Oklahoma	54,986	60,661	0
Oregon	0	5,105	6,117
Pennsylvania	151,409	56,820	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Rhode Island	0	0	0
South Carolina	41,756	-27,081	-44,330
South Dakota	2,322	7,236	0
Tennessee	0	0	0
Texas	233,714	292,221	218,804
Utah	10,379	6,595	0
Vermont	0	18,690	0
Virginia	0	0	0
Washington	0	13,708	46,829
West Virginia	0	0	0
Wisconsin	51,107	76,677	42,896
Wyoming	0	886	0
District of Columbia	0	0	0
	1,571,871	2,524,541	1,849,672

LocalWTP_ELG-N_NPDES-Alt23

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	54,438	39,937	30,831
Arizona	0	52,421	29,114
Arkansas	11,864	73,414	20,098
California	752,130	979,104	639,566
Colorado	10,303	7,638	8,456
Connecticut	0	-227,669	121,061
Delaware	232,793	116,730	117,576
Florida	0	310,039	209,913
Georgia	181,993	138,131	177,597
Idaho	0	0	0
Illinois	0	0	0
Indiana	-44,078	0	0
Iowa	-66,342	0	0
Kansas	9,655	7,084	24,043
Kentucky	0	0	16,260
Louisiana	0	58,497	84,662
Maine	33,771	0	0
Maryland	0	0	0
Massachusetts	0	163,685	174,077
Michigan	325,990	246,108	228,696
Minnesota	16,558	-13,186	41,629
Mississippi	0	10,910	35,316
Missouri	-18,995	-14,338	0
Montana	1,174	937	1,020
Nebraska	6,344	9,712	5,466
Nevada	0	0	0
New Hampshire	129,054	27,116	59,490
New Jersey	0	0	0
New Mexico	6,811	20,341	28,366
New York	0	0	0
North Carolina	180,075	107,721	91,411
North Dakota	-3,168	0	0
Ohio	312,668	140,549	0
Oklahoma	54,986	60,661	0
Oregon	0	10,457	14,272
Pennsylvania	151,409	56,820	0
Rhode Island	0	0	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	95,382	-28,043	-44,330
South Dakota	2,322	7,236	0
Tennessee	0	0	0
Texas	233,714	331,622	218,804
Utah	19,887	13,737	0
Vermont	0	27,234	1,909
Virginia	0	0	0
Washington	0	13,708	62,576
West Virginia	0	0	0
Wisconsin	25,950	76,677	42,896
Wyoming	0	886	0
District of Columbia	0	0	0
	2,716,687	2,825,879	2,440,775

LocalWTP_ELG-N_NPDES-Alt4

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	72,844	53,976	30,831
Arizona	0	52,421	29,114
Arkansas	11,864	73,414	20,098
California	752,130	1,094,693	768,071
Colorado	10,303	7,638	8,456
Connecticut	0	0	121,061
Delaware	232,793	116,730	117,576
Florida	0	310,039	209,913
Georgia	181,993	138,131	203,575
Idaho	0	0	0
Illinois	0	0	0
Indiana	-44,078	0	0
Iowa	-66,342	0	0
Kansas	9,655	7,084	24,043
Kentucky	0	0	16,260
Louisiana	0	58,497	84,662
Maine	50,504	0	0
Maryland	0	0	0
Massachusetts	0	163,685	174,077
Michigan	325,990	287,585	228,696
Minnesota	16,558	-13,186	41,629
Mississippi	0	10,910	35,316
Missouri	-18,995	-14,338	0
Montana	1,174	937	1,020
Nebraska	6,344	9,712	5,466
Nevada	0	0	0
New Hampshire	129,054	27,116	59,490
New Jersey	234,625	0	0
New Mexico	6,811	20,341	28,366
New York	175,749	66,840	0
North Carolina	180,075	107,721	91,411
North Dakota	-3,168	0	0
Ohio	312,668	140,549	0
Oklahoma	54,986	70,862	0
Oregon	0	15,637	19,960
Pennsylvania	428,096	56,820	0
Rhode Island	0	0	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	122,011	-8,044	-44,330
South Dakota	2,322	7,236	0
Tennessee	0	0	0
Texas	259,713	331,622	218,804
Utah	206	-8,466	0
Vermont	0	27,234	20,129
Virginia	66,865	0	0
Washington	0	13,708	62,576
West Virginia	0	0	0
Wisconsin	50,356	114,746	42,896
Wyoming	0	886	0
District of Columbia	0	0	0
	3,563,105	3,342,739	2,619,167

LocalWTP_ELG-P_NPDES-Alt1

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	438,613	650,873	104,395
Arizona	17,399	167,917	276,289
Arkansas	2,615,444	3,757,615	214,033
California	461,727	1,094,693	1,089,005
Colorado	59,444	45,205	34,195
Connecticut	0	-227,669	121,061
Delaware	232,793	116,730	117,576
Florida	0	1,431,172	1,631,364
Georgia	970,853	760,567	738,921
Idaho	6,808	3,534	30,715
Illinois	13,909,874	11,926,714	2,255,316
Indiana	14,967,613	4,734,990	622,333
Iowa	5,763,962	2,859,810	948,552
Kansas	1,710,481	968,489	151,111
Kentucky	78,183	0	16,260
Louisiana	0	2,003,343	297,575
Maine	0	0	0
Maryland	0	77,573	0
Massachusetts	0	163,685	174,077
Michigan	4,903,985	6,288,398	510,803
Minnesota	7,486,158	2,704,806	857,193
Mississippi	0	1,859,980	203,048
Missouri	3,593,083	3,397,319	47,182
Montana	2,347	3,760	4,182
Nebraska	1,060,792	258,455	139,931
Nevada	8,975	6,591	81,089
New Hampshire	129,054	27,116	60,692
New Jersey	0	0	0
New Mexico	94,450	60,808	107,553
New York	0	130,848	0
North Carolina	180,075	162,431	765,027
North Dakota	94,743	40,334	37,165
Ohio	7,538,192	6,629,502	739,467
Oklahoma	1,124,695	605,044	126,667
Oregon	0	20,812	67,939
Pennsylvania	151,409	170,705	0
Rhode Island	0	0	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	293,774	397,617	292,979
South Dakota	63,809	34,752	28,763
Tennessee	0	0	0
Texas	1,777,884	1,688,453	1,379,292
Utah	19,887	41,210	0
Vermont	0	18,690	-8,503
Virginia	0	0	0
Washington	18,061	40,919	78,323
West Virginia	0	8,818	136,999
Wisconsin	5,294,590	3,613,659	444,564
Wyoming	0	4,397	982
District of Columbia	0	0	0
	75,069,157	58,750,666	14,924,114

LocalWTP_ELG-P_NPDES-Alt23

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	587,482	718,971	440,414
Arizona	17,399	180,451	276,289
Arkansas	2,688,757	5,163,589	480,788
California	829,085	1,094,693	1,603,293
Colorado	59,444	52,842	42,097
Connecticut	0	-227,669	246,076
Delaware	232,793	116,730	244,880
Florida	0	1,635,789	2,458,426
Georgia	1,484,672	1,169,869	1,587,423
Idaho	6,808	6,033	41,357
Illinois	15,077,031	17,919,654	2,924,198
Indiana	18,296,395	6,702,428	622,333
Iowa	8,269,532	4,219,066	1,042,344
Kansas	1,870,934	1,131,498	182,660
Kentucky	361,274	0	16,260
Louisiana	0	2,061,313	531,690
Maine	50,504	0	0
Maryland	102,301	77,573	0
Massachusetts	0	163,685	174,077
Michigan	8,469,671	9,367,463	964,023
Minnesota	9,269,626	4,978,052	1,145,984
Mississippi	57,014	1,922,280	346,211
Missouri	4,160,548	4,243,929	63,233
Montana	2,347	3,760	4,182
Nebraska	1,280,114	387,165	161,423
Nevada	8,975	6,591	81,089
New Hampshire	129,054	27,116	120,182
New Jersey	234,625	0	0
New Mexico	94,450	60,808	107,553
New York	88,862	130,848	0
North Carolina	180,075	162,431	978,634
North Dakota	104,248	40,334	42,316
Ohio	10,117,034	10,261,244	1,374,109
Oklahoma	1,218,934	614,975	149,114
Oregon	0	31,449	76,095
Pennsylvania	151,409	282,849	0
Rhode Island	0	0	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	606,367	705,912	716,047
South Dakota	82,680	53,415	41,339
Tennessee	0	0	0
Texas	1,777,884	1,747,417	1,466,600
Utah	10,379	48,424	24,654
Vermont	0	27,234	11,626
Virginia	66,865	0	28,266
Washington	18,061	40,919	94,070
West Virginia	0	8,818	293,569
Wisconsin	6,831,440	7,058,431	1,074,686
Wyoming	0	4,397	982
District of Columbia	0	0	0
	94,895,076	84,402,779	22,280,588

LocalWTP_ELG-P_NPDES-Alt4

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	605,498	732,178	440,414
Arizona	17,399	180,451	290,934
Arkansas	2,712,892	5,228,108	542,133
California	829,085	1,151,133	1,923,400
Colorado	69,554	52,842	42,097
Connecticut	0	-227,669	246,076
Delaware	232,793	116,730	244,880
Florida	0	1,635,789	2,935,574
Georgia	1,484,672	1,216,321	1,715,997
Idaho	6,808	6,033	44,191
Illinois	15,927,308	19,751,635	3,125,850
Indiana	19,810,957	7,581,615	622,333
Iowa	9,349,206	5,101,188	1,361,812
Kansas	1,919,126	1,200,689	214,718
Kentucky	493,077	0	16,260
Louisiana	0	3,386,494	573,885
Maine	50,504	6,497	0
Maryland	102,301	77,573	0
Massachusetts	0	163,685	352,969
Michigan	10,391,343	10,693,685	1,884,693
Minnesota	10,108,195	5,899,591	1,753,958
Mississippi	57,014	1,932,416	346,211
Missouri	4,365,396	4,631,737	79,283
Montana	2,347	3,760	4,182
Nebraska	1,433,965	467,279	257,308
Nevada	8,975	6,591	81,089
New Hampshire	198,925	27,116	120,182
New Jersey	698,662	0	0
New Mexico	94,450	60,808	107,553
New York	175,749	130,848	0
North Carolina	216,878	162,431	1,070,588
North Dakota	107,416	40,334	55,212
Ohio	11,190,538	12,570,173	1,954,831
Oklahoma	1,218,934	614,975	160,566
Oregon	0	31,449	87,026
Pennsylvania	351,622	225,417	-63,988
Rhode Island	0	0	0

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	658,673	726,494	761,244
South Dakota	94,860	64,463	51,495
Tennessee	24,955	0	0
Texas	1,777,884	1,747,417	1,466,600
Utah	29,831	63,033	32,870
Vermont	12,132	36,345	21,777
Virginia	66,865	0	83,617
Washington	18,061	40,919	94,070
West Virginia	0	8,818	332,712
Wisconsin	7,342,004	7,849,171	1,352,919
Wyoming	0	4,397	982
District of Columbia	0	0	0
	104,256,854	95,400,962	26,790,503

Local WTP ELG N NPDES Alt4A

StName	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	54437.54	26238.77	15757.05
Arizona	0	52421.25	29114.08
Arkansas	11863.95	73414.23	10083.15
California	461726.6	979104.3	575175.9
Colorado	10302.9	7637.849	8455.717
Connecticut	0	-227669	0
Delaware	232792.7	116730.4	64732.85
Florida	0	310039.4	209913
Georgia	181992.6	115513	151529.6
Idaho	0	0	0
Illinois	0	0	0
Indiana	-44078.3	0	0
Iowa	-66342.1	0	0
Kansas	9654.768	7084.414	24043.17
Kentucky	0	0	16260.07
Louisiana	0	58496.62	84661.77
Maine	50503.77	0	0
Maryland	0	0	0
Massachusetts	0	163684.8	0
Michigan	325990	288145.5	184112.9
Minnesota	33787.01	-13186	41628.91
Mississippi	0	10910.2	35315.63
Missouri	-18995.4	-14337.9	0
Montana	1173.678	936.5474	1020.419
Nebraska	6344.409	9712.414	5465.9
Nevada	0	0	0
New Hampshire	72666.25	27116.19	59489.5
New Jersey	0	0	0
New Mexico	6811.448	20340.63	28365.93
New York	0	66839.88	0
North Carolina	180075.3	107720.7	91410.74
North Dakota	-3168.22	0	0
Ohio	312668.3	140549.5	0
Oklahoma	54986.18	70862.11	0
Oregon	0	0	6116.515
Pennsylvania	351622.5	-613.291	-63987.7
Rhode Island	0	0	0
South Carolina	95382.22	-47913.1	-44329.8
South Dakota	2321.879	5470.495	0
Tennessee	0	0	0
Texas	233123	291863.9	196555.2
Utah	19887.31	6315.308	0
Vermont	0	27233.87	1908.776
Virginia	66865.17	0	0
Washington	0	13708.49	62576.22
West Virginia	0	0	0

StName	WTP_Boat	WTP_Fish	WTP_Swim
Wisconsin	50105.87	95006.62	42896.42
Wyoming	0	886.2872	0
District of Columbia	0	0	0
	2,694,501	2,790,265	1,838,272

Local WTP ELG P NPDES Alt4A

StName	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	531705.1	651113.5	380928.4
Arizona	17399.34	180451.2	276289.1
Arkansas	2688757	4468592	469863.6
California	538681.1	1094693	1408998
Colorado	59563.65	60524.91	34194.95
Connecticut	0	-227669	125014.5
Delaware	232792.7	116730.4	179426.5
Florida	0	1635789	2106030
Georgia	1484672	1153225	1589163
Idaho	6808.266	3534.315	38543.95
Illinois	15319125	17567259	2866735
Indiana	18821430	7178120	622333.3
Iowa	8262397	4109474	1109876
Kansas	1823352	1151563	191223
Kentucky	493077.1	0	16260.07
Louisiana	0	2061313	424152.4
Maine	50503.77	6497.434	0
Maryland	0	77572.79	0
Massachusetts	0	163684.8	0
Michigan	8842961	9055540	1884693
Minnesota	9161874	4356168	1189067
Mississippi	28729.8	1891872	321907.8
Missouri	4252648	3852962	47181.95
Montana	2347.357	3759.962	4181.629
Nebraska	1344085	372707.5	192667.9
Nevada	8975.165	6590.743	81089
New Hampshire	72666.25	27116.19	59489.5
New Jersey	698662.1	0	0
New Mexico	94449.93	60808.42	107552.5
New York	0	130847.6	0
North Carolina	180075.3	162430.9	856757.4
North Dakota	97926.99	42725.67	42422.78
Ohio	10310799	10305468	1582084
Oklahoma	1192487	614974.9	138119.6
Oregon	0	31449.21	67939.26
Pennsylvania	428095.5	228426.3	0
Rhode Island	0	0	0
South Carolina	578880.3	691913.3	425556.8
South Dakota	87374.78	49441.84	36792.9
Tennessee	0	0	0
Texas	1704622	1672466	1401706
Utah	29830.97	56098.67	8249.89
Vermont	0	27233.87	11626.17
Virginia	66865.17	0	55388.02
Washington	18061.02	40919.33	94070.44
West Virginia	0	8817.987	264212.2

StName	WTP_Boat	WTP_Fish	WTP_Swim
Wisconsin	6562508	5716242	1352919
Wyoming	0	4396.859	981.9632
District of Columbia	0	0	0
	96,095,189	80,863,846	22,065,689

Appendix J

NationalWTP_ELG-N_NPDES-Alt1

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	-592	5,787	4,773
Arizona	-3,295	4,339	5,206
Arkansas	320	2,306	2,767
California	-23,370	30,537	36,710
Colorado	-1,704	4,620	4,508
Connecticut	-3,088	2,269	2,778
Delaware	-712	668	802
Florida	-6,374	16,517	13,448
Georgia	-7,456	8,635	6,804
Idaho	-878	1,156	1,388
Illinois	-4,953	10,952	13,141
Indiana	-4,042	5,333	6,399
Iowa	-1,355	3,227	3,143
Kansas	-358	2,418	2,899
Kentucky	-2,736	3,603	4,323
Louisiana	-4,218	3,016	4,725
Maine	-853	1,124	1,348
Maryland	-3,506	4,617	5,540
Massachusetts	-5,822	2,987	5,237
Michigan	-12,130	852	6,177
Minnesota	-4,608	6,254	5,201
Mississippi	-1,897	2,498	2,997
Missouri	-3,791	4,993	5,991
Montana	-910	670	821
Nebraska	-686	1,528	1,834
Nevada	-1,243	1,637	1,964
New Hampshire	-1,140	1,068	1,281
New Jersey	-5,532	7,286	8,742
New Mexico	-223	1,585	1,902
New York	-12,515	16,482	19,777
North Carolina	-7,367	6,946	8,334
North Dakota	-439	578	693
Ohio	-7,468	10,189	12,225
Oklahoma	-4,201	1,663	3,682
Oregon	-1,482	3,142	3,770
Pennsylvania	-8,180	10,771	12,923
Rhode Island	-667	879	1,054

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Carolina	-2,946	4,814	5,085
South Dakota	-303	687	819
Tennessee	-3,772	4,967	5,960
Texas	8,499	15,145	22,929
Utah	-2,065	1,928	2,313
Vermont	-402	406	635
Virginia	-4,714	6,208	7,449
Washington	-2,445	6,453	6,334
West Virginia	-1,241	1,635	1,962
Wisconsin	-6,491	2,586	5,703
Wyoming	-341	449	539
District of Columbia	-347	457	548
	-166,040	238,868	285,585

NationalWTP_ELG-N_NPDES-Alt23

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	13,682	9,449	11,281
Arizona	12,274	7,363	12,304
Arkansas	7,899	3,392	6,538
California	77,447	51,858	86,753
Colorado	11,777	7,239	10,654
Connecticut	5,573	3,621	7,557
Delaware	1,686	1,134	1,895
Florida	46,436	29,076	35,639
Georgia	9,379	8,740	13,020
Idaho	3,271	1,962	3,279
Illinois	34,341	18,584	31,055
Indiana	15,093	9,050	15,123
Iowa	8,044	5,052	7,428
Kansas	8,310	4,101	6,850
Kentucky	9,081	5,280	9,287
Louisiana	11,137	6,681	11,167
Maine	2,521	1,907	3,187
Maryland	13,059	7,834	13,091
Massachusetts	13,940	6,826	14,247
Michigan	19,846	7,049	20,722
Minnesota	10,942	9,274	11,272
Mississippi	7,065	4,238	7,083
Missouri	14,123	8,473	14,158
Montana	2,183	1,271	2,230
Nebraska	4,796	2,593	4,333
Nevada	4,631	2,778	4,642
New Hampshire	2,109	1,566	2,758
New Jersey	20,609	12,364	20,660
New Mexico	5,465	2,690	4,495
New York	46,620	27,968	46,736
North Carolina	17,553	11,786	17,924
North Dakota	1,634	980	1,638
Ohio	25,975	17,289	28,890
Oklahoma	6,809	3,802	8,701
Oregon	9,790	5,331	8,581
Pennsylvania	30,463	18,276	30,541
Rhode Island	2,485	1,491	2,492
South Carolina	9,583	8,840	10,814

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Dakota	2,144	1,163	1,934
Tennessee	14,049	8,429	14,084
Texas	65,475	19,762	54,185
Utah	4,852	3,272	5,467
Vermont	1,642	770	1,489
Virginia	17,561	10,535	17,604
Washington	16,495	10,132	14,968
West Virginia	4,624	2,774	4,635
Wisconsin	12,034	7,003	13,478
Wyoming	1,271	763	1,274
District of Columbia	1,293	776	1,296
	689,071	402,586	679,442

NationalWTP_ELG-N_NPDES-Alt4

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	15,740	11,107	12,189
Arizona	14,518	9,173	13,294
Arkansas	9,092	4,353	7,065
California	112,251	64,616	93,737
Colorado	13,721	8,806	11,512
Connecticut	8,906	5,523	8,224
Delaware	2,032	1,413	2,048
Florida	53,454	34,733	38,736
Georgia	13,050	11,700	14,640
Idaho	3,869	2,445	3,543
Illinois	40,007	23,151	33,555
Indiana	17,852	11,274	16,341
Iowa	9,399	6,144	8,026
Kansas	10,228	5,109	7,402
Kentucky	10,944	6,782	10,109
Louisiana	13,174	8,323	12,066
Maine	2,776	2,376	3,443
Maryland	15,447	9,759	14,145
Massachusetts	16,790	9,123	15,504
Michigan	24,446	8,722	22,752
Minnesota	13,184	11,082	12,262
Mississippi	8,357	5,280	7,653
Missouri	16,706	10,555	15,298
Montana	2,629	1,630	2,427
Nebraska	5,587	3,230	4,682
Nevada	5,478	3,461	5,016
New Hampshire	2,661	2,011	3,002
New Jersey	22,106	15,402	22,323
New Mexico	6,285	3,351	4,857
New York	45,168	34,841	50,498
North Carolina	21,146	14,683	19,510
North Dakota	1,932	1,221	1,770
Ohio	31,246	21,538	31,216
Oklahoma	8,396	5,081	9,401
Oregon	11,415	6,641	9,298
Pennsylvania	33,012	22,768	32,999
Rhode Island	2,940	1,858	2,692
South Carolina	11,395	10,301	11,613

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Dakota	2,497	1,447	2,090
Tennessee	16,619	10,500	15,218
Texas	75,361	27,730	58,547
Utah	5,850	4,075	5,907
Vermont	1,772	882	1,489
Virginia	18,914	13,124	19,022
Washington	19,225	12,333	16,173
West Virginia	5,470	3,456	5,009
Wisconsin	14,598	7,951	14,563
Wyoming	1,504	950	1,377
District of Columbia	1,529	966	1,400
	820,678	502,979	735,642

NationalWTP_ELG-P_NPDES-Alt1

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	352,826	197,002	28,798
Arizona	398,041	221,727	31,411
Arkansas	201,085	107,260	16,691
California	2,778,336	1,556,250	221,469
Colorado	344,703	193,742	27,199
Connecticut	260,834	147,286	20,422
Delaware	60,079	33,999	4,838
Florida	1,232,147	693,345	95,380
Georgia	623,944	345,872	35,486
Idaho	105,515	59,890	8,371
Illinois	916,288	485,767	76,993
Indiana	411,468	258,245	37,226
Iowa	191,648	114,393	18,416
Kansas	206,999	112,076	17,488
Kentucky	321,612	182,430	25,151
Louisiana	357,648	197,583	28,507
Maine	101,362	57,167	8,135
Maryland	416,411	234,848	33,420
Massachusetts	495,162	277,666	38,500
Michigan	732,611	406,081	59,876
Minnesota	315,675	199,769	28,341
Mississippi	225,988	123,053	18,081
Missouri	423,604	223,295	36,144
Montana	77,209	43,252	6,026
Nebraska	133,406	77,611	11,062
Nevada	147,163	83,280	11,851
New Hampshire	95,382	54,062	7,453
New Jersey	657,173	370,634	52,743
New Mexico	146,421	81,749	11,476
New York	1,486,684	834,843	119,311
North Carolina	624,526	351,851	43,309
North Dakota	52,093	29,108	4,181
Ohio	888,831	486,039	73,754
Oklahoma	255,618	149,272	22,213
Oregon	287,095	161,933	22,497
Pennsylvania	971,454	547,884	77,966
Rhode Island	79,256	44,699	6,361
South Carolina	304,660	172,771	24,514

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Dakota	61,324	34,552	4,938
Tennessee	448,301	254,964	35,956
Texas	1,747,756	954,441	133,490
Utah	174,973	98,073	13,956
Vermont	47,753	26,806	3,954
Virginia	559,974	315,816	44,942
Washington	479,243	269,699	38,212
West Virginia	147,449	83,158	11,834
Wisconsin	380,082	210,835	30,795
Wyoming	40,669	22,858	3,253
District of Columbia	41,224	23,250	3,309
	21,809,705	12,212,185	1,735,699

NationalWTP_ELG-P_NPDES-Alt23

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	457,826	295,387	39,348
Arizona	503,438	325,113	43,899
Arkansas	256,383	154,099	23,327
California	3,493,993	2,285,206	309,522
Colorado	434,858	283,265	38,013
Connecticut	330,938	216,900	28,080
Delaware	76,116	49,924	6,762
Florida	1,569,758	1,019,655	134,427
Georgia	792,442	512,392	54,062
Idaho	133,570	87,940	11,700
Illinois	1,182,412	721,737	108,513
Indiana	518,049	375,784	52,576
Iowa	224,756	160,900	25,956
Kansas	262,847	168,543	23,834
Kentucky	404,876	268,268	35,519
Louisiana	450,908	290,495	39,841
Maine	127,343	83,943	11,369
Maryland	525,768	344,849	46,707
Massachusetts	627,323	408,902	54,353
Michigan	933,896	601,922	85,468
Minnesota	396,502	278,438	38,670
Mississippi	285,971	182,604	25,269
Missouri	545,089	334,918	50,515
Montana	97,890	63,788	8,506
Nebraska	169,118	114,022	15,460
Nevada	186,446	122,288	16,563
New Hampshire	120,998	79,499	10,257
New Jersey	829,726	544,234	73,712
New Mexico	184,461	119,522	16,039
New York	1,877,115	1,227,550	166,747
North Carolina	793,270	518,909	63,300
North Dakota	65,778	42,739	5,698
Ohio	1,112,231	711,333	100,436
Oklahoma	328,348	223,091	30,272
Oregon	362,481	236,791	31,212
Pennsylvania	1,226,720	799,606	108,964
Rhode Island	100,340	65,636	8,890
South Carolina	390,493	258,558	34,593

South Dakota	77,308	50,814	6,902
Tennessee	567,482	373,310	50,251
Texas	2,218,138	1,418,657	188,487
Utah	221,830	144,009	19,505
Vermont	60,610	39,424	5,344
Virginia	707,084	463,740	62,810
Washington	605,904	395,473	53,405
West Virginia	186,674	122,109	16,539
Wisconsin	483,105	299,484	40,805
Wyoming	51,452	33,565	4,546
District of Columbia	52,190	34,139	4,624
	27,612,255	17,953,473	2,431,599

National WTP_ELG-P_NPDES-Alt4

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	497,278	330,608	44,380
Arizona	546,469	363,530	49,388
Arkansas	279,978	173,988	26,244
California	3,825,630	2,570,154	348,224
Colorado	472,119	316,531	42,766
Connecticut	359,912	242,767	31,776
Delaware	82,744	55,841	7,607
Florida	1,712,696	1,146,076	151,590
Georgia	868,160	579,236	61,282
Idaho	145,039	98,179	13,163
Illinois	1,298,795	811,631	122,367
Indiana	561,824	421,390	59,323
Iowa	244,451	181,324	29,269
Kansas	288,278	189,941	26,890
Kentucky	439,569	300,164	40,077
Louisiana	488,699	323,498	44,823
Maine	138,733	93,639	12,791
Maryland	571,551	385,723	52,547
Massachusetts	683,630	458,932	61,320
Michigan	987,075	662,311	92,157
Minnesota	435,421	309,099	44,153
Mississippi	310,741	204,718	28,429
Missouri	595,757	372,358	56,831
Montana	106,438	71,419	9,597
Nebraska	186,579	127,896	17,393
Nevada	202,681	136,782	18,634
New Hampshire	131,269	88,951	11,607
New Jersey	899,734	608,741	82,929
New Mexico	200,182	133,558	18,044
New York	2,035,630	1,373,472	187,597
North Carolina	858,018	578,907	72,086
North Dakota	71,680	47,983	6,429
Ohio	1,200,720	782,747	113,324
Oklahoma	358,777	250,258	34,154
Oregon	394,540	265,285	35,186
Pennsylvania	1,330,506	894,963	122,589
Rhode Island	109,054	73,415	10,001
South Carolina	424,143	288,753	39,024

State_Name	WTP_Boat	WTP_Fish	WTP_Swim
South Dakota	84,283	56,853	7,765
Tennessee	615,306	417,285	56,534
Texas	2,413,543	1,592,273	212,660
Utah	241,543	161,523	21,944
Vermont	65,861	44,112	6,014
Virginia	768,651	518,706	70,664
Washington	658,252	442,208	60,082
West Virginia	202,885	136,582	18,607
Wisconsin	516,788	331,363	44,420
Wyoming	55,772	37,544	5,115
District of Columbia	56,723	38,186	5,202
	30,024,109	20,091,405	2,734,999

National WTP_ELG_N_NPDES_Alt4A

StName	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	12641.04	7651.63	9874.778
Arizona	11138.54	6373.033	10770.66
Arkansas	7296.081	2865.419	5723.386
California	78396.49	44877.09	75941.67
Colorado	10794.05	6381.448	9326.473
Connecticut	5678.086	3607.045	7252.238
Delaware	1511.46	981.6411	1659.01
Florida	42887.12	25979.97	30845.13
Georgia	7522.046	7120.904	10511.7
Idaho	2968.626	1698.53	2870.58
Illinois	31476.49	16085.23	27184.64
Indiana	13698.19	7833.332	13238.63
Iowa	7359.097	4454.408	6502.378
Kansas	8346.466	3550.144	5996.759
Kentucky	8138.194	4457.861	8013.944
Louisiana	10106.92	5782.411	9775.132
Maine	1900.444	1650.557	2789.504
Maryland	11851.09	6780.723	11459.68
Massachusetts	14138.99	6800.047	13672.01
Michigan	17519.92	5020.323	17579.57
Minnesota	9808.583	8285.352	9740.763
Mississippi	6411.647	3668.491	6199.887
Missouri	12817.16	7333.47	12393.84
Montana	1957.249	1074.198	1925.855
Nebraska	4396.775	2244.452	3793.208
Nevada	4202.54	2404.528	4063.742
New Hampshire	2084.829	1322.566	2380.754
New Jersey	18703.18	10701.22	18085.46
New Mexico	5050.12	2328.434	3935.141
New York	42309.02	24207.55	40911.67
North Carolina	15736.32	10201.45	15469.75
North Dakota	1482.585	848.2764	1433.619
Ohio	23310.34	14964.25	25290.15
Oklahoma	6005.889	3101.7	7616.66
Oregon	8064.949	4614.445	7798.585
Pennsylvania	24623.37	15818.92	26734.57
Rhode Island	2255.638	1290.587	2181.14
South Carolina	8666.897	8041.14	9576.178
South Dakota	1966.003	1156.64	1693.329
Tennessee	12750.24	7295.182	12329.13
Texas	66236.43	19726.81	47432.76
Utah	4347.911	2831.626	4785.555
Vermont	1503.718	648.8563	1301.706
Virginia	14078.67	9118.469	15410.56
Washington	15114.01	8927.293	13102.95
West Virginia	4196.4	2401.014	4057.804
Wisconsin	10846.9	4884.499	11798.49

StName	WTP_Boat	WTP_Fish	WTP_Swim
Wyoming	1153.545	660.0129	1115.447
District of Columbia	1173.233	671.2775	1134.484
	636,623	350,724	594,681

National WTP_ELG_P_NPDES_Alt4A

StName	WTP_Boat	WTP_Fish	WTP_Swim
Alabama	456711.1	277630.9	38089.86
Arizona	508476.1	307592.1	42526.61
Arkansas	259047.7	150797.1	22598.07
California	3547727	2161497	299846.1
Colorado	440370.2	268093.6	36824.4
Connecticut	335199.8	205755.2	27883.23
Delaware	76892.32	47224.73	6550.393
Florida	1585580	964924	130136.5
Georgia	798259	483075.1	50058.46
Idaho	134913	83270.33	11334.12
Illinois	1209232	682176.5	105049.5
Indiana	528085.8	355485.5	50889.27
Iowa	233223	154887.9	25127.11
Kansas	267173.8	159353.5	23677.45
Kentucky	408025.1	253720.7	34379.83
Louisiana	455479.8	274593.7	38595.88
Maine	128893.1	79151.62	11014
Maryland	532547.2	326206.6	45247.09
Massachusetts	635357.6	387892.4	53982.23
Michigan	920085.7	561752.8	78096.74
Minnesota	401391.5	266331.8	39293.35
Mississippi	288817	172477.8	24479.47
Missouri	550717.4	315617.3	48935.51
Montana	98891.02	60307.73	8233.81
Nebraska	172291.1	107848.8	14977
Nevada	188346.6	115676.9	16045.17
New Hampshire	122492.7	75187.86	10193.89
New Jersey	835938.8	514813.6	71408.18
New Mexico	186301.3	113120.5	15537.41
New York	1906062	1164575	161534.6
North Carolina	800034.8	489886.7	61103.02
North Dakota	66796.24	40668.11	5660.464
Ohio	1117352	660518.4	99854.96
Oklahoma	331876.2	209992.7	30073.42
Oregon	366128.3	224104.6	30545.85
Pennsylvania	1239369	758493.8	105558.1
Rhode Island	101360.6	62087.47	8611.958
South Carolina	389627	241287.1	33485.74
South Dakota	77887.49	47899.4	6685.895
Tennessee	573248.8	353253.1	48680.02
Texas	2239431	1340825	182443.7
Utah	223493.3	136223.7	18895.16
Vermont	61225	37285.43	5176.956
Virginia	716209.9	440111.2	60846.64
Washington	612032.6	374157.7	51735.36
West Virginia	188571.8	115507.8	16021.73
Wisconsin	484722.7	288778.5	36904.02

StName	WTP_Boat	WTP_Fish	WTP_Swim
Wyoming	51973.49	31750.85	4404.2
District of Columbia	52721.06	32293.77	4479.368
	27,906,590	16,976,164	2,353,712