Conceptual Design of a Regional Water Quality Screening Model

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Assistant Secretary for Environment
Office of Environmental Assessments

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FOREWORD

The Office of Environmental Assessments (OEA), Assistant Secretary for Environment, U.S. Department of Energy, requested that Argonne National Laboratory undertake a review of existing models and data bases of value in assessing water quality implications of major national energy programs and policy issues. The methods required for this purpose must be consistent with the type of information that is available about proposed national programs and issues, including related models and methods, and with the limited time available for performing assessments. A review of such models and methods constitutes Sec. 2 of this report.

On the basis of the presentation in Sec. 2 and subsequent discussions within the Office of Environmental Assessments and with the Environmental Protection Agency, it was decided that no existing computer model fulfills the analytical requirements of the OEA. Argonne was asked to proceed with its program by developing a conceptual design or working paper that outlined proposed approaches to a model, possible alternatives, and their strengths and weaknesses. That conceptual design paper has formed the basis for further discussion and decision-making. It is reproduced as the remainder of this report with only minor corrections and clarifications.

The Office of Environmental Assessments staff, after consultation with colleagues in the Environmental Protection Agency, has decided to implement a computerized water quality assessment model along the general lines discussed in this report. A detailed description of that model will be published when it has been completed and tested.

The material in this report has already served a highly useful purpose in structuring discussion, aiding decision-making, and guiding the detailed design of the model. It is published as a report to serve as a useful summary of the state of the art and as background information for subsequent use of the new assessment model. We hope it clarifies the purposes of the model and the reasons why this general approach has been adopted.

Richard H. Ball
Project Officer
Regional Impacts Division

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1 INTRODUCTION

Various energy-related activities result in discharges of pollutants to the water environment. Such activities occur throughout the United States, will continue to occur in the future, and may result in water quality impacts of varying degrees of severity. There is a need for an improved capability to identify regions where negative impacts may occur. The purpose of this report is to present the background information and the conceptual basis needed for the design of a regional water quality screening model with such a capability. The model is intended for use in the Strategic Environmental Assessment System (SEAS) used by the Department of Energy (DOE) and also for use in assessments of water quality impacts in efforts such as the Regional Issue Identification and Assessment (RIIA) program of the Office of Environmental Assessments (OEA) of DOE.*

The screening model will be designed to provide: (1) a tool that can be used to identify areas having potential regional water quality problems; (2) a model that has realistic data requirements; (3) a design that allows the model to incorporate improvements in methodology and data as they become available; (4) a model that can be used directly with SEAS; and (5) a model that can be used independently for more detailed studies.

The accuracy of prediction of a water quality model is a function of many factors, including how well the water body being modeled can be described, how well the behavior of the particular pollutants of interest is modeled, and how accurately the quantity of the pollutants being delivered to the water body can be estimated. The accuracy actually needed is a function of the purpose to which the model is being put. A model intended to provide a definitive answer for a well-defined, site-specific situation is designed differently from one used for application in regional assessments. The goals of water quality modeling in regional energy assessments such as RIIA are to identify potential problem areas and to learn something about the magnitude and extent of the problems and then to make some judgements about the viability of an energy scenario. Areas of critical importance may require additional smaller-scale analysis to properly quantify problems occurring within them. This report is devoted to the problem of designing a water quality model for use in regional assessments. The design proposed is sensitive to the goals of regional water quality modeling and attempts to achieve these goals in a manner consistent with the availability of the information needed to support a modeling effort.

In Sec. 2, existing models and data bases of potential value in regional water quality assessments are reviewed. This material provides the background needed for the discussions which follow.

A number of issues must be faced in any modeling of water quality, small-scale or regional. Those issues that are of greatest importance to the problem of designing a regional water quality model are considered in Sec. 3. A primary concern is the matter of spatial scale and how the scale chosen limits the type of results that can be expected. The various spatial scales available for regional assessments are discussed and the question of why

*U.S. Department of Energy, *Regional Issue Identification and Assessment*, First Annual Report, Sept. 1979.

small-scale, existing water quality models cannot be used in regional assessments is considered in some detail. Other issues considered relate to the problem of identifying which pollutants are of most concern and should be included in assessments, and how model calibration and verification should be handled.

The proposed regional model is designed to accommodate residual loads provided by SEAS. As an option, residuals generated internally in the model for utilities, industrial boilers, coal extraction and coal cleaning can be used. This optional methodology is based on the approach used in Argonne's ARQUAL* model. Provision of the optional load generating capability will allow the model to be used independently of SEAS. The water quality model is designed to allow the use of more than one spatial scale. For example, the model will allow one study to be conducted at the Aggregated Sub-Area (ASA) level and another at some smaller scale. Before studies can be conducted at smaller scales, additional data must be assembled. Because of the large spatial scale used in regional assessments, it is generally not possible to model pollutant behavior in detail. The proposed model allows treatment of pollutant behavior consistent with the spatial scale used and the data available.

The proposed water quality model does not predict instream concentrations of pollutants for the present; measured concentrations are used to account for present conditions. The model does provide projections of future instream conditions based on some scenario for energy development and intended for use in screening for potential problem areas. The incremental change in residual-generating activities between the present and the future time of interest produces an incremental change in residuals over the same period. This incremental change in pollutant loading is used by the model to estimate an incremental change in instream pollutant concentrations. Changes in pollutant loading are determined for the particular region of interest and for all regions upstream. The estimated pollutant concentrations for the region for some future time is then given by the present measured concentration, to which is added the change in concentration caused by the changes in loading and flow between the present and the future time. For the upstream loads, the incremental effects at the point of interest can be determined assuming that the pollutant is either perfectly conservative or that it experiences decay. The model does not attempt to fully account for pollutant behavior. It allows a detailed sensitivity analysis to be conducted in order to determine potential problem areas. These areas are identified on the basis of a comparison between projected concentrations and water quality standards and criteria.

The model will allow existing flow and background concentration information for the ASA level to be used for studies at that scale. It will also allow smaller-scale studies to be done. The smallest spatial unit for which consistent low flow data presently exist is the Water Resource Cataloging Unit (1875 units in the U.S.). If instream concentration data were assembled for Cataloging Units, then water quality assessments would also be possible at that level of detail.

The proposed model has a number of limitations. The most important of these are: (1) the neglect of localized effects having a spatial scale much

*ARQUAL is an acronym for the ARgonne Water QUALity Model.

smaller than that of the minimum spatial units used; (2) the neglect of inputs from certain sources of water pollution; and (3) the use of a simplified treatment of pollutant behavior. These limitations are consistent with a screening approach and with the spatial scale used.

Future needs for improving the capabilities of regional water quality modeling are outlined in Section 5. These needs include more detailed spatial resolution in assessments, the ability to better estimate pollutant loads, and also the ability to more carefully account for the dependence of instream pollutant concentrations on streamflow.

2 PREVIOUS¹ RELATED WORK

The purpose of this section is to compare and evaluate models and data bases of potential value in assessing regional and national water quality impacts associated with various energy policies. Only data bases and models bearing on direct discharges and surface water quality impacts are reviewed.*

The models and data bases reviewed were chosen primarily because of their relevance to RIIA/SEAS impact analyses. Some of the material included, however, may be of broader interest.

In an effort to locate existing methodologies and data for use in regional or national water quality assessments, various sources were contacted, among them, all Title II river basin commissions, the U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and the Tennessee Valley Authority (TVA). The relevant information gathered, along with that previously identified, is discussed here.

The structure of this review is similar to that of a water quality assessment, which involves three steps:

1. Estimation of residuals generated
2. Description of the body of water
3. Analysis of the transport and fate of the pollutants

Table 2.1 outlines the various sources of information considered in these three areas.

Only those sources considered relevant to regional and national assessments of water quality impacts were selected for study. Thus, a number of sources were excluded because they were intended only for small-scale applications or contained geographically limited data.

Sections 2.1-2.4 consider the areas of load estimation, river basin description, and pollutant transport and fate, respectively, and conclusions are presented in Sec. 2.5.

2.1 LOAD ESTIMATION

For the purposes of this study, pollutant loads are considered to be of two types, energy-related and non-energy related. Furthermore, these loads may be considered to originate from one or the other of two broad categories of sources: point and nonpoint. Point sources usually discharge continuously, whereas nonpoint sources are usually active only during wet weather periods. Therefore, if the water quality problems of concern occur during

*Energy facilities can affect the quality of water resources through such different mechanisms as direct discharge (includes many nonpoint sources) stream flow depletion, atmospheric deposition, and seepage from solid waste disposal areas. Information related to the impact of direct discharges on regional surface water quality is considered here.

Table 2.1. Overview of Information Sources^a

Assessment Area	Data Base(s)	Models/Methods
Load estimation	Resources for Future (RFF)	RFF, SEAS, ANL
River basin description	RFF, EPA (Reach File), Hanford Engineering Development Lab., ANL, SEAS, EPA (STORET), USGS (NASQAN, WATSTORE)	
Pollutant transport and fate		RFF, SEAS, ANL EPA (Several)

^aSEAS: Strategic Environmental Assessment System; ANL: Argonne National Laboratory; EPA: Environmental Protection Agency; USGS: U.S. Geological Survey.

low-flow periods, the sources of interest are point sources. Energy-related activities can result in both point and nonpoint sources of water pollution. For example, power plant discharges are generally in the point category and discharges from strip-mined areas are usually nonpoint.*

Since point sources usually discharge continuously and since the rate of discharge is often reasonably constant, it is reasonable to assume, for assessment purposes, that the load is distributed uniformly throughout the year. Therefore, it is useful to discuss discharge estimates in terms of annual loads. The analysis of nonpoint source loads is considerably less straightforward. The nonpoint source estimation procedures available for use in assessments usually provide only long-term average annual loads, and there is generally no reliable method available for distributing the load throughout the year. During low-flow periods, this lack is not likely to be a problem; however, judging the amount of pollutants being delivered to a body of water during wet weather presents a substantial problem. Because low-flow periods are those of most interest, and because nonpoint sources are much more difficult to analyze, point sources will be emphasized in the following discussion.

Point Sources

The approach of a point source assessment may be one or the other of the following: (1) the use of an inventory of pollutants being discharged; or (2) the use of coefficients that relate pollutant loads to such factors as facility size and level of activity.

*The EPA distinguishes point from nonpoint according to special criteria. In the case of underground mines, for example, active mines are considered point sources, while abandoned mines are nonpoint.

Assessment of point sources by the second, coefficient method, is simple and commonly used. For the first approach, which is the preferred one, an inventory of actual sources of a certain type (e.g., municipal treatment plants), along with their measured characteristics, must be available, but such inventories are difficult to develop and are therefore in limited use in large-scale assessments. Commonly, the characteristics of a discharge can only be estimated in terms of kg/day of various residuals per unit size of the facility, or, equivalently, in terms of residual concentration (mg/L) and flow ($\text{m}^3/\text{day}/\text{unit size}$). Such discharge characteristics are based on average measured values for existing facilities or on existing or proposed effluent standards. Extrapolation to future conditions frequently requires estimation of discharge characteristics on the basis of effluent standards.

Three separate sources concerned with load estimation are examined in this study: work done by Resources for the Future (RFF), the SEAS model, and Argonne's ARQUAL model. The RFF model has an extensive point source inventory but also makes use of coefficients for noninventoried sectors. Residual loads are determined in the residuals generator (REGEN) of SEAS. Both REGEN and ARQUAL use coefficients for estimating loads.

Table 2.2 briefly outlines the three sources of information considered. The RFF approach¹ estimates loads at the county level of resolution, and it is distinguished by an extensive inventory of sources (especially municipal sources) using 1972 data. However, the RFF model encompasses only a limited number of pollutants and is intended for analyzing 1972 conditions under various levels of discharge control.

The capabilities of the SEAS model^{2,3} are somewhat different from those of the RFF model. On the basis of levels of activity, the REGEN module determines pollutant loads to which it is possible to apply various control levels. Therefore, trending is readily handled and the level of spatial detail is limited, in principle, only by the level of resolution given for the various activities. SEAS uses residual coefficients estimated from EPA effluent guidelines documents, and also based on assumptions about compliance schedules (see MITRE⁴).

ANL's ARQUAL model⁵ is in many ways similar to REGEN. It can determine loads of residuals at whatever level of spatial detail is specified in the siting information used as input. However, it deals only with energy-related activities, whereas SEAS handles both energy- and nonenergy-related sources. (However, SEAS provides a better coverage of energy than of non-energy activities.) ARQUAL deals with a wide range of pollutants and can be used in assessments considering future changes in the number of facilities.

A direct comparison of the loads predicted by the three models for a given set of conditions cannot be made because comparable outputs from each are not available. REGEN and ARQUAL use similar sources of information (e.g., the effluent limitation guidelines document for steam-electric power plants) but nevertheless do not consider the same set of residuals.^{4,5} The most important energy-related pollutants tend to be dissolved and suspended solids and heavy metals. The approaches reviewed treat these pollutants with various degrees of thoroughness: RFF combines all heavy metals into one category, and ARQUAL considers numerous heavy metals separately.

Table 2.2 Approaches to Load Estimation for Point Sources

Characteristics	Approach		
	RFF	SEAS (REGEN)	ANL/ARQUAL
Spatial detail	County	Can provide output by county; results usually provided at a much higher level of aggregation	Based on Siting Data
Pollutant sources	Numerous industries; municipal treatment plants	Energy and Nonenergy-related, with emphasis on the former	Energy-related
Pollutants ^a	BOD, TSS, P, TKN, TDS, Heavy metals	BOD, TDS, N and P for RIIA ^b ; others are available	Numerous (a total of 28)
Trends	Can apply various control levels, but does not consider trends in facilities either by size or location	Considers trends in facilities and controls	Considers trends in facilities and controls

^aBOD: biochemical oxygen demand, TSS: total suspended solids, TKN: total Kjeldahl nitrogen, TDS: total dissolved solids, N: nitrogen, P: phosphorus.

^bRegional Issues Identification and Assessment program.

Nonpoint Sources

As noted before, nonpoint sources are much more complex than point sources. The former are generally intermittent and diffuse in nature and are usually associated only with wet weather periods. Only a limited number of approaches suitable for regional assessment of nonpoint sources have been developed. Most of these nonpoint source analyses are similar to one another and predict only annual loads. There is no reliable method of estimating short-term loads during wet weather or high-flow periods, although such information is necessary for regional assessments. Furthermore, there is no generally accepted set of high-flow conditions to consider, in contrast with the case for low-flow periods, for which widely accepted standard conditions are available (i.e. seven day, ten-year flows).

Nonpoint sources unrelated to energy, e.g., runoff from agricultural and urban areas, may be causes of serious water quality problems. To properly put such sources in perspective, it is necessary to assess high-flow conditions with both nonpoint and point sources active, as well as assessing low-flow conditions with only point sources active.

The SEAS model^{6,7} considers both agricultural and urban nonpoint loads, but only annual averages are determined. A fundamental drawback of the present SEAS approach is that the basic differences between nonpoint and point source behavior are not accounted for. Other technical problems in the SEAS analysis include improper estimation of the efficiency with which pollutants are delivered to a body of water and the questionable validity of the overall approach for urban nonpoint assessment.

Resources for the Future¹ generally uses outside sources for data on urban and rural nonpoint loads. This information typically consists of annual averages with varying amounts of spatial detail. RFF attempts to disaggregate the annual loads and to account for intrinsic differences between point and nonpoint sources. However, their approach does not allow for the consideration of time trends.

The ANL method accounts for energy sectors only. Contributions from nonenergy sectors and natural sources are treated together as "background", estimated using instream concentrations for the base year in the scenario being studied.

Intermittent sources of pollution associated with mining such as mine drainage and sedimentation may be important energy-related sources. The ANL/ARQUAL⁵, RFF,¹ and SEAS⁸ approaches all attempt to account for these sources,* but it is a difficult task due to their variability in character from source to source and due to their intermittent nature, and probably none of the assessment techniques used thus far really does justice to it.

None of the approaches reviewed considers pollutant inputs from atmospheric deposition or through seepage from solid waste disposal areas.

Point sources and low flows are usually of more concern in the assessment of energy-related sources than are wet weather conditions, except

*The SEAS method for mining is not yet operational

possibly in the case of mining and biomass farming, although this may not always be the case for nonenergy sources. It therefore seems more reasonable to initially emphasize dry weather conditions than to devote limited resources to the much more difficult nonpoint source problem.

2.2 RIVER BASIN DESCRIPTION

Once the quantity of pollutants discharged is estimated, the next step in assessing water quality impacts is to consider the behavior of the pollutants in the body of water, which might be a lake, estuary, or stream. (Impacts on groundwater, not considered here, may also be important.) Given the state of the art of regional assessments, only rivers are included in this discussion. However, a lake or estuary of particular importance could be included in a regional assessment by using a water quality model specifically designed for that type of body of water.

Substantial information on stream flow, stream velocity, the constituents of interest, and the like, is needed for an accurate assessment of pollutant behavior in a river basin. For a regional assessment at any but the coarsest level, these informational needs result in rather large data requirements. Hence, the quality of the results from the analysis is determined in large measure by that of the relevant data available on river basins and residuals.

Information on quantity of water, specifically flows, is the most fundamental item in a river basin description. Flow information should be provided by Oak Ridge National Laboratory's water quantity model for use in the water quality model. Nevertheless, it is appropriate here to summarize the available national data bases that contain pertinent flow data as well as other useful information. Table 2.3 outlines the national data bases of interest.

The RFF data base^{1,9} was developed as part of their National Water Pollution Network Model. It was designed to be consistent with the county-level loading information used. The RFF flows are based only on 1972 data, the data base does not include background quality information.

The Reach File,¹⁰ being developed by the U.S. EPA, is a detailed data base, covering essentially all important streams in the U.S., and includes 80,000 river reaches. The Reach File provides a framework for structuring large collections of data on river systems, and the geometric information (i.e., the information on how the various reaches relate to one another) is essentially complete. Mean flows for each reach are being added (1980), and seven-day, ten-year low flows will be added later. Extensive data on water quality and channel geometry are also being added for about 15 major river basins, which cover much of the U.S. (including the Mississippi basin) and are intended for use by the EPA in modeling the transport of toxic substances in rivers.

The Hanford Engineering Development Laboratory (HEDL) data base,¹¹ developed for the Advanced Nuclear Systems and Projects Division of DOE, is complete. It was assembled at the Water Resource Cataloging Unit (WRCU) level for a study related to power plant cooling. There are 1875 such units, and

Table 2.3. National River Basin Data Bases

Data Base	Spatial Detail	Flows	Background Quality Information	Comments
RFF (Refs. 1,9)	60-70 miles (1051 points)	1972 average and low daily	Used only for veri- fication	Contains various data on streams
Reach File/EPA (Ref. 10)	10 miles	Mean and 7Q ₁₀ (in the process of being added)	Being added under a separate program	Extensive data base
Hanford (Ref. 11)	Water Resource Cataloging Unit (1875 points)	Average annual; monthly 50, 90, 95% exceedance flows	TDS, temperature	Also contains data on lakes and groundwater
ARQUAL/ANL (Ref. 5)	ASA ^a	95% exceedance flow	Average background concentrations for numerous constituents	
SEAS (Ref. 12)	ASA	Mean annual flow; lowest mean monthly flow		
NASQAN (Ref. 15)	Water Resource Accounting Unit	Limited period of record in most cases	Extensive, consistent quality measurements for all locations	
General data bases (e.g., STORET, WATSTORE)	These data bases are the fundamental sources of much needed information, which requires considerable manipulation before use in any regional assessments.			

^aAggregated subarea; ARQUAL contains data at a county level of detail for Federal Regions V and VII and is easily expanded to any level of spatial detail, given the proper data.

they are the smallest subdivisions on U.S. Geological Survey Hydrologic Unit maps. Data were assembled for the gauging station in each WRCU that was farthest downstream. The "dominant" county was recorded for each WRCU, as were mean, maximum, and minimum temperatures, mean TDS, average annual flows and 50, 90, and 95% exceedance flows for each month. The data base also contains some information on lakes, groundwater, oceans, and bays. All electric power plants with a capacity of 100 MW or larger are entered by WRCU.

Both ARQUAL and SEAS have a limited data base at present, with national information only at the aggregated subarea (ASA) level. Both have some low-flow data, and ARQUAL also has average background concentrations provided by the USGS. The low-flow data for ARQUAL were obtained from the Water Resources Council 1975 National Water Assessment. The ARQUAL data base has been expanded to the county level of detail for Federal Regions V and VII.

The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN)¹⁵ collects numerous quality data and some streamflow information in a consistent way at the outflow points of all Water Resource Accounting Units. Most sampling locations at this time have only a short period of record. The information is very valuable for any analysis based on Accounting Units.

Oak Ridge National Laboratory (ORNL) is planning to develop a national data base on stream flows at a level smaller than the ASA. The data base is not yet available.

The national data bases maintained by the U.S. EPA and USGS (i.e., STORET and WATSTORE) contain extensive information for many locations. Such sources were used (or are being used) to develop the Reach File and the Hanford data bases. Direct use of these general data bases requires a considerable effort for any serious national study.

2.3 POLLUTANT TRANSPORT AND FATE

A key result desired in an assessment of water quality impacts is pollutant concentration as a function of position in a stream. (In a more complete analysis, if conditions are time varying, the result desired is concentration as a function of both space and time.) Assuming that stream conditions and pollutant loading rates are known, a pollutant's concentration can be estimated if its behavior is understood, and a considerable amount of effort has been devoted to understanding pollutant behavior in aquatic systems. Unfortunately, the data required for most such analyses are too detailed for use in a regional assessment. In this section, attention is restricted to those descriptions of pollutant behavior specifically intended for assessment or screening purposes. The more realistic of these descriptions were developed by the U.S. EPA. The screening exercises for which the EPA models were intended are generally on a scale smaller than is of interest here.

Usually most pollutants are nonconservative--they settle to the bottom of the stream, decay, or are transformed in one way or another. Accounting for such nonconservative behavior can be difficult even in detailed studies, and extremely so in a large-scale assessments. The simplest analysis assumes

that a pollutant is conservative, that is, the total quantity of the particular chemical species does not change. This might also be considered to be a worst-case analysis, since it assumes no loss of the pollutant. The only possible underestimation of effects is then related to not properly accounting for dilution or inputs to the stream. Use of the total amount of the chemical in all forms and the assumption of conservation will still give a worst-case assessment in the case of chemicals for which knowledge of the actual species involved is important. The conservative assumption may, therefore, be a useful one, even if it is possible to account more properly for pollutant behavior.

The ARQUAL model developed by ANL assumes pollutants to be conservative, whereas the SEAS water quality model also allows nonconservative behavior. In the SEAS model¹², the pollutant is assumed to be transferred from one region (ASA) to another (if regions are connected by flows) and to decay by the amount T_d , where T is an "inter-ASA transmission factor" and d is the distance* between ASAs. A value for T of 0.7 for conservative and 0.3 for nonconservative pollutants is suggested. While the values of these numbers are questionable, their use may prevent significant downstream accumulations of nonconservative constituents in cases in which there is flow through many regions.

The RFF model⁹ attempts to be more realistic. Heavy metals (a combination of all heavy metals in one category) and TDS are treated as conservative. Dissolved oxygen is described using the Streeter-Phelps equation; and coliforms, phosphorus, BOD, and oil are assumed to have an exponential decay. At present, suspended solids cannot be analyzed except as conservative. Given the spatial detail used by RFF, their approach may be more elaborate than is justified (e.g., determining dissolved oxygen sag curves when the spatial resolution is 60-70 miles seems unwarranted).

Beyond these attempts at dealing with national assessments, several approaches have been developed by the U.S. EPA for assessment purposes. The intent here is not to review these studies, but merely to indicate their existence and to point out features of their methodology useful for our purposes.

The general-purpose screening methods developed by EPA include those described in the *Areawide Assessment Procedures Manual*¹³ for use in 208 studies, and in *Water Quality Assessment: A Screening Method for Nondesignated 208 Areas*.¹⁴ Although these procedures are intended for rather large areas, they require considerable effort for careful application, even to moderately sized river basins. The approaches advocated are generally classic ones, or simplifications thereof, intended for desk top calculations, and the emphasis is on problems related to municipalities. Although these approaches represent EPA recommendations for large-scale screening and assessment, their proper use, in many cases, requires spatial resolution along streams on the order of tens of kilometers. This degree of resolution requires considerably more detail than is typical in regional assessments.

*Adjacent ASAs are separated by a distance of 1; the distance between two nonadjacent ASAs bordering a common ASA is 2, etc.

The EPA is also developing screening procedures for toxic substances and priority pollutants. These procedures are of interest for indicating possible directions for the Office of Environment Assessment to explore but their use requires numerous parameters to be specified for each pollutant.

The development of models for pollutant behavior is more advanced than the development of data bases needed to describe large areas, and this situation will likely continue for some time. Once detailed data bases are available it is possible to draw on some fairly extensive theoretical developments. However, the danger exists that theory may be applied to data-poor situations, and the results obtained may reflect assumptions rather than reality.

2.4 DISCUSSION

The intrinsic difficulty associated with water quality assessments is that proper evaluation requires detailed information about the actual water environment, in addition to understanding the aquatic behavior of pollutants. Theoretical understanding of the aquatic behavior of many pollutants is well advanced. It is fair to say that, at present, the unavailability of appropriate data is considerably more of a constraint on assessment work than the lack of needed theory. Development efforts designed to support water quality assessments should be directed at the weakest link in the assessment chain--data availability.

Some general conclusions concerning appropriate approaches to regional water quality assessments can be made for both the present and the future. At present, it is necessary to rely heavily on existing methods and data bases. In the longer term (say five years), more powerful approaches (that is, approaches that more properly account for pollutant behavior) may be possible with improved data bases.

In the future, when the Reach File has been expanded to include water quality data, it should serve as an effective framework for regional assessments. Use of this data base with process-oriented models for pollutant behavior will allow more thorough regional and national assessments. It is hoped, too, that during the same period residual inventories will be updated and expanded to remain consistent with the improved environmental data.

At present, prospects are more limited; the available data bases on flows, concentrations, and parameters describing pollutant behavior are small. The most extensive, consistent, and complete national data base on flows appears to be the work of Hanford Engineering Development Laboratory.¹¹ That data base provides a framework that has substantially more detail than has been used in the past for regional water quality assessments. However, it has certain omissions that limit its value for water quality assessments. In particular, if any attempt to model pollutant behavior is to be made, background concentrations for a variety of constituents are needed, as are stream velocities, and distances between locations.

The most complete set of water quality information suitable for assessment purposes is that available from the USGS' NASQAN stations. Extensive, consistent coverage is provided for a substantial group of parameters.

NASQAN is the data source of choice for assessments at the level of Accounting Units, as well as for larger spatial units.

The most extensive point source inventory for residuals is that of Resources for the Future. Their data base compiled for 1972 contains some actual discharge inventories as well as general information on other pollutant sources. It is not clear how much effort would be required to use the RFF data base; in any event, considerable use of coefficients is necessary.

Appropriately accounting for the nonenergy sector continues to be a principal problem in the assessment of residual generation. Depending on the quality of data available, it may be worthwhile to attempt some limited modeling of pollutant behavior. A more appropriate approach might be to treat pollutants as conservative (worst case) in general but to carry out a sensitivity analysis assuming various decay rates for the pollutants known to be nonconservative. Moreover, rather than treating the regional/national modeling that is now possible as an actual assessment, an alternative procedure might be to use such modeling as a screening process to detect problem areas, which could then be individually examined in more detail.

Given the complexity of nonpoint source assessments and the generally greater importance of low-flow over high-flow conditions for energy-related activities, it is recommended that most emphasis be given to low flows and point sources at present. More methodological work on nonpoint source assessment is needed in order to incorporate nonpoint loads more usefully into regional assessments of water quality. The present heavy reliance on annual loads and low flows does not allow for a proper appraisal of nonpoint source impacts.

A major conclusion of this review is that, despite a great deal of effort, few new sources of information relevant to regional water quality impact analyses are available. The U.S. EPA and the USGS are both active in water quality assessment work. The Geological Survey makes more intensive surveys of specific basins than can be applied to the problem at hand. Much of the EPA methodology is intended for small-scale application (at least as compared to regional/national assessments) or for use in idealized environments for which a considerable amount of information is required. These approaches will become useful only when better national data bases are available.

In addition to point and nonpoint discharges, water quality can be affected by other mechanisms related to energy activities, notably air deposition, acid rain, landfill seepage, and stream-flow depletion. Development of methods and data bases for the assessment of these factors, particularly on a regional scale, has been minimal but is definitely needed to improve the assessment of water quality impacts associated with energy policies. In addition, the need exists for detailed characterizations of energy-related discharges, particularly for heavy metals and trace organics. Present approaches for assessing quantities of these discharges are quite variable and in need of improvement.

3 ISSUES IN THE DESIGN OF A REGIONAL WATER QUALITY MODEL

The design of any water quality model requires consideration of a number of issues. The issues related to the modeling of a portion of a particular stream or of regional water quality include: 1) the level of spatial detail to be used; 2) the approach used to model the behavior of pollutants; 3) the pollutants to be studied; and 4) the procedure to be used for calibration and verification of the model. These issues are examined here as they relate to regional water quality modeling. They deserve consideration before the proposed design for a regional water quality model is presented in detail. A reader whose primary interest is in the proposed approach may proceed directly to Sec. 4.

3.1 SPATIAL SCALE

In any water quality analysis there is some minimum spatial detail that is considered. Any behavior with a characteristic spatial scale much smaller than that minimum is neglected. In a regional assessment of water quality, the minimum detail may be rather large. This discussion will consider the "small-scale" problems neglected due to the spatial scale chosen for the analysis, and the options in scale open to regional assessments, as well as their advantages and disadvantages.

3.1.1 Nature of Localized Problems

In any water quality model, the spatial scale chosen determines what can be called a localized problem. "Localized" here means of a scale smaller than the smallest used in the analysis. As the minimum scale considered is increased, these localized effects can become quite large. Three types of localized problems may occur. The first relates to dilution of pollutant discharges by the receiving body of water. If the flow information used does not properly represent the flow occurring throughout the minimum spatial unit considered, then discharges within the unit at points of smaller flow may result in larger concentrations of pollutant than are estimated on the basis of the flow information available. This may be true in any water quality assessment if a discharge is to a small tributary that is not explicitly considered in the analysis. The concentrations determined would then not apply to the tributary. In a regional assessment, where the spatial unit used may contain thousands or tens of thousands of square miles, the flow data (applicable at the outlet of the spatial unit) may not even reflect main stem flows at the upstream end of the unit, much less tributary conditions. This first type of localized problem, then, involves a possible overestimate of dilution of discharges and, therefore, an underestimate of the pollutant concentration at some points within the minimum spatial unit.

It is worth noting, however, that the flow at the outflow point of the spatial unit used does allow an assessment to be made of the physical feasibility of accommodating all discharges within the spatial unit. If a given quantity of pollutant can be adequately diluted by the outflow from a unit, then it is feasible to discharge that quantity of pollutant within the region. Of course, all discharges might have to be at the downstream end of the unit to accomplish this. Determination of localized impacts near a particular

facility is not really a part of a regional assessment. Those responsible for the actual siting of facilities have to be responsive to the need to avoid water quality violations due to new discharges. A regional assessment can only say whether it appears feasible to site a given level of activity within an area. If such an activity is actually introduced into a region, constraints may exist at smaller spatial scales, even if no regional constraints are identified. Note also that since some pollutants do decay or leave a body of water, it may be possible to accommodate considerably more activity dispersed within a region than might be estimated only on the basis of discharges available at the region's outflow point. A regional assessment will, therefore, tend to overestimate regional impacts related to the physical feasibility of dilution at some point within the region.

The second type of localized problem that may occur concerns pollutants that decay (or are removed from the aquatic environment by some means) so rapidly that between the time the pollutant is discharged and the time it leaves the minimum spatial unit it has reached a "negligible" concentration. For example, suspended solids discharged to a very slowly moving stream may be deposited before traveling a long distance. It is very difficult to fully assess the impacts of pollutants whose behavior is such that dramatic changes in concentration due to such factors as decay can occur within the minimum spatial scale considered.

The third type of localized problem relates to the incomplete mixing of an effluent over a stream's cross section near the point of discharge. Complete cross-sectional mixing occurs at some point downstream from the source. In a regional assessment, complete cross-sectional mixing is assumed.

3.1.2 Options Available for Regional Assessments

By their nature, regional assessments consider large areas, and practical considerations limit the minimum spatial scale that can be used. Table 3.1 indicates the most reasonable spatial units presently available for regional assessments of water quality. Perhaps at some future time, units smaller than those shown can be considered, but at present the list given defines the practical options.

The county is a purely political unit. The ASA is based on hydrological boundaries (the Subregion), but involves aggregation and adjustment to county boundaries. Figure 3.1 shows a map of ASAs within the U.S. The Subregion, Accounting Unit, and Cataloging Unit are used by the U.S. Geological Survey and are defined on the Unit Hydrologic Maps published by them. Figure 3.2 shows a map of Accounting Units for the U.S. The data available on pollution generation (the input to the water quality model) are often tied to political boundaries (states and counties). A rational assessment of water quality should, however, be tied to hydrological boundaries. Therefore, problems involving conflicts between boundaries may arise.

An advantage of using the smaller spatial units is that the scale of the localized problems is decreased. This, of course, is accompanied by an increased effort to develop needed data. An important consideration, however, is that for assessments using rather large spatial units, the actual information obtained on water quality impacts may be rather small. There is,

Table 3.1 Spatial Units Available for Use in Assessments

Unit	Number of Units in Conterminous U.S.	Does a Consistent Data Base On Low Flow Exist for This Unit?	Does a Data Base on Background Pollutant Concentrations Exist?
Aggregated Sub-Area (ASA)	99	Yes	Yes
Subregion	204	Yes	Yes
Water Resource Accounting Unit	326	Yes	Yes
Water Resource Cataloging Unit	1875	Yes	No
County	>3000	No	No

as is often the case, a tradeoff between the effort involved and information obtained.

An additional advantage of the smaller units is that the smaller distances involved make it more reasonable to attempt to model the instream behavior of pollutants. For an analysis using ASAs, for example, there is no reason to seriously consider such modeling.

A related, and important advantage of smaller units involves the improved definition of flows for each unit. This advantage can be illustrated by a comparison of ASAs and Accounting Units. In the past, OEA's national and regional assessments using SEAS have been at the ASA level. There are 99 ASAs in the conterminous U.S. In comparison, use of Accounting Units (326 units) provides, on average, an improvement in spatial resolution by a factor of 3. In addition to this improved resolution, Accounting Units provide a significant qualitative improvement over the ASAs. In about 40% of the ASAs, use of Accounting Units provides a major improvement by either resolving multiple outflow points or by resolving major tributaries. Elimination of multiple outflows means that, except in some coastal areas, the flow associated with a particular area is actually the flow of a single stream and is not the accumulation of flows from a number of rivers, as is the case with some ASAs. So in addition to providing improved spatial resolution, use of Accounting Units will yield more physically meaningful results.

For example, to compare ASAs and Accounting Units consider Figures 3.1 and 3.2. In the Pacific Northwest, ASA 1705 covers all of Oregon west of the Cascades, as well as a part of Washington state. This same area is covered by four Accounting Units plus a part of a fifth. The outflow point of the ASA is the mouth of the Columbia River. However, this unit includes areas in southern and western Oregon that drain directly to the Pacific Ocean and that are in no way connected to the Columbia. At the Accounting Unit level, the Willamette River (a major tributary of the Columbia) becomes a separate region, as do rivers draining directly to the ocean (e.g., the Umpqua and

Fig. 3.1 Aggregated Sub-Areas Within the Conterminous United States

Fig. 3.2 Accounting Units Within the Conterminous United States

the Rogue Rivers). Another example is the Atlantic coast of Georgia. This consists of one ASA (303), but four Accounting Units. Similar improvements can be noted on the Gulf Coast, other portions of the Atlantic Coast, and along the Great Lakes. In addition, there are numerous cases of substantial improvements in the resolution of many important tributaries in the interior of the Continent when Accounting Units are used.

The availability of data for the various spatial units was considered in Sec. 2 and is discussed further in Sec. 4.4. Basically, relevant flow statistics are presently available at the ASA and Water Resources Subregion and Accounting and Cataloging Unit levels. Therefore, a unit as small as the Cataloging Unit does present itself as a possible option for assessments at this time. The problems related to using the Cataloging Unit for analysis are discussed in Sec. 4.4.

3.2 SMALL-SCALE VERSUS REGIONAL-SCALE WATER QUALITY MODELING

Numerous stream water quality models are available. These models were developed primarily because of the need to predict instream concentrations of pollutants on a fairly small scale (resolution of tens of kilometers or less). The pollutants considered have typically been of a rather conventional nature. The models generally represent streams as a network of connected segments, and pollutants are assumed to be transported horizontally from segment to segment by the movement of water. Pollutants and water can be added or removed from each segment and the pollutants can be transformed biologically or chemically.

The fundamental equation describing pollutant transport in a stream is the continuity equation for the pollutant. Treating the stream as one-dimensional, that is, neglecting vertical and horizontal variations in pollutant concentration, the continuity equation for a pollutant can be written as:^{16,17}

$$\frac{\partial c}{\partial t} = - \frac{\partial}{\partial x}(uc) + K \frac{\partial^2 c}{\partial x^2} + \sum S$$

where:

c = concentration of the substance of interest

u = stream velocity

K = dispersion coefficient

S = source or sink rate for substance

t = time

x = horizontal distance

The first term on the right side of the equation represents the effects of horizontal advection, the second term represents the effects of longitudinal dispersion and the last term accounts for any sources or sinks of the substance. Longitudinal dispersion is the "effective" diffusion that results when there is integration over the stream's cross section to yield a one-dimensional equation. K serves the same function for a stream cross

section as the molecular diffusion coefficient does on a microscopic scale. Dispersion occurs because the stream velocity across the stream's cross section deviates from the cross-sectional mean velocity.

Various stream models have been developed on the basis of the above equation. An example is QUAL-II, a commonly used stream quality model.¹⁸ These models allow streams to be broken into uniform segments and account for the locations of discharges and tributaries. Depending upon the complexity of the model, the streamflows and the discharges may be time varying. To use such "small-scale" models a number of pieces of information are required:

- stream velocity by segment
- distances between points of interest on the stream
- locations and character of discharge
- stream water temperature
- reaction rates (for chemical/biological transformations)
- some information on stream cross section
- value for K

A model based on the equation given above is intended to provide estimates of instream concentrations with a fairly high level of spatial resolution (and possibly to account for time variations as well) and, in particular, is suited for studying site-specific problems and the effects expected near discharge points. Since these have been the usual goals in water quality modeling, the small-scale model has served the needs of most analysts. Unfortunately, the models are very data intensive and are very expensive to apply to large areas (total stream length of thousands of kilometers, say), assuming that the needed data are even available to allow doing so. Also, most such models were developed for a rather conventional set of water pollutants, namely, biochemical oxygen demand (BOD) and the nutrients nitrogen and phosphorus.

Regional-scale water quality modeling has a goal different from that of small-scale modeling. It attempts to determine locations where water quality problems may arise over relatively large areas. In particular, it does not consider in detail the problems occurring near discharge points. It may point to areas where such problems may occur, but in such cases the use of small-scale models would be necessary to clarify the situation.

Since regional-scale models are concerned with effects extending over larger spatial scales and are not usually meant to handle transient effects or temporal variations in the system (at least at present) the equation given above can be simplified. No time variations are considered, therefore $\partial c / \partial t = 0$. Commonly, K is assumed to be zero. This means that longitudinal dispersion is neglected. (For example, the Streeter-Phelps equation for oxygen concentration is based on the assumption $K = 0$.) Assuming also that stream velocity is constant, the equation becomes:

$$0 = -u \frac{\partial c}{\partial x} + \sum S$$

or

$$\frac{\partial c}{\partial x} = -\frac{1}{u} \sum S$$

If a pollutant is conservative, $S = 0$ (unless there are sources present) and $c = \text{constant}$. If there is exponential decay, $S = -kc$ and then

$$c = c_0 e^{-k(x/u)}$$

Conservative behavior and exponential decay can be used to describe the behavior of a large group of pollutants. They are also useful in doing sensitivity analyses.

The simplifications just given of the more general transport equation are the ones most appropriate for use in regional models. However, the use of a model as simple as static exponential decay can still be very demanding in terms of data requirements when applied to large areas.

It would be desirable in many ways to apply detailed small-scale models in regional studies of water quality. However, doing so places unrealistic demands on resources. Regional-scale modeling has more modest goals than does small-scale modeling. Fortunately, these goals can be achieved with the use of more modest resources.

3.3 POLLUTANTS OF CONCERN

A considerable number of pollutants are generated by energy-related activities. Not all of these pollutants can or need to be considered in an analysis. There is, therefore, a need to develop a grouping of pollutants in terms of relative importance. The most basic factor that determines a pollutant's importance is the relation between the expected concentration of the pollutant in the environment and the maximum concentration of the pollutant for which there is no hazard to any organism, even if it is exposed for a long period. To judge the importance of pollutants on the basis of such considerations requires that the types of pollutants and amounts released to the aquatic environment be determined, that expected environmental concentrations be estimated, and that permissible concentrations be known. Such an approach has been attempted for one energy-related activity, coal cleaning.¹⁹ The coal cleaning study shows that problems of data and methodology exist in trying to apply a fundamental approach to the problem. Since not only coal cleaning but all energy-related activities that discharge pollutants to the aquatic environment must be considered, application of the above approach to determining a pollutant's importance for all energy-related activities is not realistic at this time.

Without benefit of a careful study to rank pollutants for inclusion in the analysis, it seems most reasonable to consider pollutants for which ambient or relevant effluent standards exist or are likely to be developed, as well as pollutants for which professional judgment indicates a need for inclusion. Table 3.2 gives a list of some important pollutants known to originate in energy-related activities. This list is not comprehensive, and the order of the pollutants in the list has no significance. Pollutants on the list are included in one or more of the following: EPA Interim Drinking Water Regulations, EPA list of Priority Pollutants, or EPA Water Quality Criteria.

The pollutants given in Table 3.2 should be considered for inclusion in the regional water quality model. Not all of these pollutants are commonly measured. To be of practical value in regional or national assessments the pollutants considered should be measured at numerous locations throughout the country. Comparison of the list of pollutants in Table 3.2 with the measurements made by the U.S. Geological Survey at their National Stream Quality Accounting Network (NASQAN) stations yields the pollutants given in Table 3.3 that are common to both lists. At least at the Accounting Unit Level of resolution, data on these pollutants are available for use with a screening model. Although the ability to estimate loads for all of these pollutants does not presently exist in SEAS, such a capability can in principle be provided and therefore consideration of all the pollutants seems justified -- at least to the extent of providing background concentration information.

3.4 CALIBRATION AND VERIFICATION OF THE MODEL

Many small-scale water quality models use spatial or temporal aggregations or simplified representations of the processes involved in the transformation and fate of pollutants. These models may use coefficients to describe various aggregated or simplified aspects of the problem. It may not always be possible to assign values to such coefficients a priori. In such cases, the model is often "calibrated" by assigning coefficients so that the results predicted by the model are made to "fit" observed conditions. In principle, if the processes involved are properly understood and described, it is possible to construct models that do not require calibration. Since calibration can be viewed as a process of "curve fitting" if based on a single set of observations, it is recommended that models be "verified" using a second set of data taken under conditions different from those used for calibration. If the model can reproduce the second set of observations without requiring a significant change in the calibrated coefficients, the model is considered to be verified.

Calibration and verification are used to help assure that a model provides reliable results. If is, therefore, desirable to apply these procedures in regional-scale modeling as well as in small-scale efforts. However, because of the scale and nature of regional studies, this may prove very difficult to do. Regional assessments will require large volumes of data to carry out a calibration or a verification. In addition, the predictions made by the model are for an averaged set of conditions for which it may be very difficult to collect the data needed for calibration or verification.

The regional-scale model proposed in this report is basically an accounting model that does not make use of coefficients that might require calibration, except possibly when pollutant decay is considered. Furthermore, the regional model is intended to serve a screening or assessment purpose, as opposed to providing a definitive analysis. Such an assessment should be carried out quickly, with a minimum requirement for inputs. The influence of any uncertainties can be explored by a sensitivity analysis. The development of ranges of relevant parameters for use in sensitivity studies is a more reasonable approach than attempting a regional calibration of the model.

Table 3.2 Some Water Pollutants from
Energy-Related Activities

Total Dissolved Solids (TDS)	Lead ^a
Total Suspended Solids (TSS)	Manganese
Ammonia ^b	Mercury ^a
Sulfates	Nickel
Oil and Grease	Selenium ^a
Chlorine/Chlorides	Silver
Cyanide ^a	Thallium ^a
Phosphorus	Vanadium ^a
Phenol ^a	Zinc ^a
Antimony ^a	Trace Organics
Arsenic ^a	
Barium	
Beryllium ^a	
Boron	
Cadmium ^a	
Chromium ^a	
Copper ^a	
Iron	

^aPriority pollutant.

^bProposed priority pollutant.

Table 3.3 Water Pollutants to be Used
in the Proposed Approach

Total Dissolved Solids (TDS)	Copper
Total Suspended Solids (TSS)	Iron
Chlorides ^a	Lead
Sulfates ^a	Manganese
Phosphorus	Mercury
Arsenic	Selenium
Cadmium	Zinc
Chromium	

^aNot presently available as a residual
in SEAS.

Verification (in the sense of validation) of a regional model can be viewed in a way different from calibration. Calibration of the model must be done over the entire geographical area of interest if it is to properly serve its purpose. Validation could be attempted in selected areas; even if done on a limited scale it would serve to increase the model's credibility.

The regional water quality model described here is not intended to predict background conditions: it attempts to predict the impacts of changes in activities that result in discharges of pollutants. Therefore, verification of the model would involve comparisons of conditions in a particular area at times for which different levels of development exist. Verification would require assembling data on energy and nonenergy-related activities in an area comprising a number of the basic spatial units used by the water quality model. Such data would be required for at least two different periods having substantial differences in economic development (or pollution control), if possible. Data would also be needed on ambient water quality conditions for the two periods, with similar flow conditions. Verification would require that the model be able to reasonably predict the observed change in water quality (at least to the extent of identifying expected problem areas) from the first to the second period.

For use in verification, an area should have the following characteristics:

- It should cover a number of the basic spatial units used in the assessment; several of the units should be connected by flows.
- There should have been a significant increase in energy-related activities in the area.
- Instream concentrations of important pollutants should be available for low flow conditions, and the flow should also be available. Data on concentrations and flows are needed for two periods with significantly different levels of energy-related activities.
- Information that will allow characterization of pollutant discharge from energy-related activities in the area should be available.

It would be preferable if verification could be done for more than one area. Appropriate areas have not yet been identified, and it is anticipated that proper verification of the model will be difficult.

4 PROPOSED APPROACH TO REGIONAL WATER QUALITY MODELING

4.1 BASIC PHILOSOPHY

The total concentration of a pollutant in a body of water is a function of the quantity of the pollutant being discharged from point and nonpoint sources (both natural and anthropogenic), inputs from the stream channel, inputs from sediments, and instream pollutant loads entering the portion of the water body of interest from upstream. If all these inputs are known and if the behavior of the pollutant is understood, then it is, in principle, possible to predict pollutant concentrations in the water. This is what is attempted in a conventional water quality model for a body of water. However, accounting for all the pollutant inputs in a regional assessment is a very difficult task. Therefore, the approach proposed here accounts for the influence of the various sources at the present time by using existing measured concentrations.

The water quality assessment methodology being considered here is intended to predict concentrations at future times and will be used primarily to estimate the impacts on water quality of energy-related activities (including industrial boilers). There is no need to predict concentrations at the present time, only for future conditions. Use of observed present conditions seems a reasonable way to establish a baseline. Estimates of impacts on water quality at future times are then based on incremental changes in pollutant inputs to the body of water. These increments can be estimated on the basis of changes in activities in the basin between the present and the future times of interest. Furthermore, since our primary interest is in impacts due to energy-related activities, pollutant loads from these sources will be emphasized.

The approach proposed is restricted to rivers and streams; lakes, estuaries, the ocean, and groundwater are not considered at present. These may be very important but must be reserved for consideration at some future time.

The model proposed here is viewed as providing a screening analysis rather than a definitive one. Given the large data requirements needed to carry out a realistic analysis of pollutant transport and fate, it is most reasonable to account for the possible effects of pollutant behavior using a sensitivity analysis approach. The methodology will point out those areas where water quality problems may arise. These locations can then be examined more carefully, if needed, using other means. Potential water quality problem areas will be identified on the basis of a comparison of predicted instream concentrations of pollutants for some future time and water quality criteria or standards.

The quality of an assessment that can be carried out is a function of the available data. Since data conditions are improving, the ability to conduct assessments should also improve in the future. Therefore, the model is designed to be flexible so that future improvements can be incorporated.

Table 4.1 outlines some of the basic concepts of model design that have just been discussed. The basic approach to regional water quality modeling

Table 4.1 Important Features of the Model

-
- Use of measured concentrations to account for existing conditions
 - Consideration of incremental changes in pollutant loads
 - Emphasis on the energy sector and industrial boilers
 - Analysis restricted to streams only
 - No attempt to fully account for pollutant behavior
 - Flexible design, so that future improvements can be incorporated
-

just presented is very similar to the one used by Argonne's ARQUAL model.⁵ The present design will allow more complex pollutant behavior and will allow more flexibility in the use of the model; however, the basic concepts used owe a considerable debt to ARQUAL.

4.2 OVERVIEW OF DESIGN

The water quality model will consist of a number of modules. These will be managed by an executive program and can be easily modified or updated as needed. The major portions of the model are the following:

- stream data base
- pollutant load generator for the energy sector
- pollutant transport module
- input/output routines
- executive program

The stream data base contains the description of the streams to be analyzed, including background concentrations. The size of the data base depends on the level of spatial detail desired in the analysis. For example, if ASAs are the basic spatial unit, data will be by ASA.

The pollutant load generator will be provided to serve as an alternative to using SEAS-generated residuals. It will provide the means of determining pollutant loads generated by various energy-related sources on the basis of the level of activity in the basic spatial units. It is included primarily in order to allow the model to be used in a "stand alone" capacity.

The pollutant transport section of the model will handle pollutant behavior in rivers. It will account for pollutant movements between spatial units and for pollutant decay. This portion of the model is one that will be updated as the available data improve.

The interfacing with SEAS siting information and residuals will be done by an input subroutine. All input/output plus the various load estimation and transport calculations will be managed by an executive program.

4.3 POLLUTANT LOAD ESTIMATION

The model will provide two options for determining pollutant loads. One will be to use the loads provided by the residuals generation (RESGEN) portion of SEAS. The second option will be to use residuals for energy sector activities generated internally in the water quality model. The internal load calculation will be based on available facility siting information.

The internal load estimation will be based on the model used by Chiu et al.⁵ The model treats utility and industrial boilers and coal extraction and preparation activities. For utility and industrial boilers, pollutant loads are determined for a number of waste streams having representative concentrations and which occur within such facilities. The volume of each waste stream is assumed to be proportional to the level of activity in the facility. Similarly, coal mine drainage, coal preparation plant discharges, and refuse pile runoff are determined on the basis of the level of coal production and the amount of coal cleaned. The methodology used for load estimation within the water quality model is described in the Appendix. The approach used by RESGEN is similar to that just described; however, not enough information is available to properly compare the two approaches.

In all cases, pollutant loading rates are assumed to be constant, determined only by the size and type of the facility involved. The possible influence of the variability of loading could be examined using a sensitivity analysis.

4.4 RIVER BASIN DESCRIPTION

Analysis of the behavior of pollutants in the aquatic environment requires a description of the stream system in which the pollutants are being transported. This description, in the form of a data base, forms a part of the water quality model. The information needed in the data base is a function of the methodology used to account for pollutant transport and fate. The information is needed for each basic spatial unit considered.

The most basic information needed is the following: flow, concentrations, stream velocity, rate coefficients for the pollutants of interest, and information on how the stream velocities and pollutant concentrations vary with flow. Unfortunately, much, if not all, of this information may not be available at many locations. Design of a regional water quality model must be sensitive to the availability of data.

Flow information for each spatial unit (at least at the ASA level) should be provided by SEAS (based on the output of Oak Ridge National Laboratory's Water Quantity Model) for use in the water quality model. Nevertheless, for possible optional use, some flow data (low flows and average flows) will be stored in the model's own data base. Therefore, flow information will be considered here.

For most of the spatial units described in Section 3.1.2, some data that are useful for water quality assessments have been developed in a consistent way on a national basis. For counties, some data have been assembled, but not on a national scale. At the ASA level, low flows have been developed

by Oak Ridge National Laboratory and background concentrations for numerous pollutants have been assembled by Argonne National Laboratory. At the ASA level, any modeling of pollutant behavior is not realistic, and therefore, no additional data are needed (unless additional pollutants are considered). At the Cataloging Unit level, the Hanford Engineering Development Laboratory has assembled low flow and average flow data for about 1700 of the 1875 units. Concentrations of a single constituent, total dissolved solids, were also collected. There are some possible problems with the Cataloging Unit data base on flows as it now exists: (1) flow statistics were developed using data for the period of record - no consideration was given to possible regulation of flow; and (2) the stations chosen to represent the Cataloging Units were the ones farthest downstream in a Cataloging Unit -- in some cases a station in the next downstream unit might serve better. These possible problems should not rule out use of the flow data. The primary difficulty with using the Cataloging Unit at this time is that additional information is also needed, primarily background pollutant concentrations. If these data were assembled, and if at some later time the flow data were refined, a very good start on a Cataloging Unit level data base would exist. The Cataloging Unit is hydrologically based and is small enough that serious consideration could be given to more careful modeling of pollutant behavior.

At the Accounting Unit level, the U.S. Geological Survey (USGS) is collecting quality information at outflow points in a consistent way in most regions in their National Stream Quality Accounting Network (NASQAN) program.¹⁵ Many of the pollutants of interest here are considered in that program. The primary problem with using NASQAN data is the short period of record involved for most locations, usually only a few years.

Cataloging units are contained within Accounting Units, which are contained within Subregions. Since flow data are available for outflow points of Cataloging Units, they are also available at the outflow points of all the larger units as well. And since water quality data are available at outflow points of Accounting Units, a flow and quality data base can be assembled at the Subregion or Accounting Unit level.

The hydrologic units used by the USGS differ in size from location to location, providing different degrees of spatial resolution. If a data base were developed using Accounting Units, it could be selectively expanded in certain areas using Cataloging Units to give a more uniform spatial coverage or to improve coverage in high priority areas.

The discussion above provides motivation for the following approach to data base development:

- Assemble existing flow and quality information on an Accounting Unit level for the conterminous United States. The information would apply at outflow points of the Accounting Units.

- As needed, expand the data base selectively at the Cataloging Unit level, emphasizing high priority areas.* For example, high priority areas could be determined on the basis of the location of existing or likely energy-related activities or of the location of existing high instream concentrations of pollutants.
- Continued development of the data base in this manner will lead to a consistent national data base at the Cataloging Unit level
- Once data are assembled for the Accounting Units, the data base can be considered "complete" in a very real sense, independent of how much additional data are added for Cataloging Units. Therefore, even if the data base is being continually improved, it will always be available for use in assessments at any stage of development.

There are two potential areas of concern associated with development of a data base using hydrologic boundaries. The first is that information on activities, and hence pollutant load estimates, is based on political boundaries. How are those loads assigned to hydrologic units? The second concern relates to aggregating the basic spatial units used to arrive at a political unit, for which results can be reported.

Consider the first issue. Water flow respects hydrologic boundaries, but the information needed to estimate pollutant loads is usually available for political units. A problem of correspondence will exist no matter which unit is chosen, since there are basically two inconsistent units involved. The question is: is it better to try to assign pollutant loads to hydrologic units or to devise artificial flows for political ones? The former approach seems more realistic from a physical point of view. Therefore, it is suggested that county-based pollutant loads be assigned to hydrologic units. (If actual locations of facilities can be established, there should be no problem.) The water quality model would contain a table indicating the correspondence between counties and hydrologic units.

The second issue, aggregating results to political boundaries, is a somewhat different matter. Use of ASAs will not allow such aggregation to be done. In fact, it can only be done if political units or units that coincide with political units or subunits are used as the basis for analysis. However, this problem of aggregation only occurs if the entire area of the basic unit of analysis is considered. In the approach proposed here, only the outflow point of each unit is being considered. No conclusive statements can really be made about all locations within the unit. (This is a problem of neglecting localized effects.) The results that can be provided are, for

*The data base and associated software will be organized to allow limited development with little effort. However, going from Accounting Units to Cataloging Units involves a factor of over five in expansion of size. In order to provide an efficient system, the system will be designed to operate at the Accounting Unit level. A five-fold expansion in data will realistically require significant programming changes. The alternative would be an initially inefficient system capable of very large expansion at some later time.

example, that potential problems exist at the outflow points of N analysis units for pollutant X. This information can be aggregated to state or other political boundaries. However it must be emphasized that conclusions are being drawn for a set of points and not areas.

In addition to information on flows, there is a need for estimates on the amount streamflow that will be depleted by consumptive use. It is assumed that consumptive use information will be provided by SEAS for use by the model.* If the model is used independently of SEAS, then consumptive use will be estimated internally using coefficients for the case of power plants. In either case, instream concentrations will be estimated in the model using flows adjusted for consumptive use.

4.5 POLLUTANT TRANSPORT AND FATE

The proposed assessment methodology will provide estimates of instream concentrations of pollutants at the discharge point of a region. Existing, measured concentrations will be used to represent present conditions. Concentrations at a future time are estimated on the basis of the incremental changes in concentration between the present and the future period of interest. These may be expressed as:

$$\left\{ \begin{array}{l} \text{concentration of a} \\ \text{pollutant at the dis-} \\ \text{charge point of a re-} \\ \text{gion for a particular} \\ \text{future year Y} \end{array} \right\} = \left\{ \begin{array}{l} \text{instream concentra-} \\ \text{tion measured at the} \\ \text{discharge point at} \\ \text{present (adjusted} \\ \text{for withdrawals)} \end{array} \right\} + \left\{ \begin{array}{l} \text{incremental concentration} \\ \text{change for the pollutant} \\ \text{at the discharge point} \\ \text{(between the present} \\ \text{and year Y)} \end{array} \right\}$$

and the incremental concentration change is given by

$$\left\{ \begin{array}{l} \text{incremental concen-} \\ \text{tration change} \end{array} \right\} = \left\{ \begin{array}{l} \text{incremental change} \\ \text{due to changes in} \\ \text{loading and flow in} \\ \text{the region} \end{array} \right\} + \left\{ \begin{array}{l} \text{incremental change due} \\ \text{to changes in upstream} \\ \text{loading and to changes} \\ \text{in flow in the region} \end{array} \right\}$$

Upstream loads may be attenuated between the point of discharge and the region of interest.

Details within a region are ignored, that is, the actual location of discharges within the region are not specified and complete mixing is assumed. Sensitivity analysis can be used to help make some judgments concerning problems within a region. However, the analysis is primarily intended for studying problems with a scale larger than that associated with the basic regions used.

The expressions given above for pollutant concentration can be written more precisely. The concentration of a pollutant at the discharge point of region i for a particular future year Y is given by:

*The model will depend on SEAS to provide comprehensive water consumption estimates for energy and, particularly, non-energy-related activities. Such estimates will be required for any studies in which the effects of consumptive use are of great importance.

$$C_i^Y = \frac{Q_i^O}{Q_i^Y} \cdot C_i^O + \frac{\sum_{j=1}^{i-1} \left(\prod_{k=j}^{i-1} \alpha_{k,k+1} \right) \Delta L_j^Y}{Q_i^Y} + \frac{\Delta L_i^Y}{Q_i^Y}$$

where:

C_i^Y = concentration for region i for future year Y

Q_i^O = flow at discharge point of region i at present

Q_i^Y = flow at discharge point for region i in year Y

C_i^O = concentration for region i for present (observed)*

$\Delta L_j^Y = L_j^Y - L_j^O$, the increment in pollutant load to region j

L_j^Y = load of pollutant to region j in year Y

L_j^O = load of pollutant to region j at present

$k, k+1$ = factor that accounts for pollutant transport between regions k and k+1

The flow at the discharge point for region i in year Y is given by:

$$Q_i^Y = Q_i^O - \sum_{j=1}^i \Delta Q_j^Y$$

where

ΔQ_j^Y = change in consumptive use and other depletions in region j between present and year Y

The attenuation factor can be defined more precisely,

$\alpha_{k,k+1} = 1$: conservative behavior

$\alpha_{k,k+1} = 0$: no accumulation of upstream load

$\alpha_{k,k+1} = \exp(-Kd_{k,k+1}/V_{k+1})$: exponential decay
where K = rate of decay

* C_i^O is actually a function of flow. For example, the concentration of dissolved solids tends to decrease as flow increases and the concentration of suspended solids does the opposite. This dependence of C_i^O on flow will not be included in the initial implementation of the model. However, it is strongly recommended that such dependence be accounted for in later versions.

$d_{k,k+1}$ = distance between outflow points of regions
k and k+1

V_{k+1} = average stream velocity in region k+1

The equation above for C_i^Y is exact for the case of no mass withdrawal of pollutants from the system. If withdrawals of water are made for which some mass of pollutants is removed from the stream and not returned, then the equation given will overestimate C_i^Y , since there is no accounting for mass removal. Pollutant mass may be removed, for example, in irrigation diversions or in the case of facilities practicing zero discharge. The expression for C_i^Y could be modified to include mass withdrawal terms on the right side. However, assembling the information needed to evaluate those terms will prove difficult, since it will require the inventory of water withdrawals as well as the fate of pollutants withdrawn in each case. Since the problem is difficult, and since neglect of the withdrawals results in an overestimation of instream concentrations at future times, accounting for mass withdrawals has been neglected at present. However, a modification to the equation and to the regional screening model should be made in the future so that the impacts due to the reduction of upstream loads in streams where major diversions exist, such as the Colorado and Rio Grande, can be more properly treated.

The approach proposed for assessing water quality impacts will make use of the methodology just outlined and will provide a screen for potential problem areas. In essence, it will be a sensitivity analysis. The model will evaluate several possible situations, beginning with the worst case. If no problems are apparent with the worst case, then there should be no difficulties experienced. If problems occur with the worst case, then other less pessimistic approaches can be examined to learn more about the likely severity of the problems.

The worst case* treats pollutants as conservative, deals with the total pollutant in all its forms (as opposed to dealing with individual species), and accounts for upstream loading. Unless there is an underestimate of the loads or an overestimate of the flows (which can be considered via sensitivity tests), this approach will give the maximum concentrations that can be expected for the various pollutants at various locations along a river. (This neglects, of course, localized problems that may occur within the basic spatial units used.) Much less pessimistically, all upstream loading could be neglected so as to determine if pollutant loading within each spatial unit were individually sufficient to cause any problems. As an additional approach, various rates of decay could be assumed for pollutants and resulting concentrations determined. To carry out this last set of calculations requires information on stream velocities, distances between stations, and pollutant decay rates. Useful results could be obtained using crude estimates for distances or travel times plus estimates or ranges in the rates of decay. Use of this information would allow a more detailed sensitivity analysis to be carried out. However, information on decay rates and distances between

*As noted, this is a worst case in the sense that conservation of the mass of pollutants introduced into the stream is assumed. It may not be truly a worst possible case since some sources of pollutants may be ignored or underestimated.

locations needs to be assembled before such an analysis can be done. Such information may not always be available.

While it may seem that consideration of only conservative behavior or exponential decay provides only a limited ability to accommodate various pollutants, it is nevertheless true that a rather large group of pollutants can still be handled with these two models. Pollutants such as suspended solids or a parameter such as dissolved oxygen would require a more complex approach. The data required to support an analysis using "only" exponential decay are such that the approach outlined here is likely to remain the state of the art for sometime - at least until the data situation changes substantially. However, as more data are assembled in the future, a more detailed treatment of pollutant behavior may become possible. The proposed water quality model will therefore be designed to allow improvements in the methodology for pollutant behavior to be readily incorporated.

4.6 RESULTS PROVIDED BY THE MODEL

The output that will be provided by the water quality model is an estimated range of instream concentrations of pollutants at a future time. The types of output provided will depend on the actual information available in a particular area. Assuming that low or average flows, background pollutant concentration, distances between spatial units, stream velocity, and a range of decay rates for the pollutant are available, then the following results will be provided for the pollutant for each spatial unit, for low or average flow conditions, and for each year* in the scenario:

- instream concentration, assuming conservative behavior and including upstream loading (worst case).
- instream concentration, assuming conservative behavior, but with no upstream loading
- instream concentration, assuming nonconservative behavior (exponential decay) and including upstream loading for:
 - (1) minimum decay rate
 - (2) average decay rate
 - (3) maximum decay rate
- an indication of when estimated concentrations exceed relevant standards or criteria.

Information on the contribution of pollutants from different sources (energy and non-energy-related) will be carried through the calculations so that an indication can be made of the output of the relative contribution of these various sources.

If decay rates cannot be estimated, and distances and stream velocities are not available, then nonconservative behavior will not be considered.

*Changes in instream concentrations for years after the base year result only from changes in loads and flows explicitly accounted for in input to the model, i.e., if no nonenergy sector loads are available, concentrations reflect only the effects of energy sector loads.

Provision will also be made to include a type of behavior different from exponential decay, in the output results for nonconservative behavior, if warranted for a pollutant and if needed data are available to perform the calculations.

Use of the nonconservative behavior option for an ASA level analysis is probably not realistic since parameters cannot be properly estimated. Parameter values can be varied to determine the sensitivity of the output to the various factors involved in the analysis. The outputs listed above should provide the basis for a rational assessment of water quality impacts on a regional scale. Problems occurring within individual spatial units could not always be detected by such an approach.

4.7. LIMITATIONS IN THE PROPOSED APPROACH

The proposed approach is intended to be used for screening purposes. It will not provide definitive answers. The approach, therefore, has the following limitations:

- The approach neglects localized effects. This topic has been discussed at some length in the section devoted to issues. The spatial extent of the localized effects neglected is tied to the spatial scale used.
- Certain sources of pollutants are neglected. It is unlikely that all sources of pollutants can ever be included in a regional assessment. However, the approach specifically neglects a number of sources: nonpoint sources, atmospheric deposition, and any seepage from waste disposal areas. At present, the emphasis is on point sources. If the model is used in conjunction with SEAS, then any point source not considered by SEAS will be neglected. If used independently, the sources considered are either energy-related or associated with industrial boilers. Neglect of nonpoint sources is likely to be of importance when dealing with average flow conditions if nonpoint source loading changes over the time period studied but will probably have little effect for low flows.
- The model uses a simplified treatment of pollutant behavior. In particular, pollutants are assumed to be either conservative or to experience an exponential decay. While these two possibilities cover a wide range of likely applications, they will not cover all. Availability of data on a national scale will limit uniform use of more complex approaches in the near future.
- The approach considers a restricted group of pollutants. Not all possible pollutants can or need to be included. The list of pollutants to be used was developed using professional judgment alone. This may result in the neglect of certain important pollutants. Even for pollutants judged to be important, it may not be possible to

consider them all, since data on loadings or background pollutant concentrations may not be available.

- Full compliance with discharge requirements is assumed. All discharges are assumed to comply with relevant standards. Any spills or accidents are neglected.
- All discharges are assumed to have "average" characteristics. The methodology used does not distinguish between facilities of a particular type - all are assumed to have the same, average characteristics. Accounting for individual differences on a plant-by-plant basis would be a very large undertaking.
- Dependence of background pollutant concentration on flow level is neglected. This dependence will be neglected in the initial version of the model. However, it should be accounted for in later versions. Since both low and average flows will be available for study, provision of only a single base year concentration will result in some inaccuracy. The single concentration provided initially will probably best reflect average flow conditions.
- Secondary effects associated with energy development are neglected. No discharges associated with secondary growth are included, unless SEAS can provide such inputs.
- Thermal discharges are ignored. Thermal effects are usually localized and site-specific and are not considered in the assessment.

5 FUTURE NEEDS

This section describes a number of topics that should be further addressed in order to help improve the capabilities of the water quality model discussed here.

5.1 DEVELOP AN IMPROVED DATA BASE TO SUPPORT MODELING ACTIVITIES

Several subjects related to this topic are worthy of attention. The first involves the problem of what spatial scale is most appropriate for conducting regional assessments. The other subjects relate to actual data base construction.

5.1.1 Study the Spatial Scale Appropriate for Regional Assessments

The issue of what spatial scale to use in regional assessments should receive more attention. To address this issue, the question of what goals need to be achieved by regional water quality modeling should be examined more carefully. The accuracy of a water quality model needed to achieve such goals should be determined and related to the spatial resolution required for input data. In addition, a study of a major river basin should be carried out with several scales of spatial resolution to determine the improvement provided by smaller scales.

5.1.2 Extension to a Cataloging Unit Level Data Base

As was indicated earlier, the Cataloging Unit is a useful spatial element for regional analysis. However, to fully take advantage of such a scale, much additional data are required. In particular, additional flow statistics are needed, background pollutant concentrations must be assembled, and information on stream velocities and distances between stations collected. The existence of such an expanded data base would greatly enhance regional water quality assessment capabilities. Use of Cataloging Units would provide a nearly six-fold improvement in spatial resolution over that provided by Accounting Units.

5.1.3 Develop a Data Base Based on the Reach File

The U.S. Environmental Protection Agency (EPA) is currently developing a data base, called the Reach File, on streams in the United States. This data base will contain a digitized trace of most important streams in the U.S. Flow data will be added for existing gauging stations and extrapolated to other between-station locations to give a resolution of less than 10 miles. Eventually, other information, including water quality data, will be added to this framework. The Reach File should form the basis for much future work on water resources in this country. Development of a data base consistent with the Reach File is advisable if only because additions to the Reach File could also be incorporated into such a data base. On the basis of the results obtained from the study of appropriate spatial scale, a data base could be assembled that is intended to serve the needs of a regional assessment and

that constitutes a subset of the larger Reach File data base. One or two subsets of this reduced data base could also be identified if less refined regional assessments are needed. It is not suggested that both this approach and the approach based on Cataloging Units be pursued simultaneously. However, they are both worthy of consideration. A data base using the approach just proposed cannot be constructed at present but will probably be of longer term value than the Cataloging Unit approach. In either case, spatial resolution can be improved selectively, with highest priority areas improved first.

5.2 IMPROVE THE ABILITY TO ESTIMATE POLLUTANT LOAD

The ability to estimate loads might be considered to be more a part of RESGEN than of the screening model. However, improved estimates of pollutant loads at the county level, especially for priority pollutants and unregulated pollutants, are needed in order to carry out a more realistic analysis. Since the utility of the screening model is very much dependent upon the accuracy of the load estimates, improving those estimates deserves high priority.

5.3 ACCOUNT FOR DEPENDENCE ON STREAM FLOW OF BACKGROUND INSTREAM CONCENTRATION

Pollutant concentration in a stream can depend on stream flow and can either increase or decrease as flow increases. This behavior should be accounted for in the screening model in those geographical areas and for those pollutants for which it is possible to do so.

Since the data needed to account for this dependence of concentration on stream flow will be assembled when the model's data base is constructed, relating background concentration to stream flow is one of the more economical, as well as potentially useful, model enhancements.

5.4 CONSIDER NONPOINT SOURCES OF WATER POLLUTION

Nonpoint sources are inherently much more complex to assess than point sources. Once point source problems and associated data base requirements are better addressed, nonpoint sources should also be considered. In terms of water quality modeling, this means consideration of a different set of flow conditions and possibly a consideration of transient effects associated with wet weather. Nonpoint sources related to energy are most likely to be associated with resource extraction and biomass farming. Development of improved capabilities related to nonpoint sources of the latter type is currently being carried out at Argonne.

5.5 ALLOW ACCESS TO THE MODEL'S DATA BASE VIA A GENERAL DATA BASE MANAGEMENT SYSTEM

The screening model's data base will contain a variety of useful information on streams in the United States. Allowing this information to be accessed by analysts for other purposes may be useful.

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APPENDIX A
POLLUTANT LOAD ESTIMATION

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POLLUTANT LOAD ESTIMATION

An option for estimating pollutant loads from energy sector activities will be contained within the model. Utility and industrial boilers and coal extraction and preparation activities will be considered. The material presented in this appendix is taken from Chiu et al.¹ The loads are assumed to be constant and a function only of facility type and size.

A.1 POLLUTANT LOAD ESTIMATION FOR UTILITY AND INDUSTRIAL BOILERS

Energy for electricity generation is expected to be derived from coal, oil, gas, and nuclear sources; industrial boilers are expected to use the same energy sources, with the exception of nuclear fuel. The effluent guidelines regulating the concentrations of effluent streams from energy conversion facilities are based on Best Available Technology (BAT) and New Source Performance Standards (NSPS). The BAT requirement will become effective not later than July 1984 for existing facilities; the NSPS became effective in July 1977 for all new facilities.

The aqueous effluents that are produced in energy generation processes and are regulated by effluent guidelines are listed in Table A-1; all these effluents are considered. The expected characteristics of each stream, when the various standards are implemented, are described in Table A-2 and are incorporated into the model.

Table A-1 Effluents from Industrial and Utility Activities

Activity	Utility				Industrial			
	Coal	Oil	Gas	Nuclear	<250 x 10 ⁶ Btu/hr	>250 x 10 ⁶ Btu/hr	Oil	Gas
Boiler blow-down	X	X	X		X	X	X	X
Metal Cleaning Wastes	X	X	X	X	X	X	X	X
Low-volume Wastes	X	X	X	X	X	X	X	X
Cooling Tower Blowdown	X	X	X	X				
Flue-gas Desulfurization	X					X		
Ash Handling	X				X	X		
Coal Pile Run-off	X				X	X		

Table A-2 Characteristics of Industrial and Utility Effluents

Pollutant Concentration (mg/L)	Boiler Blowdown	Metal Cleaning	Low Volume	Cooling Tower Blowdown	Flue-gas Desulfurization	Ash Handling		Coal Pile Runoff
						Fly	Bottom	
TSS	-	80-200,30 ^{a,b}	70,30 ^{a,b}	-	30,30 ^{a,b}	30,30 ^a	2.4,2.4 ^a ,1.5 ^b	625,50 ^{a,b}
TDS	-	3000-20000	1000-9000	-	3500-10500	750-1250	350-750	250-29000
Ammonia	1-3	.05-3.5	0.15-0.45	-	0.35-0.95	0.5	0.5	-
CN	-	-	-	-	0.005-0.015	-	-	-
Sulfate	-	700-2200	8-24	-	900-2000	40-240	40-240	1600-3600
Oil & Grease	15,15 ^{a,b}	15,15 ^{a,b}	15,15 ^{a,b}	-	-	15,15 ^a	1.2,1.2 ^a ,0.75 ^b	-
Phosphate	30	0.5-1.5	-	5.5 ^a ,0 ^b	0.05-0.15	0.007-0.022	0.025-0.075	0.3-0.9
Chlorine	-	-	-	12.5,0.2 ^{a,b,c}	-	-	-	-
Potassium	-	0.5-3.5	-	1-9	-	-	-	-
Aluminum	-	-	-	-	0.2	1.2	1.2	-
Arsenic	-	-	-	-	0.016	0.01	0.01	-
Barium	-	-	-	-	0.15,0.03 ^d	0.07,0.03 ^d	0.07,0.03 ^d	-
Boron	-	-	-	-	-	0.5	0.5	-
Cadmium	-	-	-	-	0.004	0.01	0.01	-
Copper	1.0,1.0 ^{a,b}	3-11,1.0 ^{a,b}	-	0.05-0.15	0.03	0.3225	0.015	1.8,0.5 ^d
Chromium	-	2.5-11.5,0.3 ^d	-	10-14,0.2 ^a ,0 ^b	0.03	0.6,0.3 ^d	0.045	0.8,0.3 ^d
Iron	1.0,1.0 ^{a,b}	1000-1600,1.0 ^{a,b}	-	0.05-2.2,1.0 ^d	0.1	3.6,1.0 ^d	1.55,1.0 ^d	250,1.0 ^d
Lead	-	-	-	-	-	0.01	0.01	0.1
Manganese	-	-	-	-	0.4,0.05 ^d	0.31,0.05 ^d	0.405,0.05 ^d	0.027-0.05 ^d
Mercury	-	-	-	-	0.0004	0.001	0.001	0.01
Nickel	-	5 ^a ,0.5 ^d	-	-	0.22	0.01	0.01	0.03
Selenium	-	-	-	-	0.41,0.29 ^d	0.04	0.04	0.03
Zinc	-	0-10,1.0 ^d	-	15-25,1.0 ^a ,0 ^b	0.04	0.055	0.105	0.1-12.5,1.0 ^d
Flow Rate (gal/day per MW capacity)	50-60	15-20	100-150	2000-5488	100-500	100.0 ^d	400,250 ^{a,b}	See Text

^aBAT Effluent Guideline Limitations.^bNSPS Effluent Guideline Limitations.^cMaximum of 2 hr/day discharge.^dAssumes coagulation and precipitation treatment to meet effluent guideline limitations for TSS, Cr, Fe, and Zn.

Some entries in Table A-2 show single values; these pertain to effluent characteristics that are valid for all scenarios and are not affected by effluent guidelines. Other entries show ranges of pollutant concentrations that were observed prior to the 1977 application of discharge standards; the means of the ranges indicated are used. Finally, some entries show two or three values; in these cases the footnoted values will apply when particular guidelines identified in the footnotes are implemented.

It should be noted that the characteristics of effluents from flue-gas desulfurization, ash handling, and coal-pile runoff vary widely among facilities; however, the values shown for these effluents in Table A-2 represent a range of representative concentrations adequate for the purposes of an assessment. The volume of coal-pile runoff in a region is partially dependent upon the actual precipitation and evaporation rates in an area. It is assumed that 40% of the average annual precipitation in each spatial unit will result in coal-pile runoff. Further, it is assumed that a 90-day coal reserve will be maintained in a pile that covers 0.02 acres per megawatt of operating generating capacity.

All values in the table are provided according to an assumed generating load factor (operating capacity) of 55% of installed capacity.

For analytical purposes, fuel consumption by the industrial sector is assumed to occur entirely in boiler heating, although fuel is also consumed in other water-polluting processes in a production facility. This assumption provides a method for evaluating effects on water quality when it is also assumed that industrial boiler fuel use creates effluents similar to electricity generating facilities. It is also assumed that air quality regulations apply to industrial boiler facilities that use more than 250×10^6 Btu of fuel per day. Coal facilities in this size range require desulfurization, and are assumed to have a flue-gas desulfurization effluent. Thermal efficiency is assumed to be 75%.

The loading rates for each pollutant vary according to the effluent from which the pollutant was derived. The loading rates for utility and industrial facilities can be calculated by the equation:

$$L_i = \left(\sum_{j=1}^N C_{ij} Q_j \right) \cdot P$$

where:

L_i = loading rate of pollutant i ,

C_{ij} = concentration of pollutant i in waste stream j
(identified in Table A-2),

Q_j = flowrate of effluent j (identified in Table A-2,
except for coal-pile runoff, which is dependent on
local precipitation levels.

P = energy generation level,

i = pollutant (from Table A-2),

j = effluent (from Table A-2), and

n = number of effluents evaluated for a particular production process (from Table A-1).

A.2 POLLUTANT LOAD ESTIMATION FOR COAL EXTRACTION AND PREPARATION

The pollutants from coal extraction activities originate from mine drainage, discharges from coal preparation plants, and runoff from refuse piles and reclamation lands. It is assumed that all future pollutant sources will comply with EPA effluent limitation guidelines.

A.2.1 Mine Drainage

The pollutant concentrations that are assumed for the effluents from mines and coal preparation activities are identified in Table A-3. The table distinguishes between acid and alkaline mine drainage. Table A-4 indicates the drainage type in each Coal Supply Region (CSR) and also indicates the drainage volumes from deep and surface mines according to region. The pollutant loading from mine drainage is calculated by the equation:

$$L_i = 10^{-6} \cdot C_i \cdot Q_D \cdot P$$

where:

L_i = annual loading (kg/yr) of individual pollutant i from mine drainage,

C_i = concentration (mg/L) of individual pollutant i in mine drainage,

Q_D = mine drainage volume, L/t of coal produced, and

P = annual coal production, t/yr.

A.2.2 Coal Preparation Plant Discharges

The pollutants derived from coal washing plants and their assumed concentrations are listed in Table A-3. The effluent volume from coal washing is estimated based on the assumption that 50% of the coal mined is cleaned and that 96% of all cleaning is by wet methods.³ In Coal Supply Regions 7-10 (arid western regions), all wet cleaning is accomplished by closed-circuit methods and therefore no effluent streams are produced. In the other eight regions, it is assumed that 60%² of the wet cleaning will employ recirculation methods and the remaining 40% will produce 2,150 liters of effluent discharge per metric ton of coal washed.⁴

The pollutant loading rates are calculated according to the equation:

$$L_i = 10^{-6} \cdot C_i \cdot Q_w \cdot P_w$$

Table A-3 Estimated Characteristics of Drainage from Active Mines and Coal-Preparation Facilities

Pollutant (mg/L)	Surface Mines				Deep Mines				Coal Preparation	
	Acid		Alkaline		Acid		Alkaline			
	a	b	a	b	a	b	a	b	a	b
Total Iron	26	3.00	0.78	0.78	178	3.00	1.54	1.54	25.2	2.55
Manganese	28.7	2.00	0.61	0.61	4.6	2.0	0.08	0.08	1.1	0.46
Aluminum	37.2	3.28	0.20	0.20	22.7	2.0	0.13	0.13	5.6	0.53
Zinc	0.97	0.23	0.14	0.14	0.84	0.20	0.06	0.06	0.3	0.03
Nickel	0.45	0.20	0.02	0.02	0.46	0.20	0.01	0.01	0.1	0.04
TSS	299	48	84	35	124	20	23	20	31241	35
TDS	4038	4015.34	2768	2669.18	4723	4697	2609	2516	1433	1433
Sulfate	1735	1628.33	1163	1029.82	2233	2095	444	393	949	894
Ammonia	4.3	2.09	4.59	4.99	7.96	3.89	1.03	1.12	1.34	0.66
Chloride	-	-	-	-	128	152	260	272	-	-

^aAssumes 50% compliance with effluent guidelines.

^bAssumes total compliance with effluent guidelines.

Source: Ref. 2

Table A-4 Mine Drainage and Coal Preparation Runoff
by Coal Supply Region and ASA

Coal Supply Region	ASA	Type	Mine Drainage		Refuse Pile Runoff (L/t of coal cleaned)
			Volume (L/t of coal) ^a		
			Surface	Deep	
1: Northern Appalachia	203, 204, 206, 502, 502, 503	Acid	210	2002	31
2: Central Appalachia	205, 504, 507, 601	Acid	189	230	44
3: Southern Appalachia	306, 307, 308, 602	50% Acid	189	230	42
4: Midwest	703, 505, 506, 704, 705	50% Acid	1064	200	31
5: Central West	703, 1009, 1010, 1011, 1103, 1104, 1105	50% Acid	0	200	29
6: Gulf	801, 802, 1107, 1201, 1202, 1203, 1204, 1205	20% Acid	443	0	29
7: Fort Union	901, 1001, 1005	Alka- line	601	0	11
8: North West Great Plains	1002, 1003, 1004, 1007, 1701, 1703	Alka- line	696	0	11
9: Rocky Mountains	1102, 1301, 1401, 1402, 1403, 1601, 1602	Alka- line	601	0	11
10: Southwest	1302, 1501, 1052, 1501, 1502	Alka- line	0	0	8.8
11: Northwest	1702, 1705, 1706	Alka- line	601	0	37
12: Alaska	1901	Alka- line	601	0	37

^aSource: Ref. 6.

where

L_i = annual loading (kg/yr) of pollutant i from coal washing,

C_i = concentration (mg/L) of pollutant i in coal washing effluent,

Q_w = volume of effluent from coal washing (L/t of coal cleaned), and

P_w = coal cleaned annually (t/yr).

A.2.3 Refuse Pile Runoff

Refuse is produced from coal cleaning and is expected to cause pollutant streams when exposed to rain and snowfall. It is assumed that 50% of coal produced will be cleaned. The estimated coal refuse pile runoff per metric ton of coal cleaned is given in Table A-4. It was derived based on the assumption that annual precipitation results in an effluent runoff stream, and that the average area exposed to precipitation is 7.08×10^{-6} hectare per metric ton of coal cleaned,⁵ with an exposure time of one year before the refuse pile is buried or covered. The characteristics of the runoff stream are assumed to be similar to those of drainage from active mines. The loading rate for each pollutant is expressed by:

$$L_i = 10^{-6} \cdot C_i \cdot Q_R \cdot P_w$$

where:

L_i = annual loading (kg/yr) of pollutant i from refuse pile

C_i = concentration (mg/L) of pollutant i in refuse pile runoff

Q_R = volume of refuse pile runoff (L/t coal cleaned), and

P_w = coal cleaned annually (t/yr).

REFERENCES FOR APPENDIX

1. Chiu, S.Y., et al., *The Water Quality Impacts of Increased Coal Utilization*, ANL/EES-TM-74, Argonne National Laboratory, (April 1979.)
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3. U.S. Department of the Interior, *Mineral Yearbook*, Bureau of Mines, Washington, D.C. (1973).
4. Hittman Associates, *Environmental Residual Coefficients for the Project Independence Evaluation System Model*, Columbia, Md. (July 1976).
5. Hittman Associates, *Environmental Impacts, Efficiency and Cost of Energy Supply & End Use*, Vol. 1, Columbia, Md. (Nov. 1974).
6. The MITRE Corporation, *Annual Environmental Analysis Report: A Preliminary Environmental Analysis of Energy Technologies Using the Assumptions of the National Energy Plan*, Vol. IV (draft) (September 1977).