

## **Appendix E**

### **The National Water Pollution Control Assessment Model**

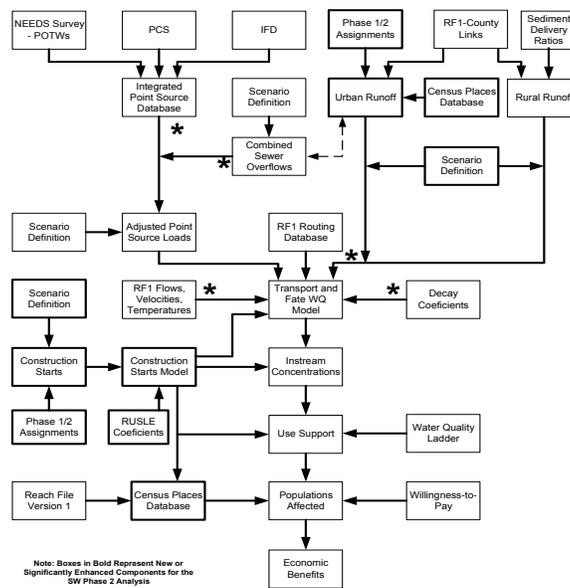


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**The National Water Pollution Control Assessment Model  
Benefits Assessment of Stormwater Phase 2 Program**

**DRAFT - June 1999**

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**Fig 1. National Water Pollution Control Assessment Model Components**

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### **Executive Summary**

The overall objective of this study is to estimate the water quality and economic benefits that can result from various pollution control policies. For this purpose the National Water Pollution Control Assessment Model (NWPCAM) is developed. This model estimates water quality and the resultant use support for 632,000 miles of rivers and stream in the continental United States plus 34,500 miles of smaller streams associated with construction site runoff. The focus of the analyses in this study is evaluating the economic benefits of implementation of the stormwater Phase II rule. To estimate economic benefits, the model first develops the water quality baseline and then estimates the further changes in water quality as a result of the additional controls of the Phase II rule on construction sites and the automatically designated municipalities in urbanized areas. There are many input databases (point sources, combined sewerage overflows, urban runoff, modeling coefficient, etc.), processes, and post-processing tools that are used for the NWPCAM. To develop the water quality baseline, loadings from municipal and industrial point sources as well as nonpoint sources including rural and agricultural sources are used. Table 1 summarizes the primary assumptions used for the development of the baseline and Phase II analyses. The model uses various studies or data sources for estimation of these loadings into the US waters. In view of these loadings, NWPCAM projects the water quality changes in the network of streams and rivers. To identify the effect of the Phase II controls for 120,047 construction sites and the 5,038 automatically designated municipalities in the urbanized areas, the model takes into account the reduction in loadings and projects the instream changes in water quality in terms of swimmable, fishable, and boatable waters on the basis of standards for the level of fecal coliform, dissolved oxygen, biological oxygen demand, and total suspended solids in waters.

The model then identifies where the water quality change takes place so that the number of households associated with those waters can be identified. Once the numbers of households are estimated, the study uses the willingness to pay (WTP) for the improvement in water quality to swimmable, fishable and boatable to monetize economic benefits. On the basis of Carson-Mitchell WTP estimates of \$177, \$158 and \$210 per household for swimmable, fishable or boatable waters, respectively, the water quality change is monetized. The benefit estimates are based on the improvement in local and non local waters. The local economic benefit analysis uses a definition of "local" that differs from the original Mitchell-Carson Survey, which considered "local" as "state." In this analysis, "local" waters are defined as reaches that are located near each of the population locations. The definition of "local" depends on whether it is

a Census Populated Place or Minor Civil Division. For Populated Places, a circle with an equivalent area to the Place was drawn, centered on the Place Latitude/Longitude coordinates as given by the Census Bureau. Any reaches that fell in whole or in part within that circle were considered “local” to that Place. For Minor Civil Divisions, the closest reach is considered to be the “local” water. The estimation of the “local” benefits is based on use support changes in reaches that are “local” to each population location. The benefits depend on the portion of the local and the national impaired waters improved as a result of the phase II soil and erosion controls for construction sites and the application of pollution prevention measures to control storm water run off from the automatically designated municipalities in the urbanized areas. The benefits estimates fully incorporate the “small streams” benefits as well.

*Thus, the model estimates that implementation of Phase II controls, without the consideration of post construction controls, will result in an increase of 4,127 swimmable miles, 4,548 fishable miles, and 2,936 boatable miles. The total benefits of Phase II controls for 120,047 construction sites, without the post construction controls, and 5,038 automatically designated municipalities are estimated to be \$1.63 billion per year.*

While the numbers of miles that are estimated to change their use support seem small, the benefits estimates are quite significant. This is because urban runoff and, to a large extent, construction activity occurs where the people actually reside and the water quality changes mostly occur close to these population centers. NWPCAM indicates that the changes in pollution loads have the most effect immediately downstream of the pollution changes. This is because rivers “treat” the wastes (using similar processes that occur in a wastewater treatment plant) as they move downstream. As a result, the aggregate willingness to pay (economic benefits) is large because large numbers of households in these population centers are associated with the local waters that reflect improvement in designated use support. If the waters are improved in reaches that are further from the population centers their economic value is comparatively less. NWPCAM benefit estimates “capture” this economic phenomenon. Moreover, the model fully incorporates the construction sites modeling (including the “small streams”) and an improved population database for the estimation of benefits. In addition, the benefits estimates are derived using rather conservative assumptions of the pollution control effectiveness of the Phase II program, although EPA believes that the actual implementation of the Phase II minimum measures will result in an overall program effectiveness of approximately 80%. The Phase I and Phase II urban runoff controls used in this analysis employ pollutant removals that are characteristic of detention basins.

To determine the impact of the alternative assumptions, a sensitivity analysis is conducted.

Table 1. NWPCAM Summary For Stormwater Phase II Benefits Analysis

Variable	Baseline For Phase II	With Phase II Implementation
Number of Construction Sites	Current State Programs: 100,316 Phase I: 184,520	Phase II: 120,047 Phase II "R" Waivers: 13,057 0-1 Acres (Unregulated): 91,332
Number of Acres of Construction Sites (Estimated from Input Dataset of Numbers of Starts)	Current Programs: 207,869 Phase I: 1,845,204	Phase II: 289,819 Phase II Waivers: 33,517 0-1 Acres (Unregulated): 45,491
Construction Site Parameters	7% Slope, Medium Soils	7% Slope, Medium Soils
Construction Site BMPs	1. Between 0 and 4 Acres: Silt Fence, Seed & Mulch, and Stone Check Dams 2. Greater Than 4 Acres: Seed and Mulch, Stone Check Dams, and Sediment Traps	1. Between 0 and 4 Acres: Silt Fence, Seed & Mulch, and Stone Check Dams 2. Greater Than 4 Acres: Seed and Mulch, Stone Check Dams, and Sediment Traps
Combined Sewer Overflows (CSOs)	742 CSOs on 505 Reaches	
CSO Runoff Control	Detention basin-level of control for CSOs, capturing 85% of the runoff, with 33% removal of biological oxygen demand (BOD5), 60% removal of total suspended solids (TSS), and 70% removal of fecal coliform (FC).	
Urban Runoff Sources Note: Population adjustments made to reflect 1998 values and populations served by CSOs.	Phase I: 1,723 Places, 72.4 million people Not Phase I or Phase II: 35,718 Places with 81.7 million people	Phase II: 5,038 Places, 78.5 million people
Urban Runoff Controls	Capture 85% of the runoff, with 33% removal of BOD5, 60% removal of TSS, and 70% removal of FC.	Capture 85% of the runoff, with 33% removal of BOD5, 60% removal of TSS, and 70% removal of FC.
Swimmable, Fishable, and Boatable Miles	219,547 (32.91%)	223,674 (33.53%) Increased 4,127 miles
Fishable and Boatable Miles	418,190 (62.69%)	422,738 (63.37%) Increased 4,548 miles from Phase I
Boatable Miles	480,515 (72.03%)	483,451 (72.47%) Increased 2,936 miles from Phase I
No Support Miles	186,589 (27.97%)	183,653 (27.53%) Decreased 2,936 miles from Phase I
Economic Benefits		Local: \$1,401.4 million Non-Local: \$ 227.1 million Total: \$1,628.5 million

Alternative analysis assumes different levels of controls, such as 60% or 80% pollutant removals for urban run off. Supplemental sensitivity analysis in conjunction with the controls in the 60% to 80% range indicates that the estimated economic benefits in NWPCAM increase by \$200 to \$300 million from the \$1.63 billion estimate, respectively.

The benefit estimates can be considered quite robust, since model sensitivity analyses have consistently shown that the estimates are stable, even under assumptions of large changes in model input values. As an example, tests were conducted in conjunction with this analysis assuming that the construction sites loads are off by +/- 25%. The resultant local economic benefits estimates show a change of only +/- 5%. Moreover, a statistical groundtruthing of the model to Storage and Retrieval ambient water quality data indicates that the NWPCAM "baseline" scenario can also be considered as a reasonable predictor of the actual use support circa for 1990s.

## **Introduction**

Under PL 92-500 in 1972, now known as the Clean Water Act (CWA), Federal authority to regulate water pollution control facilities was expanded. The CWA established a national water pollution control policy based on technology-driven effluent standards for industrial wastewater and a minimum level of secondary treatment for wastewater discharged to surface waters by municipal facilities. The goal of the CWA was to improve water quality conditions to attain "fishable and swimmable" waters nationwide. The CWA's national policy requirement for a minimum level of secondary treatment for municipal wastewater facilities was seen as a feasible goal that could result in significant improvements in dissolved oxygen levels as well as other related water quality and environmental benefits. Questions concerning the environmental benefits, as well as the cost-effectiveness of this landmark legislation for water pollution control, have been raised by Congress, special interest, environmental, and business advocacy groups.

Unfortunately, information on the status of our Nation's waters and the influence of control measures on water quality is not comprehensive enough for such an analysis (Knopman and Smith, 1993). Although the 1972 CWA included provisions for program evaluation, Congress did not authorize the U.S. Environmental Protection Agency (EPA) to require methodological consistency among the states or to coordinate the states' efforts to gather, store, and retrieve data. The U.S. Geological Survey (USGS) maintains two long-term, nationally consistent, surface-water-quality monitoring networks--the National Stream-Quality Accounting Network (NASQAN) and the USGS Hydrologic Benchmark Network. However, these networks were developed to monitor water quality trends over time, particularly those "resulting from large scale processes, such as changes in land use and atmospheric deposition, rather than localized effects such as changes in the amount or quality of point source discharges" (Lettenmaier et al., 1991).

Others have modeled water quality in attempts to address policy-relevant issues, but did not take into consideration localized changes. Gianessi and Peskin (1981) include many pollutants in their water quality network model; however, their measurements are appropriate for large-scale watershed analyses and do not capture the local effects due to point sources. EPA's Office of Water used time series monitoring data from 22 major waterways to detect trends and changing conditions of several chemical parameters (U.S. EPA, 1992c). These analyses, however, were not intended to establish cause-and-effect relationships. A second EPA effort (U.S. EPA, 1992a) assessed the effectiveness of the Construction Grants Program, but again the case studies were limited to major waterways.

Most of the adverse effects of point source discharges, urban runoff, and construction site runoff occur within a limited number of miles immediately downstream of the discharge. In addition, many point sources (i.e., major and minor dischargers) are linked to the EPA river and stream network, the EPA River Reach File. Therefore, an accurate assessment of the effectiveness of historical water pollution controls should concentrate on these waters. Although no single monitoring program captures the relevant population of waters downstream of point sources,

EPA did support the database development necessary for modeling the ambient water quality effects of controlling point source discharges of some pollutants from most major industrial sources and almost all municipal sources (U.S. EPA, 1993a).

The inconsistencies in data reported by the States, coupled with the diversity of objectives of the national networks, seemed to preclude the aggregation of this data to assess national changes in water quality as a result of changes in point source loadings. However, a recent analysis (Tetra Tech, Inc. and Stoddard, 1998) of Storage and Retrieval water quality database (STORET) has demonstrated that there have been in fact significant, detectable improvements in water quality over the past 30 years, and that this can be shown using statistical analyses of STORET data. This analysis also reviewed several case studies, including those of the New York Harbor, the Potomac River, the Ohio River, and the Upper Mississippi River plus several others that demonstrate significant improvements that have taken place as a result of point source controls. However, this type of analysis cannot be used for estimation of benefits of the stormwater Phase II rule. Nor can it be used to establish a cause and effect relationship required to estimate aggregate economic benefits of a specific storm water program. To quantify benefits one needs to establish not only the cause and effect relationship between the water quality and the storm water pollutants but also to quantify it. Therefore, the National Water Pollution Control Assessment Model (NWPCAM) includes the set of mathematical relationships that approximate the hydrological/ecological processes with reference to fecal coliform, biological oxygen demand, oxygen demand, total suspended solids that affect the instream water quality.

In order to estimate benefits, the model first develops the water quality baseline and then estimates the further changes in water quality as a result of the additional controls of the Phase II rule on construction sites and the automatically designated municipalities in urbanized areas. To develop the water quality baseline, loadings from municipal and industrial point sources as well as nonpoint sources including rural and agricultural sources are used. The model uses various studies or data sources for estimation of these loadings into the US waters. In view of these loadings, NWPCAM projects the water quality changes in the network of streams and rivers. To identify the effect of the Phase II controls for 120,047 construction sites and the 5,038 automatically designated municipalities in the urbanized areas, the model takes into account the reduction in loadings and projects the instream changes in water quality in terms of swimmable, fishable, and boatable waters on the basis of standards for the level of fecal coliform, dissolved oxygen, biological oxygen demand, and total suspended solids in waters.

### ***Purpose and Objectives of the NWPCAM***

The objective of this work has been to build a national-level water quality model to estimate the water quality and economic benefits that can result from various pollution control policies. The result of this effort is the National Water Pollution Control Assessment Model. This model estimates water quality and the resultant use support for 632,000 miles of rivers streams, larger lakes, and some estuaries in the continental United States plus 34,500 miles of smaller streams

added from construction sites analyses. The model was used to examine policies that include the Construction Grants Program, overall point source pollution control policies, and wet weather controls such as controls on combined sewer overflows (CSOs). The model can be run for various "baseline" conditions and for alternative scenarios, such as implementation of Phase II stormwater.

The NWPCAM has been used for modeling current conditions with analyses that focus on the effects that various control policies can have on current water quality. The model has not yet been used as a predictive tool for future conditions but can be used for predictive analyses by applying growth factors to various loadings.

The scope and objectives of the NWPCAM make it very different from a typical site-specific model. Objectives include:

- To conduct national-scale, planning-level simulations to determine the effectiveness of alternative regulatory control policy scenarios on point sources.
- To detect significant local-scale changes in water quality.
- To aggregate local-scale changes at larger regional and national levels.
- To link policy-driven changes in water quality to populations and to estimate the resultant economic benefits.
- To design a national-scale model framework that rests upon a foundation capable of performing hydraulic transport, routing and connectivity of surface waters in the entire continental U.S.
- To select water quality state variables based on a relatively simple kinetic framework that can: (a) represent the major processes that control water quality impacts, and, (b) can use parameters linked to available methods to estimate economic benefits.
- To use national-level data sources in order to preclude locally or regionally biased results.

The NWPCAM is implemented on the EPA IBM 3090 mainframe at the National Computer Center in Research Triangle Park, NC. The model is programmed in SAS with a full-screen user interface under TSO/ISPF.

### ***System Enhancements for Phase II Stormwater Rule Analysis***

The benefit estimation required significant enhancements to the databases and NWPCAM framework. Primarily, it required an explicit identification of Phase I and Phase II urban runoff locations. Moreover, it required the development of the submodel or sub-system for analysis of construction sites. An improved database of populated areas, including Populated Places and Minor Civil Divisions (MCDs), was needed to provide a clear assignment of Phase I and Phase II regulated communities and other urban runoff locations. A new database of construction starts/sites was also needed to estimate the locations of the construction sites across the country so that they could be integrated into the NWPCAM framework. The development of the submodel was required to estimate and route the loadings from the construction sites into EPA's Reach File Version 1 (RF1) stream network.

These enhancements are discussed in more detail below and additional technical details are provided later in this report.

1. In order to provide an explicit breakdown of Phase I and Phase II communities for estimating benefits for the Phase II controls for automatically regulated municipalities, Census Bureau databases of population sites, based on their files of Populated Places and Minor Civil Divisions, are linked to NWPCAM. This enhanced population database provides a better understanding and estimation of the urban runoff loadings in the modeling and the estimation of the "local" economic benefits. Moreover, there was a need to establish a cross-link between the Populated Places/MCDs and Construction Sites so that sites can be geographically located for assignment of Revised Universal Soil Loss Equation (RUSLE) coefficient to estimate loadings for RF1 NWPCAM framework. Obviously, without the establishment of such links between locations of the construction sites and the populations centers, economic benefits of construction site controls cannot be fully assessed. As a result, there are separate urban runoff loading estimates for the 42,479 separate Census Bureau Populated Places and Minor Civil Divisions in the system, with estimates of annual pollutant loadings for each place and each portion of the reach associated with the place. The source of these loadings is a database of urban loadings by county that is a counterpart to the rural loadings source database. These places are also used for estimating local economic benefits based on changes in water quality on reaches close to each place.

More specifically, there was a need to identify the specific Phase I and Phase II places in order to model controls on their runoff. To accomplish this, data files containing the lists of communities making up Phase I and Phase II were merged into the enhanced NWPCAM places database so that explicit identification of places associated with each Phase could be made. In addition, the NWPCAM database contains an overlay of Urbanized Areas, in order to identify urban communities. The Phase I or II places were matched to the NWPCAM places database. As a result, each place is identified as either a Phase I urban area, Phase II urban area, or other. Consequently, 1,723 separate places,

comprising 72.4 million people, are incorporated as Phase I urban sites and 5,038 other places, comprising 78.5 million people, for 1998, are included as Phase II urban sites. The rest of the 35,718 places and minor civil divisions comprise 81.7 million people including the CSO population<sup>1</sup>. The population totals for Phase I and Phase II places for 1998 are adjusted for populations already served by CSOs, using data from the CSO NEEDS Survey. However, there was some problem in matches, mainly because of differences in place names between the various files.

The NWPCAM places database contains many small communities with less than 2,500 people, so the total number of people assigned to places in NWPCAM is greater than the reported Census Bureau urban population. The Census Bureau defines an urban place on the basis of population of greater 2,500 people. By using this definition, one can compare that portion of populations which is associated with those places, in both databases, for quality control purpose. By imposing the Census Bureau definition of “urban” on the NWPCAM places database (i.e., places in urbanized areas and designated places with more than 2,500 people), an urban total of 192 million people for 1990 is found in NWPCAM. In comparison, the Census Bureau reports the population of 187 million for 1990 (the base year for the NWPCAM places database). This represents a difference of 3%, which can be considered a reasonable difference, given the fact that the NWPCAM is developed from multiple Census Bureau databases.

The point sources of 742 separate CSO loadings, on 505 different reaches, from the NEEDS Survey, are included in the RF1 framework. The urban runoff loadings for Phase I and Phase II communities are cross-linked to the CSO populations, so that double-counting of urban runoff loads does not occur. That is, urban runoff loadings are subtracted if it can be determined that the runoff loadings are already accounted by the CSO component of the system.

The NWPCAM modeling options allow setting pollutant reduction levels for CSOs, Phase I, and/or Phase II places as desired. Currently, the NWPCAM assumes that 85% of the CSO and urban runoff is captured by sewer systems, with the remaining being delivered untreated to the streams. This 85% assumption is selected because it was used in the NEEDS Survey CSO analyses.

2. The Phase II regulation contains controls on construction sites, so a construction starts/sites database is fully incorporated into NWPCAM. The construction site communities totaling 19,378 are incorporated into the NWPCAM framework, with estimates of annual TSS runoff. Each community has estimates of the total number of sites under construction by size range, such as 0 to ½, ½ to 1 acres, etc. The annual estimates of loadings are based on application of the Revised Universal Soil Loss. This

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<sup>1</sup>The total population for 1998 is projected at 270 million of which about 233 million people are included in the modeling of the water quality impacts.

equation determines the soil loss on the basis of rainfall, erodability, slope, preconstruction farming conditions, and the application of the best management practices on a construction site. To account for the climatic differences, the coefficient values of RUSLE are separately developed for 15 representative cities. The coefficient values that relate to "Representative Cities" are presented in the U.S. Army Corps of Engineers study for OWM (COE, 1998). To determine the boundaries of the representative cities for determining the number of sites for a representative area, a correspondence between Major Land Resource Areas (MLRAs), which characterize soil and climate for estimation of erosion in various parts of the United States, is used. As RUSLE coefficients also vary by slope and soil type in the model, a 7% slope is assumed with medium soils in this analysis. On the basis of MLRAs and Representative Cities the RUSLE coefficient are set for every one of the 19,378 construction site communities. Table 2 shows the RUSLE coefficient by "representative city" for pre-construction and construction conditions with no best management practices (BMPs), and the coefficient for each of the construction BMPs. The use of these coefficients is discussed in the "Construction Site Loadings" section.

Two issues related to construction site loadings and use support are addressed in the development of a new "small streams" modeling component. The first issue was that many of the construction sites were on small streams that were not already included in the NWPCAM/RF1 framework. The second issue related to the estimation of reduction in loadings from settling as runoff from the construction sites flows to RF1. Therefore, a "small streams" water quality submodel is added to the NWPCAM. The model routes the construction site runoff to the main NWPCAM/RF1 network. This model decays the loadings using the same methodologies as for the rest of the NWPCAM. Data for flow in the "small streams" is based on a hydrologic analysis that relates distance from RF1 to drainage area, and then uses an RF1 flow analysis to estimate mean summer flow as a function of the drainage area. For this initial work on "small streams," a straight-line distance from the construction sites to RF1 is used, that is, sinuosity of the streams is not taken into account. The instream water quality modeling itself does not utilize sinuosity as a parameter, but some future work with sinuosities could improve/change the lengths of the flow paths.

The Phase II rule provides exemptions for areas of low rainfall. This exemption is implemented by exempting construction sites between 1 and 5 acres that have a RUSLE rainfall erosivity factor ("R") less than 5. The average construction period is assumed to last 6 months, so an R factor of 10 is used in this analysis to account for a full year. Because the MLRA's are overlaid on each community with construction, an "R" factor is assigned to each site. Phase II controls are waived for sites with an "R" factor less than 10. In examining Table 1, note that the "Las Vegas" representative city is the only one that has an "R" factor less than 10, so that those sites that fall within the "Las Vegas" MLRAs will have this particular waiver.

Construction BMPs are incorporated by adjusting the respective RUSLE coefficient that reflect the effects of a given BMP, or multiple BMPs. The BMPs are based on COE report and are selected to be consistent with the Phase II economic analysis carried out by the Office of Wastewater Management: for sites between 1 and 4 acres, a combination of silt fences, seeding and mulching, and stone check dams is used. For sites greater than 4 acres, a combination of seeding and mulching, stone check dams, and sediment traps is used. These BMP effects vary by MLRA, since the RUSLE coefficient vary by MLRA. For estimates, the baseline modeling of the construction sites assumes BMPs at all sites greater than 5 acres (Phase I controls) and the BMP controls for already existing state programs so that benefits of these controls are not attributed to the Phase II rule.

3. The economic benefits analysis (Mitchell-Carson) incorporates the improved population database and the construction sites “small streams” analysis. This means that the benefits are based on better defined set of populations than in previous versions of the NWPCAM and will reflect some of the water quality improvements that can be expected at the smaller streams that are most likely to be affected by many construction sites.

## **Methodology**

### *Model Development Steps*

A model for predicting water quality and beneficial use attainment under different policy scenarios will address several key issues. First, the model must control for loadings from both point and nonpoint sources. Decreasing discharges from a specific point source, even going to zero discharge, may have little or no effect on beneficial use attainment if discharges from other sources are limiting factors. Second, streamflow and stream velocity data are required to simulate dilution and self-purification effects through pollution decay. Third, water quality parameters examined in the model must be related to beneficial use attainment and must reflect all of the essential processes that limit point source controls. Fourth, a methodology is needed to characterize point source loadings under different scenarios (i.e., no treatment of point source discharges or limited treatment in the absence of the CWA). All of these issues must then be integrated into a river network that can characterize a meaningful "universe" of waters. These basic, but essential, components are integrated into the NWPCAM.

In addition to predicting water quality and beneficial use attainment, the NWPCAM can be used to estimate the number of persons living near changed waters. This is an important dimension for evaluating the economic benefits of pollution control policies. It is not enough to know how many miles of rivers and streams have been improved; one also wants to know how the changes affect the nearby population. A first step in this direction is to determine the population proximate to the improved water resource. The next step involves estimating the population's willingness to pay for the water quality improvements.

A major challenge in developing the NWPCAM was to “wire” all of the components into one

system, all of it linked into EPA's Reach File Version 1 river network. As with many models, the bulk of the work is in managing the data so that the numerical modeling can be applied. The effort expended on constructing and integrating the input data at this national scale is much greater than that required for the actual software implementation.

A second challenge was to develop simple yet valid approaches to the water quality kinetics. The principle of "Ockham's Razor" (named after a 14th century monk) is applied, which states that, given no contravening information, the simplest solution to a problem is the best. Fortunately, there are traditional approaches to water quality modeling that employ simple steady-state linear modeling approaches (i.e., first-order decay). These techniques have been employed for many years for wasteload allocations that have formed the basis of pollution control decisions. The large body of work using these approaches also provides a basis for setting model coefficients at reasonable starting points. Therefore, the NWPCAM employs steady-state first order decay processes as the modeling approach.

A third challenge addressed in the model development was to provide for incremental additions and improvements. A model at this large scale must, by necessity, be incremental in its development. For instance, the first version of this model (called the Clean Water Act Effects Model) incorporated only 5-day biochemical oxygen demand (BOD5) and total suspended solids (TSS) and had urban and rural nonpoint sources, municipal point sources, and "major" industrial point sources. Major point sources are defined by each State as those point sources that have a "significant" effect on water quality; there is no clear, universal definition of significant among the States. The next version of the model added fecal coliform (FC) and dissolved oxygen (DO) modeling, with the same point sources as those used in the first version. A third version then added combined sewer overflows and approximately 20,000 "minor" industrial dischargers. In going from the first to the third versions, the scope of water quality parameters and pollution sources were both increased. It is this third version of the model that is presented in this report.

Plans are underway for further incremental development. A preliminary version has been developed that models toxic water pollutants, and this model is undergoing further development at this time. It is also expected that nutrients will be incorporated into the model in the near future. Modeling of nutrients and the resultant algal growth cycles poses particular challenges. Up to this point, the conventional and toxic pollutant modeling techniques in the inland waters have employed linear kinetics, which allow fairly simple closed-form solutions. The nutrient modeling will be nonlinear, so numerical integration techniques will be needed. One significant impact of adding nutrients to the model will be the introduction of ammonia and nitrogen, which would deplete DO further. We recognize that the exclusion of ammonia from the DO modeling has been a significant limitation, and this will be addressed in one of the next incremental improvements.

Another significant improvement that will take place in a future nutrient modeling increment is enhanced modeling in lakes and some estuaries. Lakes and estuaries are currently modeled as one-dimensional systems; the nutrient modeling effort is expected to employ two-dimensional

(and perhaps three-dimensional) modeling techniques in these waters in future versions. The current NWPCAM models everything as one-dimensional, which means the waters are represented as linear features. Two-dimensional modeling will permit modeling “wide” features such as lakes. Three dimensional modeling add the depth variant to the two-dimensional modeling.

Yet another major incremental development that is expected in the near future is a separate effort to model estuarine and coastal waters. This increment will require significant effort because these systems are much more complex than the primarily one-dimensional inland rivers and streams now being modeled in the NWPCAM. The estuarine and coastal modeling will be linked to the current NWPCAM inland modeling by using the NWPCAM streamflows and pollutant loadings as inputs to the coastal and estuarine models<sup>2</sup>.

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<sup>2</sup>The NWPCAM is being reimplemented on a PC using Microsoft Access and Visual Basic. This step will make the model more accessible to users and will improve linkages to postprocessing analyses such as the use of ArcView Geographic Information System mapping of results.

### *Modeling Approach*

The NWPCAM performs national-level modeling of conventional pollutants in the major inland rivers and streams, larger lakes and reservoirs, and some estuarine waters in the lower 48 states. This is done using the RF1 framework, which covers approximately 632,000 miles of rivers, lakes, reservoirs, and estuaries. The best available nationally consistent data sources were used to predict ambient concentrations of BOD<sub>5</sub>, TSS, FC, and DO along all river reaches. The model controls for loadings from both point and nonpoint sources, and uses streamflow and stream velocity data to model pollutant fate.

Estimates of total stream miles in the United States range from 1.2 million (U.S. EPA, 1992b), an aggregation of states' estimates, to 3.6 million (U.S. EPA, 1993b), calculated using EPA's expanded surface water network, Reach File Version 3 (RF3). The latter estimate includes intermittent streams. The subset of river and stream miles included in RF1 are the major rivers and streams. Therefore, RF1 waters are not inclusive of **all** of the Nation's streams. Nonetheless, this system does include most waters affected by major industrial, municipal, and CSO point sources and major urban runoff.

The water quality parameters used in this approach (BOD<sub>5</sub>, TSS, FC, and DO), were selected based on several criteria:

- They can be modeled reliably using simple first-order decay kinetics.
- They are key "conventional" parameters targeted in wastewater treatment.
- Common wastewater treatment characteristics for these parameters are well known and consistent, so that estimating reasonable loadings corresponding to differing levels of point source controls is feasible.
- Detailed data are available both on point source loadings and nonpoint source loadings of the pollutants.
- Existing indices of beneficial use are based, in part, on these water quality parameters.

DO is a widely recognized indicator of beneficial use attainment and is a primary instream benefit of BOD<sub>5</sub> control. Modeled values for percent DO saturation are based on mean summer water temperatures. The classic Streeter-Phelps approach is used to model DO as a function of reaeration, UBOD (i.e., ultimate BOD, estimated by  $1.46 \cdot \text{BOD}_5$ ), and sediment oxygen demand (SOD). Reaeration is modeled using the methods applied in the WASP model (Ambrose et al., 1987). This method estimates reaeration as a function of stream depth and velocity. The streamflow condition modeled is mean summer flows and velocities developed in conjunction with RF1 (Grayman, 1982). Stream depths are computed using stable channel analysis

(Henderson, 1966). SOD is modeled with a default value of 0.5 g/m<sup>2</sup>/d, increased to 1.5 g/m<sup>2</sup>/d below point sources and CSOs.

Fecal coliforms are included as a fourth parameter because pathogens are clearly important in determining whether water quality supports swimming. The model employs a simple first-order decay model using data from CSO loadings. The municipal effluent values are set to a low default value as disinfection is assumed to occur (except in no treatment scenarios). There are no industrial point source or nonpoint source estimates for fecal coliforms in the model.

The fate of BOD<sub>5</sub>, TSS, and FC is modeled using first-order decay equations. The percent DO saturation is modeled based on mean summer water temperatures using the Streeter-Phelps approach. That is, DO is modeled as a function of reaeration, UBOD, and sediment oxygen demand. Reaeration is modeled as a function of average stream depth and velocity, with stream depth computed using stable channel analysis (Henderson, 1966).

These pollutants form the basis for linking water quality to the Resources for the Future (RFF) Water Quality Ladder. This ladder is used as a uniform basis for assigning four categories of beneficial use support (swimming, fishing, boating, no use support) to each computational element in the NWPCAM. Because the model includes the ability to characterize point source loadings under different scenarios (e.g., “without pollution control policies”), the model can be used to estimate the effect of changes in water quality or beneficial use on persons living near those river reaches. This is an important dimension of evaluating the economic benefits of changing water quality.

### *Model Components and Processes*

Figure 1 shows the components, processes, and sequence of actions that are required for a NWPCAM run. Boxes in bold are components that have been either added or significantly enhanced for the Storm Water Phase II analyses. The central path of the NWPCAM starts with the RF1 Routing Module. The primary inputs to this module are the RF1 routing framework, point source loads, combined sewer overflows, NPS loads, reach flows and velocities, and pollutant decay coefficients. The routing module computes pollutant concentrations for each subreach. These concentrations are then compared to the water quality ladder to determine which subreaches (i.e., river and stream miles) are not meeting a particular beneficial use. Next, the number of households corresponding to these reaches is computed using data from the 1990 Census of Populated Places.

The upper left portion of Figure 1 shows the processing of point source loads. The 1988 Survey (NEEDS88), Permit Compliance System (PCS), and Industrial Facilities Discharger (IFD) databases are joined to create a consolidated point source database. This database contains a unique set of pollutant loadings for each discharger that is in NEEDS88, PCS, and IFD, together with the links to RF1. The point source loadings are then adjusted for the relevant point source control regime being evaluated and are entered into the RF1 routing module.

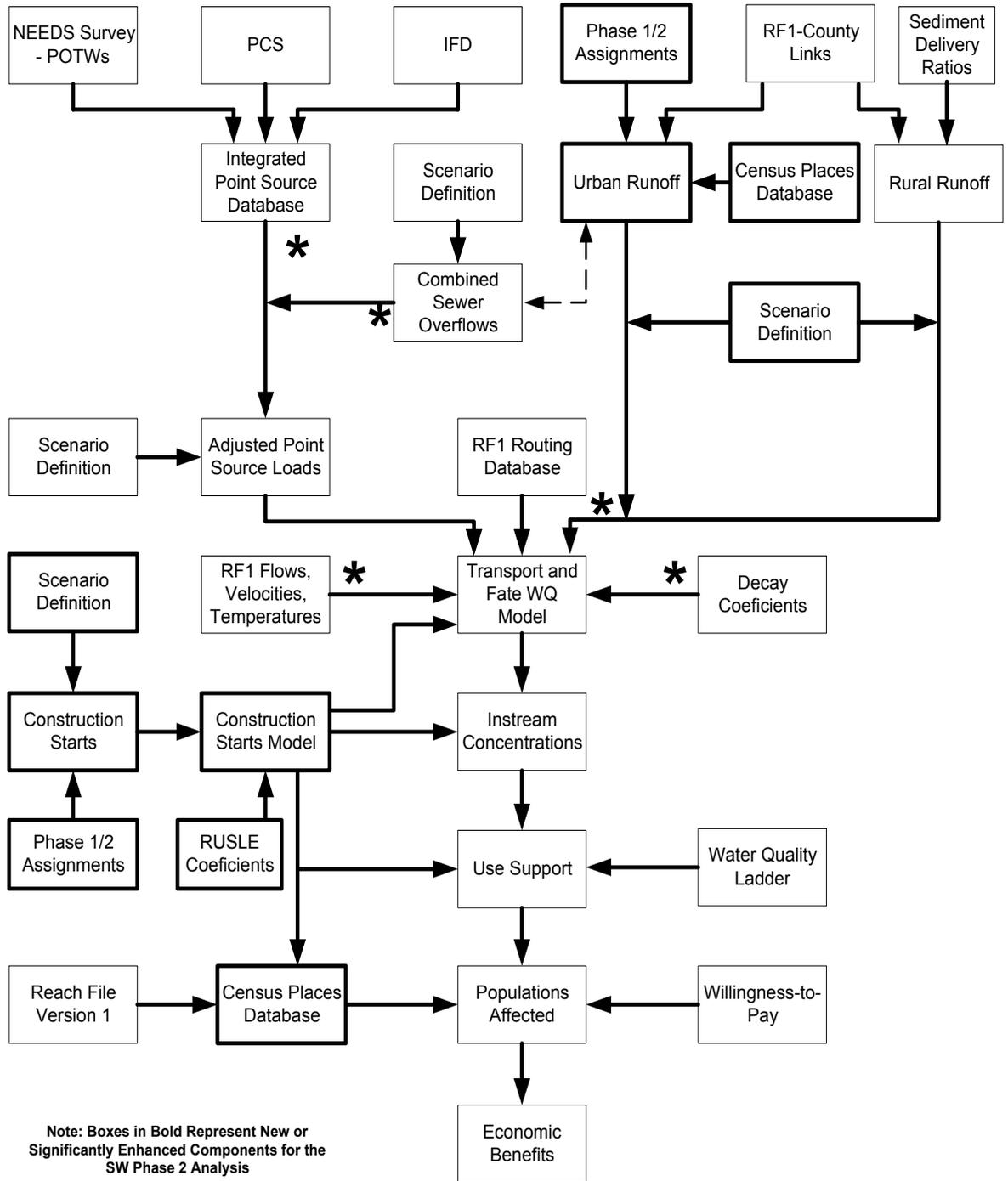
The upper right portion of Figure 1 shows the processing of the urban runoff and rural NPS loadings databases. The urban and rural county loads are combined and allocated to each reach based on proportional lengths of reaches in each county and the relevant Sediment Delivery Ratios (SDRs) for each watershed. The Urban loads are adjusted by CSO loads to avoid double-counting. The SDR is a coefficient that represents the reduction in pollutant loadings going from the field-level discharge, down drainage channels and smaller streams before reaching the river network (in this case RF1). In essence, the NPS loads are multiplied by the SDR to get the net loading to the RF1 reaches. The NPS loads are then entered into the RF1 routing module.

Pollutant loadings in the system include 24,854 minor and 2,261 major industrial point sources and 9,890 municipal point sources (publically owned treatment works, POTWs). The system includes 742 CSO loadings on 505 Reaches. The model also includes urban runoff loadings at 42,479 individual places (Phase I, Phase II and other) and 509,272 construction sites. In addition, NWPCAM includes the rural loadings, primarily from agriculture.

The 37,005 point sources in the model are linked to 12,676 different RF1 reaches. Figure 4 shows a map of the reaches that have point sources. This map shows the distribution of point sources across the U.S. The pattern is as one would expect, with most of the point sources lying in the eastern half of the U.S. with the exception of concentrations located around major cities on the West coast.

The model includes options to change loadings in a way that can simulate various pollution control policies. For instance, urban runoff loadings can be changed that can simulate the pollutant reductions that could be expected from detention basins, construction site loadings can be modeled by applying coefficient that simulate the effects of various BMPs, etc.

There is concern about the accuracy of the inputs to the model and the effect this could have on model results. The effects of errors in the input data elements that have an “\*” next to them are addressed in a detailed sensitivity analysis. As can be seen in Figure 1, the sensitivity analysis addresses each of the major inputs to the water quality model.



**Fig 1. National Water Pollution Control Assessment Model Components**

## **Transport**

### *RF1*

The EPA 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.

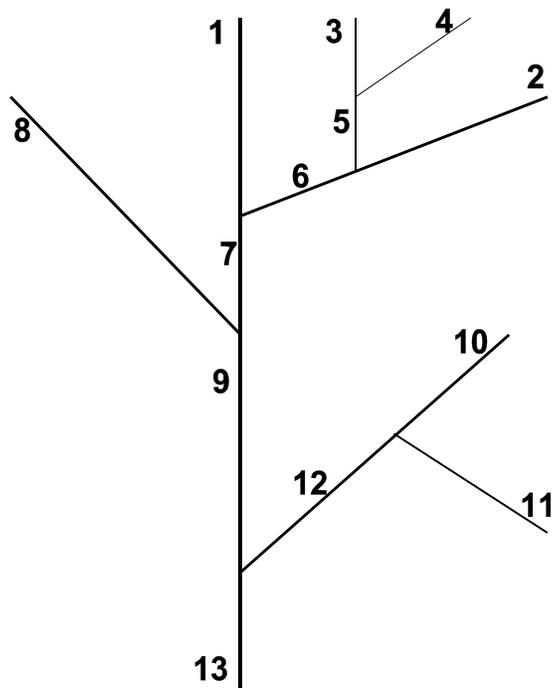
RF1 contains approximately 632,000 miles of rivers, streams, and larger lakes. There are approximately 68,000 reaches, of which approximately 61,000 are transport reaches (i.e., water flows down them) with an average length of about 10 miles. The remaining 7,000 reaches are nontransport reaches (e.g., shorelines).

Estimates of mean and low flows and velocities for each transport reach in RF1 have been developed by Grayman (1982). The estimates for mean summer flows and the corresponding velocities were adjusted using mean monthly flow estimates for RF1 reaches (Grayman, 1982). This data provide the basis for the pollutant mixing and routing components of the NWPCAM.

### *Routing*

RF1 has a very powerful routing design ideal for upstream and downstream. This routing design works reach by reach, requiring no more than one Reach database record to be "in memory" at a time and can be set up to run quite rapidly.

There are four fundamental variables involved in the routing design. The basic routing variable is the Hydrologic Sequence Number (SEQNO). This variable gives the order in which reaches are processed. Figure 2 shows a simple river network schematic with the SEQNOs labeled on each Reach. In addition to the SEQNO, three other variables are essential to the routing design, LEV, J, and SFLAG. LEV is the stream level. A mainstem would have a LEV=1, a tributary off of that would have a LEV=2, a tributary off of that a LEV of 3, etc. In RF1, the maximum LEV is 10. In the routing design, the LEV is, in effect, the array subscript for holding accumulated

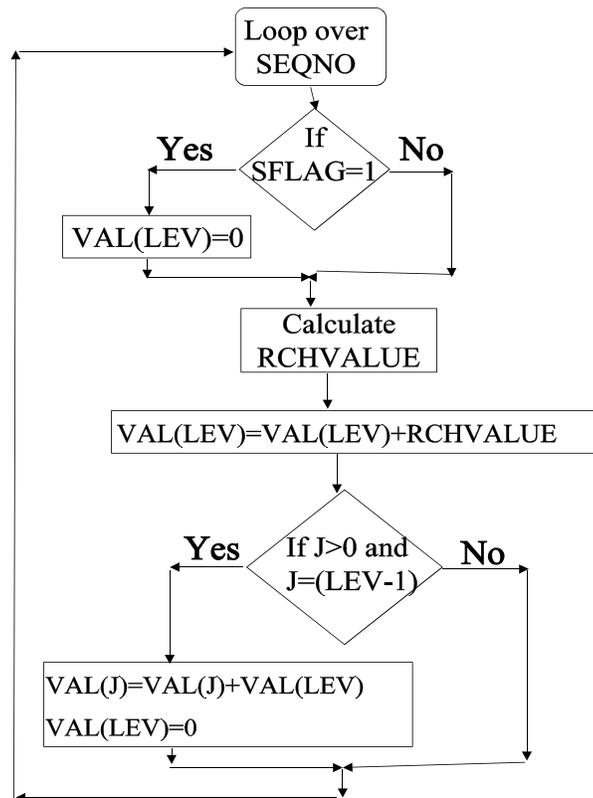


**Figure 2. Hydrologic Sequence Numbers.**

values as you move down the network. An array of these values is maintained, carrying the values downstream.  $J$  is the LEV of the Reach downstream. If  $J > 0$  and  $J = (LEV-1)$ , then it indicates when the given Reach is the end of a level path and that the accumulated values from the current LEV need to be added to the values of the lower LEV. SFLAG is a flag that indicates if a Reach is a “start” Reach, i.e., no Reaches are upstream of it. If  $SFLAG = 1$ , then it is a start Reach. The basic routing algorithm is shown in Figure 3.

#### *Computational Elements*

The average length of an RF1 Reach is 10 miles. This is too long to be used as a single computational element; in many cases, the entire effect of a discharger could occur within a 10-mile stretch. Therefore, the reach file for the NWPCAM is broken into computational elements of one mile or shorter. Breaks occur beginning from the head of the reach either at 1-mile increments, at major dischargers, or at the end of the reach. For instance, if a reach is 5.25 miles long with a major discharger at 3.75 miles from its head, it is broken into six segments: three 1-mile segments at the upstream end of the reach, a 0.75-mile segment, another 1-mile segment, and one 0.5-mile segment at the downstream end of the reach. This means that the new Reach



**Figure 3. The Basic Routing Algorithm**

File contains many more reaches than the original RF1. While the original RF1 contains approximately 61,000 routing Reaches, the expanded RF1 contains approximately 655,000 routing elements. The routing variables, i.e., SEQNO, LEV, J, and SFLAG are set for each segment so that the same routing algorithm described above still works for this expanded Reach File.

## Pollutant Loadings

### *Point Source Loadings*

The point source data are from EPA databases (U.S. EPA, 1990; Tetra Tech, 1993). Two sources for point source loadings were available: (1) the NEEDS88, which contains BOD<sub>5</sub> and TSS loadings for virtually all municipal wastewater treatment plants in the United States, and (2) the PCS, which contains data from the National Pollutant Discharge Elimination System (NPDES) Discharge Monitoring Reports. If data were available from both NEEDS88 and PCS, the PCS data for 1990 were used.

The lack of minor dischargers (representing many thousands of dischargers) was considered a significant issue in the first versions of the model. Loadings data for minor industrial dischargers is not consistently available in PCS. On advice of PCS staff, only major point source loadings can be considered comprehensive. A third source of point source data, the IFD database, is used in conjunction with PCS to estimate loadings for minor dischargers. For many minor dischargers, IFD contains data on the type of industry, represented by the Standard Industrial Classification (SIC) code, and in many cases the wastewater flow. To develop loadings estimates for minor dischargers based on this data, a methodology is adapted from techniques first pioneered by the National Oceanic and Atmospheric Administration (NOAA) staff for estimating loadings in coastal areas. This methodology uses what data is available to compute Typical Pollutant Loadings (TPLs) and Typical Pollutant Concentrations (TPCs) by pollutant (TSS and BOD<sub>5</sub>), 2-digit SIC code, and major/minor classification. TPLs and TPCs represent median concentrations and loadings, respectively, that can be expected from a given industrial sector. These are used to estimate the loadings from dischargers for which no loadings are available. TPLs and TPCs are computed as the median loading or concentration, respectively, with a threshold requiring at least eight observations to produce a TPL or TPC.

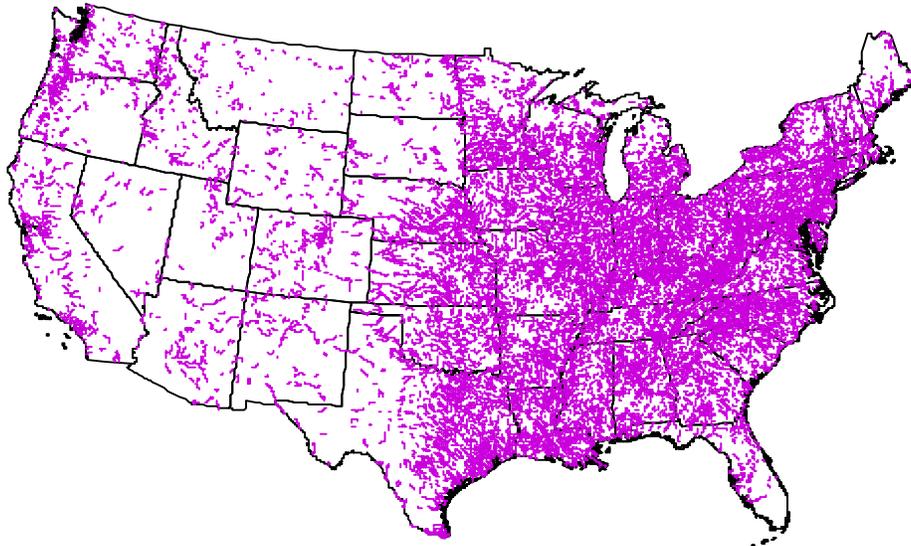
The TPLs and TPCs are then merged with the IFD inventory of dischargers. If there is a valid TPC, then the loading is estimated by multiplying the TPC by the wastewater flow in IFD. If there is no TPC but there is a TPL, then the TPL is used. In this way, loadings estimates were generated for 24,854 minor dischargers which could be included in the NWPCAM.

### *NPS and Urban Loadings*

NPS loadings are based on county-level loadings for BOD<sub>5</sub> and TSS that were developed for 1990 and 1972 (Lovejoy, 1989; Lovejoy and Dunkelberg, 1990). The annual loadings are allocated to reaches by county and type of Reach. The NPS loadings are provided separately for rural and urban areas by county. In this study, to determine loadings for individual places using the urban runoffs estimated by Lovejoy, the 1990 Census of Populated Places data is overlaid on the Reaches, and Reaches that lie within these Populated Places are assigned the urban portions of the loadings. The remaining Reaches are defined as rural and the rural loadings are assigned to these Reaches. RF1 contains the county Federal Information Processing Standard (FIPS) code(s) for each reach. The loadings are allocated proportionally to the total length of stream miles in each county. For instance, if the total length of RF1 rural streams in a given county is 100 miles, then we allocate 1% of the county rural NPS loads to each mile. For stream segments overlapping more than one county, the NPS loads were allocated from each county by assuming an equal proportion of the segment was in each county; if the segment was in two counties, then half of the reach length was assumed to be in each county. For urban NPS loads the allocation is proportional to stream length as well as the population associated with the Reach.

Only a portion of rural NPS loads actually gets into the stream. The allocation of rural NPS loads to each reach depends on the SDR, which can vary greatly by watershed area (Vanoni, 1975). SDRs are estimated for each of the 2,111 watersheds in the NWPCAM. The

methodology for developing the watershed-level SDR estimates is covered later in this report. The 37,005 point sources in the model are linked to 12,676 different reaches. Figure 4 shows a map of the reaches that have point sources. This map shows the distribution of point sources



**Figure 4. NWPCAM Reaches with Point Sources**

across the U.S. The pattern is as one would expect, with most of the point sources lying in the eastern half of the U.S. with the exception of concentrations located around major cities on the West coast.

#### *Construction Site Loadings*

The construction site loadings of TSS are based on a methodology developed by the Corps of Engineers for USEPA/OWM. This methodology uses the Revised Universal Soil Loss Equation. The revised soil loss equation determines the magnitude of loadings taking into consideration rainfall, soil Erodability, slope, farming preconstruction conditions and the application of best management practices. The coefficients (Table 2) used in the RUSLE are:

R - Rainfall Erosivity

K - Soil Erodability

LS - Topographic

C - Cover Management; Includes 2 BMPs: #1=Seeding, #2=Seeding and Mulching

Appendix E

P - Support Practice; Includes BMPs Such as Straw, Sediment Traps

**Table 1. Soil Erosivity, Erodibility, Topography, Cover Management and Support Factor Variable Values**

Representative		Pre-Cons.	Construct.		Pre-Cons.	Construct	Seeding	Seed & Mulch	Pre-Const.	Constr.	STRAW	Silt Trap	STONE	Sedm. Trap
City	R	K	K	LS	C	C	C	C	P	P	SDR	SDR	SDR	SDR
Hartford	130	0.27	0.34	1.06	0.283	0.878	0.44	0.261	1	1	0.65	0.49	0.3	0.4
Duluth	95	0.27	0.34	1.06	0.225	0.873	0.666	0.362	1	1	0.65	0.49	0.3	0.4
Las Vegas	8	0.27	0.34	1.06	0.04	0.809	0.458	0.139	1	1	0.43	0.4	0.3	0.4
Charleston	400	0.27	0.34	1.06	0.359	0.917	0.546	0.295	1	1	0.8	0.66	0.3	0.4
Bismarck	50	0.27	0.34	1.06	0.206	0.844	0.655	0.345	1	1	0.58	0.45	0.3	0.4
Helena	14	0.27	0.34	1.06	0.16	0.827	0.655	0.379	1	1	0.41	0.4	0.3	0.4
Atlanta	295	0.27	0.34	1.06	0.34	0.898	0.578	0.385	1	1	0.76	0.61	0.3	0.4
Denver	40	0.27	0.34	1.06	0.214	0.841	0.697	0.365	1	1	0.54	0.43	0.3	0.4
Boise	12	0.27	0.34	1.06	0.143	0.818	0.567	0.442	1	1	0.41	0.4	0.3	0.4
Nashville	225	0.27	0.34	1.06	0.34	0.891	0.538	0.408	1	1	0.69	0.53	0.3	0.4
Amarillo	100	0.27	0.34	1.06	0.298	0.859	0.573	0.408	1	1	0.72	0.57	0.3	0.4
Portland	65	0.27	0.34	1.06	0.228	0.864	0.263	0.219	1	1	0.43	0.4	0.3	0.4
Des Moines	160	0.27	0.34	1.06	0.309	0.885	0.643	0.451	1	1	0.69	0.53	0.3	0.4
San Antonio	250	0.27	0.34	1.06	0.361	0.877	0.536	0.434	1	1	0.77	0.62	0.3	0.4
Fresno	12	0.27	0.34	1.06	0.113	0.822	0.251	0.202	1	1	0.4	0.4	0.3	0.4

Appendix E

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The coefficient values used for these variables in determining loadings are presented in the Appendix. In the COE methodology, the RUSLE coefficients are defined based on climatic zones indicated by 15 “Representative Cities” to account for the impact of climatic differences, and the BMPs to be considered. To determine the boundaries of the climatic zones represented by these “Cities” Major Land Resources Areas/Regions are used in this study. As a result, the “Representative Cities” are linked to Major Land Resource Areas so that all of the construction sites can be assigned the appropriate coefficients to incorporate the impact of the climatic differences in estimating loadings. Figure 5 shows a map of the MLRAs and the corresponding “Representative Cities” assigned to each city; this is used as a GIS overlay on the construction sites locations to determine each site’s RUSLE coefficient. The construction sites loadings are based on a list of 19,427 communities for 1998 in the continental U.S. with estimates of numbers of construction starts/sites of 509,272 (Table 3), by the following size ranges:

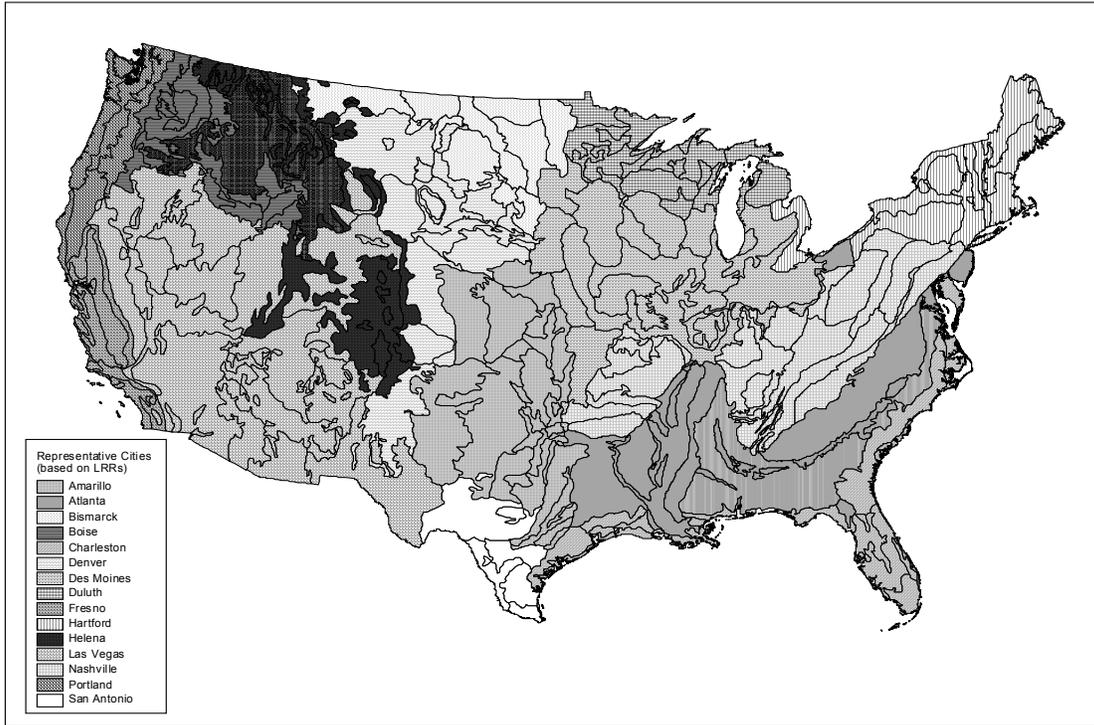
- 0 - ½ Acre
- ½ - 1 Acre
- 1 - 2 Acres
- 2 - 3 Acres
- 3 - 4 Acres
- 4 - 5 Acres
- 5 + Acres

**Table 3. Number of Construction Sites by Size Range**

Size Range (acres)	Phase I and Existing State Programs	Phase II and Unregulated 0-1 Acre and Waived Sites	Phase II Sites
0 - ½	11,092	46,015	N/A
½ - 1	11,889	45,317	N/A
1 - 2	33,255	5,685	58,702
2 - 3	19,228	3,241	29,305
3 - 4	11,665	1,701	15,676
4 - 5	13,187	2,428	16,364
Greater Than 5	184,520	N/A	N/A
Total (509,272)	284,836	104,389	120,047

Figure 5.

**Major Land Resource Areas of the Lower 48 States**



The number of construction sites and the communities is based on the construction site<sup>3</sup> database which was developed by EPA for economic analysis. This database provides a list of 19,427 communities with estimates of the number of construction starts/sites in each community. A database containing the exact location of each construction site in a community does not exist at the national level. Moreover, it is impossible to develop such a database. Therefore, these communities are treated as point sources of construction loadings in the model. The loadings are estimated on the basis of the RUSLE equation for each community. Construction site TSS loadings are determined as follows:

1. Calculate Site Unit Load (SUL) in Tons/Acre/Year for each size range:

$$SUL_{Size} = R * K * LS * C * P)_{PreC} / 2 + R * K * LS * C_{BMP} * P_{BMP})_{Con} / 2$$

The COE methodology assumes 6 Months of pre-construction activity followed by 6 Months of construction activity. Therefore, this equation has two separate components associated with preconstruction and construction conditions. The unit load for each site varies depending on the site location according to the climatic zones and the BMPs applied. If no BMPs are applied on a site then the corresponding variable value remains constant indicating no reduction in loadings.

2. Calculate Total Sediment Loadings (TSSL) for each community in Tons/Yr:

$$TSSL_{com} = 3(SUL_{Size} * nsites * Size^4)$$

Table 4 presents the estimates of the construction site TSS loadings by size range for the “baseline” and the Phase II scenario conditions. The table also shows the percent reduction in TSS loadings by size range. The reductions only occur for sites in the 1-5 acre range (the scope of Phase II rule), and reflect application to only those sites that are not covered by existing equivalent state program to control sediments or have an “R” factor less than 10.

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<sup>3</sup>The distribution of Phase II construction sites by size is presented in the Economic Analysis of the Final Phase II Storm Water Rule, 1999. The distribution and total number of sites presented in the Economic Analysis (110,223) is slightly different from the distribution and total of sites used in this study because the waiver was based on a slightly different data set.

<sup>4</sup>For estimating TSS loadings, mid values of the ranges, and 10 acres (assumption) for greater than 5 acres sites are used.

**Table 4. Construction Starts TSS Loadings in Thousand Tons/Year**

Size Range (ac.)	Baseline Loadings	Phase II Loadings	Phase II Effectiveness <sup>a</sup> (% Net Reduction)
0 - ½	404	404	0%
½ - 1	1,185	1,185	0%
1 - 2	3,506	1,566	55%
2 - 3	2,893	1,377	52%
3 - 4	2,230	1,065	52%
4 - 5	2,951	1,453	51%
5 Plus	18,418	18,418	0%
Total	31,587	25,468	19%

a. Construction sites greater than 5 acres (Phase I sites) and less than 1 acres are not regulated by the Phase II rule, therefore zero is shown for the aggregate effectiveness/impact of the program in reducing over all loadings at the national level.

In estimating reduction in TSS loadings due to Phase II soil and erosion control, construction starts/sites presented in the following states because of equivalent programs are excluded.

- @ Connecticut (all sites)
- @ Delaware (all sites)
- @ District of Columbia (all sites)
- @ Georgia (two-to five-acre sites)
- @ Maryland (all sites)
- @ Michigan (all sites)
- @ New Hampshire (two- to five-acre sites)
- @ New Jersey (all sites)
- @ North Carolina (all sites)
- @ Pennsylvania (all sites)
- @ Puerto Rico
- @ South Carolina (all sites)
- @ West Virginia (three- to five-acre sites)
- @ Wisconsin (three- to five-acre sites)

In addition, due to the Coastal Nonpoint Pollution Control Program all construction sites in states of Florida and Rhode Island and sites in CZARA countries in Alaska, Massachusetts, the Virgin Islands and Virginia are excluded.

However, these sites are included in estimating the baseline loadings presented in this table.

*“Small Streams” Modeling*

Construction sites loadings are routed to the overall NWPCAM/RF1 framework by assuming a “small stream” into which the loadings are placed. For each community of construction sites, one small stream is assumed to transport loadings. Thus, 34,500 miles of small streams are added to the water stream network. The rationale for this “small stream” development is that many, if not most, construction sites are on smaller streams that are not in the RF1 network. As a starting point, the length of each small stream is assumed to be the distance of the given construction site community Latitude/Longitude coordinate to RF1. The flow in this stream is estimated in a two-step process. The first step is to estimate the drainage area as a function of the length of the stream. Data from “The Water Encyclopedia” (van der Leeden et. Al., 1990) contains analysis of stream lengths, stream orders, and drainage areas. Using this data, a log-log regression fits the table quite well ( $R^2 = 0.9998$ ). The resulting formula for estimating drainage area as a function of length is:

$$D.A. = 1.086 * L^{1.868}$$

where

D.A = Drainage Area in sq. Mi.,

L = Length in Miles.

The next step is to estimate an average summer flow in cfs/sq. mi. This was done by analyzing the mean summer flows at the headwater reaches in RF1. Separate unit flows were developed for each of the 329 USGS Accounting Units (the 6-digit watersheds). The headwater drainage areas of the RF1 reaches was estimated by dividing the total lengths of headwater reaches by the total reach lengths. The unit flows were then derived by dividing the total headwater reach flows by the estimated headwater drainage areas. This produces estimates of unit mean summer flows in cfs per sq. mi.

Thus, given a length, a mean summer flow is estimated for each construction site. A minimum length for the small streams is set at 1 mile. This minimum is selected for 2 reasons: (1) 1 mile is the standard computational element length in the NWPCAM system; and, (2) the analyses of stream sizes and orders in “The Water Encyclopedia” finds that the average order 1 (headwater) stream length is 1 mile. Stream velocities and depths are estimated using the same techniques as for the rest of the NWPCAM/RF1 reaches. Background concentrations for TSS are assumed for each “small stream” based on an analysis of STORET ambient water quality data. The mean annual loadings from the construction sites are placed into the “small stream”, then decayed and routed to the RF1 reach. These routed loads are then used in the NWPCAM/RF1 framework.

For each “small stream”, a use support under the given conditions is computed by comparing the modeled concentration of TSS at the midpoint to the RFF Water Quality Ladder criteria presented in the Use Support section. Each “small stream” therefore has an associated length

and use support, which is then included with the rest of the NWPCAM/RF1 tables that summarize miles by use support. Finally, the majority of these “small streams” are directly linked to the same Populated Places/MCDs used in the economic analyses, so that the “small streams” are fully integrated into the modeling of water quality impacts of the Phase II controls.

4. Using a database combining Census Populated Places and Minor Civil Divisions, 19,378 (99.7%) of these named communities were linked to Populated Places/MCDs with Latitude/Longitude Coordinates.<sup>3</sup> Similarly, loadings for each community are linked to the NWPCAM/RF1 framework.

### *Development of Baseline*

To measure the impact of the Phase II rule, it is essential to develop the baseline. The baseline is not exogenously given for measuring additional improvement in water quality, therefore the model needs to develop it. From the baseline, further controls of the Phase II are applied. Additional improvement is measured by the difference of the projected baseline water quality and the resultant water quality due to Phase II rule. The model incorporates the minor and major industrial point sources, municipal point sources POTW loadings, and rural loadings primarily from agriculture. For individual places the model first derives the loadings based on the Lovejoy county level estimates and then employs the applicable controls to determine the magnitude of ultimate loadings. The NWPCAM estimates baseline loadings on the basis of following conditions:

1. All CSOs are controlled by detention basins and assume 85% capture of the runoff (the 85% capture is based on NEEDS Survey assumptions),
2. Detention basin controls are at each of the 1,723 individual NWPCAM Phase I urban sites and assume 85% capture of the runoff,
3. Construction sites BMPs are in place based on existing state and Coastal Zone Authorization Act Amendment programs, and
4. Construction sites BMPs are in place at sites greater than 5 acres.

The Phase II scenario conditions take the baseline conditions and further impose:

1. Detention basin controls at each of the 5,038 individual NWPCAM Phase II urban sites and assume 85% capture of the runoff, and
2. Construction sites BMPs are in place at sites between 1 and 5 acres with an “R” factor > 10 or not already controlled by existing state programs.

The model normally requires an engineering surrogate for treatment of specific pollutants contained in discharges, whereas the Phase II program includes structural and nonstructural controls. Therefore, model uses detention basins as a proxy to represent the impact of the

municipal program. Based on surveys of existing literature and textbooks (e.g., “Wastewater Engineering”, Metcalf and Eddy, 1972) on removal of pollutants from detention basins, the changes in urban runoff loadings due to controls assume 33% removal of BOD5, 60% removal of TSS, and 70% removal of FC. These removal rates can be considered as reasonably conservative median values. The model uses these loadings in determining the impact on water quality. The computations are presented in the next section.

## **Model Computations**

### *Temperature and Saturation Concentration of Dissolved Oxygen*

Instream temperature data consists of the mean summer temperatures, by Hydrologic Region, derived the STORET database. This data is used to calculate the saturation concentration of DO. The model then estimates the DO by subtracting the computed DO deficit from this saturation concentration. Table 5 shows the mean summer temperatures and DO saturation concentrations for each Hydrologic Region. As described later, the instream temperatures are used for adjusting several model coefficients. The DO saturation concentration is computed using a multiple regression analysis from EPA’s QUAL2e water quality model.

### *Stream Flows and Velocities*

For the NWPCAM, streamflows and velocities for each RF1 reach come from estimates developed by Walter Grayman for EPA (Grayman, 1982). The flows are based on an analysis of USGS gaging station data. For reaches that did not have USGS gaging stations, or did not have stations with an adequate period of record, the flows were interpolated or extrapolated using the relative values for known streamflows versus “arbolate sums.” The arbolate sum of a Reach is the sum of all reaches upstream of that Reach. Flow estimates were developed for mean flow, low flow (approximately the 7-day, 10-year [7Q10] condition), and mean monthly flow. For the NWPCAM, a mean summer flow was developed for each Hydrologic Region by averaging the flows from June through October. Table 6 shows the results of the regression of mean annual flow on mean summer flow by Region. The QMULT is the resulting multiplier used to adjust the mean annual flow to a mean summer flow. This mean summer flow is the primary reach flow used for modeling in the NWPCAM.

Table 5. Temperature and DO Saturation

Hydrologic Region	Mean Summer Temperature °C	Saturation Concentration of DO(mg/l)
1	18.50	9.3709
2	22.50	8.6603
3	26.00	8.1137
4	18.90	9.2952
5	21.90	8.7607
6	24.20	8.3870
7	21.00	8.9151
8	27.00	7.9686
9	19.00	9.2764
10	19.00	9.2764
11	22.50	8.6603
12	27.44	7.9061
13	19.60	9.1653
14	13.00	10.5368
15	23.10	8.5621
16	15.00	10.0840
17	13.50	10.4202
18	20.70	8.9677

**Table 6. Ratio of Mean Summer Flows to Mean Annual Flows with  $r^2$ , by Hydrologic Region**

REG	QMULT	$r^2$
1	0.61570	0.97610
2	0.51487	0.98305
3	0.49160	0.92584
4	1.03010	0.99924
5	0.46148	0.99215
6	0.63766	0.97408
7	0.91831	0.99835
8	0.70271	0.99903
9	1.03865	0.98480
10	1.14324	0.99513
11	0.80123	0.97457
12	0.65310	0.92625
13	1.15050	0.96363
14	1.15698	0.99348
15	1.12585	0.99650
16	0.90159	0.92208
17	1.17489	0.98593
18	0.58765	0.87646

Velocities are based on estimates also developed by Grayman. These estimates are based on a compendium of time-of-travel studies. Velocities for the mean summer condition come from a log-log regression analysis of mean flows versus mean flow velocity by Hydrologic Region. Table 7 shows the results of this analysis.

Appendix E

**Table 7. Coefficients for  $V = VA(Q^{VB})$ , with  $r^2$ , by Hydrologic Region**

REG	VA	VB	$r^2$
1	0.22185	0.28841	0.93793
2	0.23365	0.28288	0.94476
3	0.21836	0.29048	0.93925
4	0.22574	0.29507	0.91129
5	0.24173	0.26899	0.90456
6	0.23020	0.28499	0.95693
7	0.22324	0.27796	0.93871
8	0.28393	0.25710	0.94205
9	0.18801	0.30005	0.88882
10	0.22650	0.23037	0.86182
11	0.21718	0.27234	0.87888
12	0.21198	0.27369	0.88289
13	0.20999	0.27549	0.90543
14	0.24428	0.24088	0.88334
15	0.26391	0.17197	0.76953
16	0.21151	0.26507	0.82518
17	0.20565	0.28129	0.91492
18	0.19500	0.30904	0.89871

*Stream Channel Geometry*

Stream channel geometry (depth and wetted perimeter), which is used for modeling of TSS and DO, is estimated using a “stable channel analysis” developed by the U.S. Bureau of Reclamation (Henderson, 1966). The analysis considers the bed shear in relation to the local depth at each point. The result of the analysis is that, given an assumption for the channel side slope angle, the depth and wetted perimeter can be estimated as functions of channel cross-section area. Cross-section area can be computed by dividing the streamflow by the velocity:

$$AREA = \frac{FLOW}{VEL}, \quad (1)$$

where

FLOW = streamflow (ft<sup>3</sup>/s)  
 VEL = stream velocity (ft/s)  
 AREA = channel cross-section area (ft<sup>2</sup>).

For the NWPCAM, a 35 degree slope side angle is assumed, which is the angle considered “typical” in the exposition by Henderson. Under this assumption, the RF1 reach channel geometry is computed as

$Y_0 = (AREA / 2.86) = \text{depth at channel center (ft)}$   
 $YBAR = Y_0 * 0.445 = \text{mean depth (ft)}$   
 $P = 4.99 * Y_0 = \text{wetted perimeter (ft)}$ .

*Sediment Delivery Ratios for Rural NPSs*

Rural NPSs are modeled as an average annual loading with a SDR applied to each loading. As described earlier, the SDR is a coefficient which takes into account the losses in pollutant loadings as the water and pollutants move from across the land, down smaller streams, and then to the RF1 reach. In the NWPCAM, the relationship described in Vanoni is used for developing SDRs in each of the 2,111 cataloging units (CUs). This relationship provides an estimated SDR as a function of drainage area. The drainage area per mile of Reach is calculated as

$$A_{CU} = \frac{AREA_{CU}}{j \cdot RCHLENGTHS_{CU}} \quad (2)$$

where

$A_{CU}$  = drainage area (mi<sup>2</sup>) per mile of Reach  
 AREA = CU area (mi<sup>2</sup>)  
 $3RCHLENGTHS_{CU}$  = sum of the lengths of reaches in the CU.

The SDR for each CU is then estimated from the log-log plot from Vanoni as:

$$SDR_{CU} = 0.422 * A_{CU}^{(-0.31)} \quad (3)$$

*Modeling Water Quality Parameter Fate*

The fate of the water quality parameter is assumed to be driven by a first-order decay process, based on the following differential equation:

$$\frac{dc}{dt} = -K(c), \quad (4)$$

where

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

The closed-form solution of this simple differential equation is

$$C_t = C_0 * e^{(Kt)}, \quad (5)$$

where

$C_0$  = concentration at time zero  
 $C_t$  = concentration at time t.

Extensive experience from a large number of studies has shown that this differential equation can be adequate for modeling many of the complex physical and biological processes that take place with many constituents in water. The “trick” to this approach is in selecting the decay rate,  $K$ .  $K$  is generally 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 the NWPCAM, the temperature adjustments to  $K$  have been adopted from EPA’s QUAL2e model.

### *BOD5*

BOD5 is modeled using the first-order decay process described above. The decay value,  $K_{BODinput}$ , is an input variable and can be changed for any given model run. The default decay rate is -0.2/d, with the following temperature correction:

$$K_{BOD} = K_{BODinput} * 1.047^{(T-20)}, \quad (6)$$

where  $T$  = stream temperature ( $^{\circ}C$ ).

### *Total Suspended Solids*

TSS is modeled based on a presumed net settling velocity,  $V_{TSS}$ , of the particles. Research and

literature searches have found a “typical” range for particle settling to be 0.1 to 1.0 m/d. The default net settling velocity,  $V_{TSS}$ , used in the NWPCAM is 0.3 m/d, which represents a “fine grain” particle. Using a given settling velocity, and the estimated mean depth of the channel,  $YBAR$ , a first-order decay process is developed by estimating  $K_{TSS}$  as

$$K_{TSS} = \frac{V_{TSS}}{(YBAR + 0.3048)} \quad (7)$$

### *Fecal Coliforms*

FC is modeled as a first-order decay process with the default decay rate,  $K_{FCinput}$ , of -0.8/d, with the following temperature correction:

$$K_{FC} = K_{FCinput} * 1.07^{(T-20)}, \quad (8)$$

where

T = stream temperature ( $^{\circ}$ C).

### *Dissolved Oxygen*

DO modeling is dependent upon several interacting parameters: the oxygen demand from organic materials (BOD in this model); the Sediment Oxygen Demand, the reaeration from the atmosphere, and the saturation concentration of DO. The actual modeling is of the DO deficit from its saturation level, which is useful since the RFF Water Quality Ladder used for the calculation of economic benefits uses values for the DO deficit. This modeling approach can be found in various places in the water quality modeling literature. A particularly concise source is *The Temporal and Spatial Distribution of Dissolved Oxygen in Streams* by Dr. Donald O'Connor of Manhattan College.

The Ultimate BOD load is the deoxygenation caused by biochemical oxygen demand. UBOD is estimated from BOD5 by the following relationship:

$$UBOD = 1.46 * BOD5 \quad (9)$$

The Sediment Oxygen Demand, SOD, is a deoxygenation effect caused by the benthic demand of bottom sediments, and is expressed as grams of oxygen per square meter of bottom area per day. In the NWPCAM, this value varies depending upon whether or not there are point sources on either that reach or on the reach immediately upstream. Reaches affected by point sources are

presumed to have a higher SOD because of materials deposited by those point source(s). If there are no point sources involved, the  $SOD_{input}$  is set to  $0.5 \text{ g/m}^2/\text{d}$ . If there are point sources involved, then the  $SOD_{input}$  is set to  $1.5 \text{ g/m}^2/\text{d}$ . This term is then divided by the ratio of the channel's cross-section area to its wetted perimeter,  $AREA/P$ , to get the correct units for concentration of  $\text{mg/L}$  of  $O_2$  demand. In the NWPCAM, the actual modeling is of loads, so the  $SOD_{input}/(AREA/P)$  is multiplied by the streamflow (in  $\text{m}^3/\text{s}$ ) to get the correct units for computing SOD in  $\text{g/s}$ .  $SOD_{input}$  is also adjusted for stream temperature. The final formula is

$$S = \frac{SOD_{input}}{\left(\frac{AREA}{P}\right)} (FLOW (1.06^{(T&20)})) \quad (10)$$

The reaeration rate per day,  $K_2$ , is the reoxygenation rate and represents the atmospheric contribution to replenishing the water with  $O_2$ . A slow moving, still body of water will have less reoxygenation than a fast-moving, "bubbly" stream.  $K_2$  has been extensively studied over many years, and various researchers have developed methods for estimating it based on depth and velocity. The NWPCAM uses the method used in EPA's WASP model, which combines the results from three researchers: O'Connor-Dobbins, Owens, and Churchill (Ambrose, 1987). Each researcher's studies tended to be in different ranges of depth-velocity combinations. The general form of the equation for estimating  $K_2$  is

$$K_2 = REAK \left( \frac{VEL_m^{VTERM}}{YBAR_m^{DTERM}} \right) \quad (11)$$

where

- $K_2$  = reaeration rate (/d)
- $VEL_m$  = velocity (m/s)
- $YBAR_m$  = depth (m).

Values for REAK, VTERM, and DTERM values are shown in Table 8. The selection of the specific estimation method for  $K_2$  depends on the stream depth-velocity combination in the given reach.

**Table 8. Reaeration Calculation Values**

	Owens	Churchill	O'Connor-Dobbins
REAK	5.349	5.049	3.93
VTERM	0.67	0.969	0.5
DTERM	1.85	1.85	1.5

The  $K_2$  estimate is then adjusted for temperature as follows:

$$K_2 = K_2 * 1.024^{(T-20)} \quad (12)$$

The Dissolved Oxygen Deficit,  $DO_{Def}$ , is the deficit of DO from the saturation concentration. It is a function of the deoxygenation from UBOD, SOD, and the reaeration as represented by  $K_2$ . The formula for computing  $DO_{def}$  is

$$DO_{def} = DO_{def0} ( e^{-k_2 t} ) + \frac{K_{BOD} ( UBOD )}{K_2 + K_{BOD}} ( ( e^{-k_2 ( t )} - e^{-K_{BOD} ( t )} ) ) + \frac{S}{K_{SOD}} ( ( 1 - e^{-K_{SOD} ( t )} ) ) \quad (13)$$

where

- $DO_{def0}$  = initial DO deficit
- $DO_{def}$  = DO deficit at time t (d)

The actual instream DO is computed as

$$DO = DO_{Sat} - DO_{Def} \quad (14)$$

### Use Support

Use support is calculated using a modified version of a water quality ladder developed by W.J. Vaughan for Resources For the Future, by choosing appropriate reference conditions for  $BOD_5$ , TSS, DO, and FC that correspond to swimmable, fishable, and boatable quality waters (see Table 9). The RFF water quality ladder parameters are DO,  $BOD_5$ , turbidity, pH, and FC. For use in the NWPCAM, two modifications are made to the ladder. First, the original ladder contains pH as a criterion; pH is not modeled in the NWPCAM, so it is not included. The second modification is the substitution of TSS for turbidity (JTU). This is a reasonable substitution, since the original development of the JTU measurements were in terms of controlled TSS concentrations and the two are directly related. The omission of pH, nutrients, and the other water quality parameters that could influence beneficial uses suggests that the model may

overestimate the number of river and stream miles in attainment when any of these other factors are limiting.

The model computes the beneficial use for river and stream segments of one mile or less by: (1) determining the values for each water quality parameter, (2) comparing these values to the reference conditions for meeting each of the beneficial uses, and (3) assigning the beneficial use to the entire segment. Use support for any given computational element is based on meeting of any of the four criteria. For instance, if the FC, BOD5, and TSS limits are met for Swimming, but the limit for DO is met only for Game Fishing, then the computational element is classified as Game Fishing. Every computational element is assigned a use support classification. If any of the criteria is not met for Boating, then the element is classified as “None”, indicating no recreational use support.

**Table 9. NWPCAM Water Quality Ladder**

<b>Beneficial Use</b>	<b>Fecal Coliforms (MPN/100 mL)</b>	<b>Dissolved Oxygen (mg/L) / (% sat.)</b>	<b>5-day BOD (mg/L)</b>	<b>Total Suspended Solids (mg/L)</b>
Drinking	0	7.0 / 90	0	5
Swimming	200	6.5 / 83	1.5	10
Game Fishing	1000	5.0 / 64	3.0	50
Rough Fishing	1000	4.0 / 51	3.0	50
Boating	2000	3.5 / 45	4.0	100

Table 10 is a summary the number of miles meeting the designated uses as defined in the RFF water quality ladder under baseline and Scenario Phase II conditions. Miles are reported for swimming, game fishing, boating, and no support, plus changes in miles in each use category.

**Table 10. Summary of Miles Meeting Designated Uses Under Baseline and Scenario Phase II Conditions**

Use Support	Baseline Miles (mid-1990s)	Phase II Miles	Change in Miles (Phase II - Baseline)
Swimming, Fishing, and Boating	219,547	223,674	4,127
Fishing and Boating	418,190	422,738	4,548
Boating	480,515	483,451	2,936
No Support	186,589	183,653	-2,936
Total Miles	667,104	667,104	n/a

**Economic Benefits**

Literature review indicates that the Carson-Mitchell study (1993) represents the best available source of nationally derived values on in-situ and existence services and, thus, is used here to develop the benefits of the Phase II controls for construction sites and automatically designated municipalities. For determining economic benefits, the willingness to pay (WTP) values estimated by Carson and Mitchell are updated to 1998 values. The WTP values are \$210/household/year for Boatable, \$158/household/year for Fishable, and \$177/household/year for Swimmable waters. Also, since the populations in the NWPCAM databases are for 1990, the populations are uniformly increased by 8% to reflect the U.S. population growth from 1990 to 1998.

To apply WTP estimates to valuing *local* changes in water quality where only a subset of the waters are affected, Mitchell and Carson (1986) describe three “multipliers.” First, a *percent-local* multiplier, which defines the percentage of the stated WTP amount that is applied specifically to water quality improvements in the local area in question. Second, an impairment removal multiplier to describe how WTP changes in relation to the fraction of local water that improves (the stated WTP applies to improvements in virtually all impaired waters). And third, a *population* multiplier, which is simply the size of the population benefitting from the local improvement in water quality.

Percent-local Multiplier: In their survey, Mitchell and Carson asked respondents to apportion each of their stated WTP values between achieving the water quality goals in their own state and achieving those goals in the nation as a whole. On average, respondents allocated 67 percent of their values to achieving in-state water quality goals and the remainder to the nation as a whole. Mitchell and Carson argue that for valuing *local* (substate) water quality changes, 67 percent is a reasonable upper bound for the local multiplier. For the purposes of this analysis the locality is defined as urban sites and associated populations linked into the NWPCAM framework.

Impairment Removal Multiplier: Mitchell and Carson define a simple multiplier that is essentially the fraction of total local water that is initially below a beneficial use target (boatable, fishable, swimmable) but that would attain the target as a result of a policy change. As a lower-bound approximation, it is assumed that the WTP for partial attainment of the specific targets varies in direct proportion to this multiplier. Therefore, for each beneficial use category, the multiplier is calculated at every urban site that is projected to attain the level of use support as a result of the policy.

Population Multiplier: The affected population is defined as the number of households living in the locality of a water quality improvement. The populations are based on the Census populations associated with each urban site in the NWPCAM. For each beneficial use category, if a segment of RF1 or “small stream” attains the level of use as a result of the policy and falls within the defined boundaries of a populated place, then each household within the populated place is included in the multiplier.

The local economic benefits analyses use a definition of “local” that differs from the original Mitchell-Carson Survey, which considered “local” as “state”. In this analysis, “local” waters are defined as reaches that are located near each of the enhanced population locations. The definition of “local” depends on whether it is a Census Populated Place or an MCD. For Populated Places, a circle with an equivalent area to the Place was drawn, centered on the Place Lat/Long coordinate as given by the Census Bureau. Any RF1 reaches that fell in whole or in part within that circle is considered “local” to that Place. For MCDs, the closest RF1 reach is considered the “local” water. “Local” benefits are computed based on use support changes on the RF1 reaches that are “local” to each population location. The totals for miles and economic benefits also fully incorporate the construction sites “small streams” results.

Table 11 shows the total number of households that are associated with the “local waters” that reflect increases in use support. The number of households is computed by dividing the population by 2.62, which is the average household size. Note that even though the miles that change use support is a small percentage of the total miles in the NWPCAM, the numbers of households “associated with these changes is quite significant. Resultantly, the magnitude of the economic benefits is also significant because the greater is the number of households associated with local waters the greater is the magnitude of economic benefits according to the economic theory for environmental goods.

**Table 11. Households Associated with “Local” Waters that reflect Increase in Use Support Under Phase II Rule**

Use Support	Households (millions)
Swimming, Fishing and Boating	24.2
Fishing and Boating	25.7
Boating	23.4

To apply Mitchell-Carson results to value *nonlocal* water quality changes, a similar approach is used. For each category of beneficial use, the fraction of WTP that is assumed to be for local water quality changes only (67 percent) is deducted, which leaves 33 percent (of total WP to attain each use target) for nonlocal water quality changes. This value is multiplied by the fraction of previously impaired national waters (in each use category) that attain the beneficial use as a result of the policy. To measure aggregate national WTP for nonlocal water quality improvements, we then multiply this value by the total number of households in the U.S. Using the methodologies described above, Table 12 summarizes the local and nonlocal benefit estimates due to Phase II controls.

**Table 12. Local and Nonlocal Benefits Estimates Due to Stormwater Phase II Controls**

Use Support	Local Benefits (\$million/yr)	Nonlocal Benefits (\$million/yr)	Total Benefits (\$million/yr)
Swimming, Fishing, and Boating	306.2	60.6	366.8
Fishing and Boating	395.1	51.9	447.0
Boating	700.1	114.6	814.7
Total	1,401.4	227.1	1,628.5

The total estimated benefits of Phase II controls for 120, 047 construction sites and 5,038 automatically designated municipalities in urbanized areas are \$1,628.5 million per year. It is worthwhile to note that while the numbers of miles that are estimated to change their use support seem small, the benefits estimates are quite significant. This is because the vast majority of the water quality changes occur where the people live, and the NWPCAM modeling “captures” this phenomenon.

## Conclusions

*The model estimates that implementation of Phase II controls, without the consideration of post construction controls, will result in an increase of 4,127 swimmable miles, 4,548 fishable miles, and 2,936 boatable miles. The total benefits of Phase II controls for 120,047 construction sites, without the post construction controls, and 5,038 automatically designated municipalities are estimated to be \$1.63 billion per year. It is worthwhile to note that while the number of miles that are estimated to change their use support seems small, the benefits estimates are quite significant.*

Water quality policy can be broad-based, but the effects are primarily local. A strength of the NWPCAM is that it applies the broad-based policies while also being able to model at the local level. Urban runoff and, to a large extent construction activity, occurs where the people reside. NWPCAM indicates that the changes in pollution loads have the most affect immediately at and a limited distance downstream of the pollution changes. This is because rivers “treat” the wastes (using similar processes that occur in a wastewater treatment plant) as it moves downstream. This means that, for a given stream or river, the “memory” of the pollution in the river can be quite small even 10 or 20 miles downstream. Therefore, controls on the pollution sources mostly improve the water quality near where the controls are in place, which is also where the people live.

The benefits estimates in this analysis are derived using conservative assumptions of the pollution control effectiveness of the Phase II program. The Phase I and Phase II urban runoff controls used in this analysis employ pollutant removals that are characteristic of detention basins. Alternative sensitivity analyses assume different levels of control, such as 60% or 80% pollutant removals for urban run off. Supplemental analyses in conjunction with these assumptions indicate that controls in the 60% to 80% range will increase the economic benefits estimates in NWPCAM by \$200 million to \$300 million, respectively.

The results can be considered quite robust, since model sensitivity analyses have consistently shown that the benefits estimates are quite stable, even under assumptions of large changes in model input values. As an example, tests were done in conjunction with this analysis assuming that the construction site loads are off by +/- 25%. The resultant local economic benefits estimates show a change of only +/- 5%. It is worthwhile to note that sensitivity analyses performed on the NWPCAM indicate that the system estimates of changes in use support are fairly steady under changes in flow regimes. For instance, a global change of +/- 25% in flow yields a change of approximately +/- 14% or less in miles of change of use support when comparing a scenario to a baseline run. Other tests indicate that the resultant change in economic benefits will be even less than the 14%.

Further work on the NWPCAM could address improved modeling of wet weather runoff events. Some methodologies that could be applied include use of a stochastic process that would randomize events at various urban sites, using a pattern that reflects the statistical distributions of

storm events. Other areas include using the NWPCAM for forecasting by applying growth factors to the loadings; this could be implemented fairly easily once these factors are determined. Another area is evaluation of Total Maximum Daily Load (TMDL) policies. The NWPCAM is unique in being able to integrate most of the individual discharger and watershed-wide processes on a national scale, which can facilitate use for TMDL policy analysis.

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