EPA-600/5-78-006a
April 1978

Socioeconomic Environmental Studies Series

A DEMONSTRATION OF AREAWIDE WATER RESOURCES PLANNING

Office of Air, Land, and Water Use
Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the SOCIOECONOMIC ENVIRONMENTAL STUDIES series. This series includes research on environmental management, economic analysis, ecological impacts, comprehensive planning and forecasting, and analysis methodologies. Included are tools for determining varying impacts of alternative policies; analyses of environmental planning techniques at the regional, state, and local levels; and approaches to measuring environmental quality perceptions, as well as analysis of ecological and economic impacts of environmental protection measures. Such topics as urban form, industrial mix, growth policies, control, and organizational structure are discussed in terms of optimal environmental performance. These interdisciplinary studies and systems analyses are presented in forms varying from quantitative relational analyses to management and policy-oriented reports.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/5-78-006a
April 1978

A DEMONSTRATION OF
AREAWIDE WATER RESOURCES PLANNING

by

Charles S. Spooner
John Promise
Philip H. Graham

Metropolitan Washington
Council of Governments
1225 Connecticut Avenue, N.W.
Washington, D.C. 20036

Project 802149

Project Officer

Roger Don Shull
Office of Air, Land and Water Use
U.S. Environmental Protection Agency
Washington, D.C. 20460

Prepared for
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DISCLAIMER

This report has been reviewed by the Office of Air Land and Water Use, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

This report documents a demonstration of areawide water resources planning by the Metropolitan Washington, D.C. Council of Governments (MWCOG). The study was initiated prior to the current 208 program, and although the purposes and approaches are similar to a typical 208 project, the results should not be viewed as a prototype for the water quality analytical methods, evaluative procedures, scope and level of detail expected by the U. S. Environmental Protection Agency (EPA) in certifiable 208 plan reports. Certain agencies may find that some or all of the techniques described are applicable to their local situation, but many others will have neither staff nor data, time and financial resources to utilize the spectrum of tools described.

Publication by EPA does not indorse MWCOG techniques, nor does it imply that utilization of these detailed techniques are requisite to preparation of an adequate 208 plan. EPA has, for instance, recently published an Areawide Assessment Procedures Manual (EPA Report 600/9-76-014, July 1976) which describes a much simpler set of techniques which may be more relevant in areas where the systems are neither so large nor complex as those in Washington, D.C.

ABSTRACT

The MWCOG Framework Water Resources Planning Model developed and tested under this study is a comprehensive analytical tool for use in areawide water resources management planning.

The physical simulation portion was formed by linking component computer models which test alternative future community development patterns by small area, estimate water demands by usage categories, calculate sewage flows based on water demands and add infiltration/inflow, simulate stormwater runoff, test application of alternative waste treatment management systems, and simulate the quality response of region's major water body.

The impact assessment portion of the Framework Model includes methodologies for assessing the fiscal, social, and environmental impacts of alternatives. The Framework Model has been tested for the Metropolitan Washington region by identifying the cost-effectiveness of six alternative areawide water resources management strategies, and is currently in use planning programs.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

Figure		Page

LIST OF TABLES

ACKNOWLEDGEMENTS

This report summarizes the study conducted by the Metropolitan Washington Council of Governments started under Environmental Protection Agency Project #16110FEY on May 3, 1971 and completed June 30, 1974 under Project #802149. The study under the guidance of Mr. Walter A. Scheiber, Executive Director of the Metropolitan Washington Council of Governments, was directed by the following Directors of the Department of Health and Environmental Protection: Dr. John Lentz, May 1971 - January 1972; Mr. Dennis R. Bates, February 1972 - May 1972; Mr. John Capper, June 1972 - January 1973; and Mr. Dennis R. Bates, February 1973 - present.

The Principal Investigators were Dr. John Lentz prior to January 1972, Mr. Lawrence S. Costello from February 1972 to April 1973, and Mr. Dennis R. Bates to completion.

The Metropolitan Washington Council of Governments applied research team was comprised of the following:

Environmental Engineer	Charles S. Spooner
Environmental Engineer	John Promise
Environmental Engineer	Philip H. Graham
Assistant Director	Kenneth Karch
Director, Data Systems	Jack C. Barrett
Systems Analyst	Steve R. Leventhal
Analyst/Programmer	Elizabeth St. J. Loker
Analyst/Programmer	Thomas V. Gill
Analyst/Programmer	John P. Molineaux
Program Documentation Specialist	Patricia Weiss
Director, Remote Sensing Projects	Harry J. Mallon
Graduate Research Assistant	Robert Dereniuk
	Margery Leiserson
	William Febiger
	J. Michael Kasper
	Jay Lankford

The Environmental Protection Agency Project Officers are as follows:

Project #16110FEY Water Quality Office Project Officer	William P. Sommers

Project #802149
Washington Environmental Research Center
Implementation Research Division
Systems Analysis Branch
Project Officer — Dr. Roger Don Shull

The five-constituent nitrogen-limited Estuary Quality and Hydraulic Programs and Potomac Estuary data were provided by:

Annapolis Science Center
Region III
Environmental Protection Agency
Annapolis, Maryland — Leo Clark

Consultation services to provide an operational MAIN II program and library deck, and to provide technical guidance in the use of the MAIN II computer program were performed by:

Hittman Associates
Columbia, Maryland — Michael Nawrocki, Donald Davis

Consultation services to modify the Estuary Hydraulic and Quality Models to accommodate hydrograph and pollutograph inputs for storm conditions simulations were provided by:

Water Resources Engineers, Inc.
Springfield, Virginia — Dr. Robert Schubinski, Robert Taylor, John Matticks

The artwork in this report was prepared by Gloria Saberin, a member of the MWCOG Graphic Arts staff, under the direction of P. Charles Saberin, Chief of Graphic Arts. The report was typed by Eve Auchincloss.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of this study are grouped under four major headings. First, general findings of the study are presented. Next, improvements in planning tools and methodologies as a result of development of the MWCOG Framework Water Resources Planning Model are detailed for each model component and element.

Next, conclusions from exercising the Framework Model to simulate the application of six alternative areawide water resources management strategies in metropolitan Washington for 1992 are discussed. Finally, recommendations for future improvements in the Framework Model during areawide waste treatment management planning are described.

GENERAL FINDINGS

1. The MWCOG Framework Water Resources Planning Model developed during the study is a sophisticated and versatile analytical tool for simulating the physical areawide water resources system, and for analyzing the fiscal, environmental and social impacts of alternative areawide water resources management strategies.

2. The Framework Model can serve as a major planning tool for agencies designated to conduct areawide waste treatment management planning as provided in Section 208 of the Federal Water Pollution Control Act Amendments of 1972. The Framework Model has been designed to satisfy or to assist with satisfying the following requirements of the Section 208 planning process:

- Identifying future development patterns and sewage flows, including infiltration/inflow
- Testing alternative structural waste treatment control techniques
- Testing alternative non-structural control techniques, such as land use regulation and water conservation practices
- Evaluating alternative waste load allocations
- Identifying water quality impacts of alternatives

- Identifying costs and financial arrangements including user charges

- Comparing cost-effectiveness of alternative strategies

- Assessing the environmental and social impacts of plan implementation

- Assisting public participation and plan review

3. The submodels which have been linked to create the Framework Model physical components are generally available, and in many cases, have newly created counterparts which can be substituted in applications of the Framework Model in many metropolitan areas of the country.

4. Basic policies for water quality management planning, water supply, and stormwater control planning should be considered together in the Washington metropolitan area.

5. The Framework Water Resources Planning Model should continue to be integrated into the continuing planning process of the Council of Governments and be used in the emerging areawide waste treatment management planning process and the formulation of the Metropolitan Growth Policy Program.

6. Use of the Framework Water Resources Planning Model physical components requires that many assumptions of river flow and background conditions be made. These assumptions influence each simulation and therefore the conditions under which questions of policy are answered using the Framework must be clearly stated.

7. As part of the Reexamination of the Year 2000 Policies Plan conducted by the Council of Governments and its member local governments, the water quality-related management "options for action" available to the metropolitan Washington region have been identified.

8. The associated costs and benefits of the various water quality-related management options have been assessed in qualitative terms, using a three-budget framework for analyzing fiscal, natural resource, and community response impacts, as part of the Year 2000 Policies Plan Reexamination.

9. From this reexamination has emerged a consensus that the available resources within these three hypothetical budgets that can be devoted to the solution of a problem such as water quality are finite, and that there will need to be

difficult tradeoffs among these budgets.

10. A definition of the "effectiveness" of an areawide strategy has been developed combining measures of the extent, constituent, concentration, duration, and annual joint probability of occurrence of the response of a receiving water to the areawide water resources management strategy.

11. To illustrate applications of the Framework Model in the areawide planning process, the cost-effectiveness of six alternative areawide water resources management strategies for metropolitan Washington in 1992 have been compared.

REFINEMENTS/IMPROVEMENTS MADE BY FRAMEWORK MODEL

Framework For Physical Simulation

1. Community Development Component

   a. The EMPIRIC Activity Allocation Model is used as the Community Development Component to project the areawide distribution of growth for alternative forecast years as a prerequisite to simulating the future water resources system in the Washington Metropolitan Area.

   b. Many of the Community Development Component parameters of importance to the simulation of the water resources system are also important to other areas of planning.

2. Water Demand Component

   a. Water demand is forecast by the following sectors of usage: single-family domestic (in-house), single-family sprinkling, apartment domestic, apartment sprinkling, commercial/industrial by major employment group, free service, and distribution losses.

   b. Forecasting techniques are based on principal factors influencing water demand including economic level of consumer, climate, number of households and the type of billing.

   c. Projections by usage sector are made for up to 200 user-specified geographical areas for use in detailed water supply and waste treatment planning activities.

3. Sewage Generation Component

   a. Residential domestic and commercial/industrial sewage flows are inferred directly from the Water Demand Component output of residential domestic and commercial/industrial water demands, respectively, by small geographic area. (Residential sprinkling and public/unaccounted water demand do not contribute to sewage flows). No other agency or government in Metropolitan Washington calculates sewage flows based directly on water demands.

   b. Infiltration/inflow is determined separately by small area based on the amount of land developed during the forecast period as projected by the Community Development Component, thus providing useful information for Infiltration/Inflow studies. Residential domestic flows, commercial/industrial flows, and infiltration/inflow are added to produce annual average daily sewage flow.

   c. Pollutant loads for user-specified parameters are determined for residential and commercial/industrial sectors separately, thus facilitating use of the model in establishing user charges as required by EPA guidelines.

4. Stormwater Runoff Component

   a. The rainfall analysis prepared for use in the Framework Model provides the basis from which to estimate the volume and recurrence of storm events in the region by storm decile.

   b. Forecasts of stormwater runoff and quality are made using the Stormwater Runoff Component. The Component incorporates the EPA Stormwater Management Model and uses projections of population, households, and employment densities provided by the Community Development Component.

   c. Since the scale of application of the Stormwater Runoff Component did not permit detailed analysis of the potential for combined sewer overflows, all combined flows were considered to receive the same level of treatment as sanitary sewage in all simulations in this report.

5. Waste Treatment Management Component

   a. Sewage flows and stormwater runoff (to be treated) are aggregated into user-specified sewage service areas, therefore allowing different service areas for treatment works to be tested.

   b. Alternative pollutant removal efficiencies for each pollutant are user-specified, thus permitting the simulation of alternative waste treatment management systems.

6. Receiving Water Component

   a. The EPA Estuary Model, originally designed to simulate steady state point discharges has been modified as a part of the Receiving Water Component to simulate time varying non-point discharges from storm events as well as point discharges from treatment works.

   b. The Receiving Water Component contains presentation and analytical programs to summarize the water quality effects of alternative water resources management strategies through three-dimensional estuary profiles for each constituent under examination.

Framework For Impact Analysis

7. Water Quality Objectives Element

   a. Using the three-dimensional estuary profiles and summary tables for dissolved oxygen produced by the Receiving Water Component, the "capability" of an areawide water resources management strategy can be defined as the extent of a constituent concentration of less than or equal to a stated beneficial constituent concentration, or greater than or equal to a stated harmful constituent concentration, for greater than or equal to a stated duration.

   b. The annual joint "probability of occurrence" of the conditions simulated all occurring during a stated time period can be determined, such as for the assumed river flow, or projected storm event.

c. The product of the "capability" of an areawide strategy and the annual joint "probability of occurrence" of simulated conditions is the expected "effectiveness" of the areawide strategy.

d. Using cost estimates from the Cost Element, the cost-effectiveness of alternative strategies can be compared.

8. Natural Resources Impact Element

a. The approach contained in the Framework Model will assist in satisfying the requirements of the Federal National Environmental Policy Act (NEPA) and state-adopted EPA's, and may fulfill the environmental impact analysis requirements of Section 208 areawide waste treatment management planning processes under PL 92-500.

b. Under this approach the user selects or combines any of the following five detailed methodologies identified in the study: 1) ad hoc; 2) overlays; 3) checklists; 4) matrices; and 5) networks. A review of these methodologies revealed significant similarities among them.

c. An analysis by MWCOG of the methodologies used during the performance of recent water resource studies conducted in the metropolitan Washington area revealed that:

1. Environmental impact analyses are conducted by organizations other than local government staffs (i.e., consultants, regional planning agencies, EPA) although they may be commissioned by the local government.

2. The environmental impact analysis techniques employed by these organizations differ markedly in content and scope but generally fall into the "ad hoc" and "checklist" categories. The level of detail is often considerably less than that suggested in "textbooks" on the subject.

3. Most studies emphasize the mitigation and minimization of possible adverse impacts.

4. The impacts assessed are primarily from capital-intensive structural treatment facilities.

5. Methodologies which lend themselves to "carrying capacity" considerations (i.e., overlays and networks) are not being used in impact studies or in large scale planning development.

6. Significant decisions have been made by local governments based on the results of many of these studies.

d. From this discussion, the following conclusions regarding the Natural Resources Impact Element were made:

1. No single impact assessment methodology yet developed is appropriate to all metropolitan regions under all conditions. Therefore, the Element should not be restricted to only one methodology.

2. There are significant similarities in the five types of impact assessment methodologies which should serve as the major steps in the Natural Resources Impact Element.

3. The Element should permit the ready identification of adverse impacts to be minimized, eliminated, or recognized as unavoidable or overriding.

4. Because of limited reserves of air, land and energy resources, impact assessment methodologies which assess the carrying capacity of these resources should begin to be utilized in metropolitan Washington.

e. Adverse impacts are identified in the procedure as either capable of being minimized or eliminated by "mitigating" measures, as "unavoidable" but not in themselves sufficient to eliminate the alternative from selection, or as "overriding" enough to eliminate the alternative.

9. Cost Element

   a. Conventional techniques of engineering economics and guidelines published by EPA are adequate to fully consider the comparative resource costs of capital-intensive alternatives and are incorporated in the Framework Model.

   b. Methods tc compute the costs of non-capital intensive programs such as water conservation public education are lacking.

10. Financial Arrangements Element

   a. Debt service on bonds for given years is calculated using construction costs provided by the Cost Element.

   b. Revenue requirements for given years for alternative waste treatment management systems are compared under different grant assumptions.

   c. Operation, Maintenance, Repair (OM&R) user charges are determined consistent with EPA guidelines based on OM&R costs provided by the Cost Element.

   d. Generalized customer charges for given years are estimated using population and household projections provided by the Community Development Component.

11. Social Impact Element

   a. The approach will assist in satisfying federal and state Environmental Policy Acts, fulfill the social and economic impact analysis requirements of the Section 208 areawide waste treatment management planning process, and comply with requirements of several associated Federal Acts.

   b. Social factors are identified and grouped into three categories: (a) individual-related; (b) neighborhood-related; and (c) regional.

   c. The analysis procedure outlined in the Natural Resources Impact Element is also utilized in this element.

12. Implementability Element

   a. This Element identifies points during the procedure outlined in the Framework Model where public participation consistent with EPA guidelines is essential.

   b. Mechanisms useful in gauging the implementability of alternative areawide water resources management strategies are identified.

CONCLUSIONS FROM MODEL TESTING

1. Calibration model runs of the Water Demand Component for the metropolitan area in 1968 were within four percent of the recorded water demands for 1968.

2. Model estimates of water demand by usage category for the metropolitan area were generally within seven percent of the recorded results, with a detailed demonstration in the subregional element of the District of Columbia producing comparable results.

3. Model estimates for 1968 of 314.6 MGD of average daily metropolitan Washington sewage flow compare favorably with the value of 319.4 MGD recorded for that year.

4. Utilization of water-saving devices in new construction after 1976 will result in water savings for the metropolitan area of up to 25 million gallons per day by 1992 in the residential sector alone, with substantial savings in the commercial sector expected as well.

5. Results of Framework Model runs to date have been used extensively by state water pollution control agencies, U.S. Army Corps of Engineers, several local governments, MWCOG, and numerous consultants.

6. Water supply planning will play an increasingly important role in estuary quality management planning as demand for water increases.

7. The cost-effectiveness of the following six areawide water resources management strategies for 1992 have been identified and compared:

Strategy No.1	-	Secondary Waste Treatment
Strategy No.2	-	Advanced Waste Treatment
Strategy No.3	-	Stormwater Treatment
Strategy No.4	-	Water Conservation
Strategy No.5	-	Dry Waste Collection
Strategy No.6	-	Indirect Estuary Re-use

A description of these strategies is contained in Chapter IV. The storm event and river flow conditions used in the simulations are relatively "normal", not unusually severe conditions.

8. None of these areawide water resources management strategies is projected to meet adopted state minimum dissolved oxygen standards for the upper Potomac Estuary in the year of simulation, 1992.

9. As less kilometers of the estuary are affected by depressed dissolved oxygen levels, the costs of the strategies employed to gain this improvement rise. Strategy No.1 (Secondary Treatment) has the least "effectiveness" and lowest cost. Strategy No.3 (Stormwater Treatment) has the greatest "effectiveness" and highest cost.

10. Although Strategies No.2, 4, and 5 have the same "effectiveness", the Water Conservation Strategy has the lowest relative cost.

11. The areawide strategy which results in the greatest increment of "effectiveness" for the least increment of cost is Strategy No.4 - Water Conservation.

12. Urban runoff is a source of water pollution too important to be ignored in water resources management planning in the region for year 1992 even if all combined sewer overflows are eliminated.

RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

1. The Community Development Component should be refined to the small area level and should be altered as needed as part of the Growth Policy Program in the Washington Metropolitan Area.

2. A Water Supply Component should be added to the Framework Model to simulate the impacts of various water supply alternatives for use in detailed water supply studies.

3. The Sewage Generation Component should be further refined to include more information on user-specified pollutant concentration factors, and possibly be linked to the runoff data produced by the Stormwater Runoff Component to estimate infiltration/inflow.

4. The Rainfall Analysis of the Stormwater Runoff Component should be expanded to include further study of area storm distribution and severities.

5. The Stormwater Management Model of the Stormwater Runoff Component should be calibrated for the heavily developed watersheds of the region.

6. The Receiving Water Component should be expanded to simulate water quality in embayments and tributaries to the Potomac Estuary, and should be further calibrated for the estuary during and immediately succeeding storm events.

7. Water demand coefficients utilized in the commercial sector of the Water Demand Component should be refined based on future field surveys in metropolitan Washington.

8. Methods to compute the costs of non-capital intensive programs such as water conservation public education need to be developed.

9. Additional studies are needed to assess the magnitude and frequency of combined sewer overflows in the metropolitan Washington region to permit their simulation in the Stormwater Runoff Component. The Framework Model analysis should then be repeated to determine any changes in the most effective water resources management strategy.

CHAPTER I

OBJECTIVES AND IMPLICATIONS OF THE STUDY

NEED FOR THE STUDY

While signing the Federal Water Pollution Control Act of 1965, President Johnson declared that within ten years the Potomac would be a model river. Today, as a visitor to the Nation's Capital stands alongside the Tidal Basin under the cherry blossoms and gazes across at the Jefferson Memorial, he need only turn his head a few feet to read the following sign:

<u>POLLUTED WATER</u>
NO FISHING
FISH CONTAMINATED
National Park Service

Or, on a stroll or bicycle ride by the banks of the Potomac Estuary, be greeted by such signs as:

POLLUTED WATER BATHING HAZARD

since water contact sports are prohibited in the upper estuary and its tributaries by regulations of the District of Columbia.

In October of 1972 the Congress overrode a presidential veto to enact the Federal Water Pollution Control Act Amendments. This Act declares as a national goal that the Nation's waters provide for the protection and propagation of fish and wildlife, and provide for recreation in and on the water, by July 1, 1983. Can the metropolitan Washington region accomplish during the next ten years what it has been unable to achieve during the past ten years?

A key to answering this question may rest with Section 208 of the Act.[17]* Section 208 provides for establishment of a continuing areawide waste treatment management planning process and development of annual plans in areas throughout the country which have substantial water quality control problems as a result of urban-industrial concentrations or other factors. The metropolitan Washington region is one such area,** and the success or failure in meeting the 1983 objectives may depend in large measure on the region's ability to accurately assess its future needs and to analyze a wide variety of alternate methods for meeting these needs.

Until very recently sophisticated tools for performing these assessments and analyses were not readily available, and where available were not actually being incorporated into the continuing and comprehensive planning processes of local governments. The need for such tools is recognized in the Section 208 planning guidelines prepared by the U.S. Environmental Protection Agency.[65] Consideration of both the need for better planning tools, and the need to incorporate the results into the areawide planning process, led to the conclusion by EPA, even before passage of the 1972 Act, that the Metropolitan Washington Council of Governments was uniquely suited to undertake development and application of such planning tools.

First, the Metropolitan Washington Council of Governments, as the official Metropolitan planning agency for the Washington Standard Metropolitan Statistical Area, was in a position to insure that the results would be applied to the areawide comprehensive planning process. MWCOG's members are the elected officials of governments in the metropolitan area. Specifically, they represent:

- The District of Columbia

---

* Numbers indicate references at end of report.

**Subsequent to completion of this study, the Metropolitan Washington Council of Governments was designated by EPA in March, 1975, as the Section 208 areawide waste treatment management planning agency for the National Capital area.

- All surrounding counties in Maryland and Virginia which are in the SMSA (except Charles County, Maryland, recently added to the SMSA).

- All independent cities in the Virginia part of the SMSA.

- Most cities over 10,000 in the Maryland part of the SMSA.

- Members of the Maryland and Virginia legislatures who represent districts in the metropolitan area.

- Members of the U.S. Congress who represent, in whole or part, parts of the metropolitan area.

Member jurisdictions are represented on policy committees and advisory boards of MWCOG by these officials and representatives of special purpose and state agencies. The actions of policy board representatives, with recommendations from MWCOG staff, technical committees, and citizen advisory committees, determine development goals and policy for the region. The program areas in which MWCOG staff is actively involved include regional planning, transportation planning, public safety, human resources, housing, health and environmental protection.

Secondly, MWCOG has incorporated into its planning program a sophisticated analysis tool called the EMPIRIC model to evaluate the impacts of alternative public policies on the distributions and rate of growth within the region.[37] The model distributes metropolitan control totals of households and employment into small areas based on policy inputs which specify transportation, open space and water and sewer programs.

In addition, in the summer of 1969 the Potomac Enforcement Conference, which had met originally in the late 1950's, was reconvened because of continued deterioration of river water quality. Recommendation No.4 of the May, 1969, Potomac Enforcement Conference directed the Federal Water Quality Administration (now the Environmental Protection Agency), in cooperation with state, interstate, and local agencies, to initiate detailed analysis of alternate methods of meeting future waste requirements and sewage needs in the Metropolitan area.

One of the work elements recommended by the Short-Term Planning Committee to accomplish Recommendation No.4 was a long-term future needs study to be performed by the Metropolitan Washington Council of Governments.[124] It was envisioned that a joint research proposal would be submitted by MWCOG to the Office of Water Resources Research of the U.S. Department of the Interior, and to the predecessor of the Environmental Protection Agency, as part of an effort to develop a "Comprehensive Urban Water Resources Planning Program for the Washington Metropolitan Area". In 1971 the Council of Governments received grant awards from these agencies for the joint study.[125,126,127]

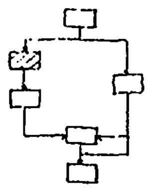
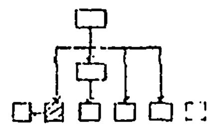
OBJECTIVES OF THE STUDY

Thus, this overall study effort was undertaken with a principal objective "to find a way in which the Metropolitan Washington Council of Governments as a planning and political organization, can effectively develop and implement a comprehensive planning program which utilizes both sophisticated analytical and technical tools and political sensitivity to structure an optimum water resources development program".[125]

The purpose of the portion of the overall study supported by the U.S. Department of the Interior Office of Water Resources Research was to identify and evaluate effects of water and sewage facilities on growth, and to develop and evaluate methods for expressing relationships between water and sewage service and urban growth in a form useful for urban water resources planning. That research is described in the final report of that portion of the project, Water Resources Management for Metropolitan Washington: Analysis of the Joint Interactions of Water and Sewage Service, Public Policy, and Land Development Patterns in an Expanding Metropolitan Area,[1] published in December of 1973 by the Council of Governments.

The EPA-sponsored portion of the study, discussed in detail in the remainder of this report, had several major project objectives. How these objectives were attained during the study is depicted in Table 1. The first objective was to develop an operational definition of the metropolitan scale

Table 1
DEVELOPMENT OF FRAMEWORK MODEL

Objectives of Study	Physical Simulation Components	Impact Analysis Elements
1. Develop an operational definition of system		
2. Choose appropriate component models, methods, & approaches; modify as necessary and link to form Framework Model	MAIN II - Water Demand Model	Cost Element based on EPA cost-effectiveness guidelines
3. Identify water quality-related management options available to Metro Washington; identify in qualitative terms their associated costs and benefits.	Participated in development of *Reexamination of Year 2000 Policies Plan* Identified "options for action" and assessed using "three-budget system"	
4. Test framework by identifying cost-effectiveness of selected areawide water resources management strategies.	Grouped options for action into six areawide strategies Model exercised using 1992 development pattern for 6 strategies cost-effectiveness of strategies	Identified cost of 6 strategies
5. Make conclusions and recommendations	a. ______ b. ______ c. ______	

water resources system. The physical system begins with the community development pattern of the region, from which both water demands and stormwater runoff can be estimated. Based on water demands, sewage flows can be directly calculated and, with infiltration/inflow added, "treated" through the application of alternative waste treatment management systems. Finally, this wastewater, and stormwater runoff is discharged to the region's major water bodies, or is recycled or applied to the land. In addition, the impact analysis portion of the operating definition incorporates consideration of the fiscal, social, and environmental impacts of alternative systems and assumed conditions.

A second objective was to select and modify appropriate computer models, methods, and approaches capable of simulating each of the components of the physical water resource system, and to link these components to form a model of the metropolitan water resources system. The resulting analytical tool has been termed the MWCOG Framework Water Resources Planning Model. The Framework Model also includes elements for applying fiscal, social, and environmental impact assessment methodologies in the region. The attainment of these first two project objectives is described in a Technical Summary of the Framework Water Resources Planning Model published by MWCOG in May, 1974,[2] and is further discussed in this report in Chapter III.

The third objective of the study was to identify the water quality management options available to the metropolitan Washington region. This activity was undertaken as an integral part of the Year 2000 Policies Plan Reexamination conducted by the Council of Governments and its member local governments as discussed in Chapter II. A three-budget framework for analyzing the fiscal, environmental, and social impacts of the various "options for action" in all problem areas of regional concern was developed and used during the Year 2000 Policies Plan Reexamination to fulfill the next study objective. This objective was to identify in qualitative terms the associated costs and benefits of various water quality-related management options. This is also presented in Chapter II.

The final study objective was to test the Framework Model for the metropolitan Washington region by identifying the cost-effectiveness of selected areawide water resources management strategies. Six areawide strategies were identified by combining various water quality-related options for action. The final chapter includes highlights from a typical computer run of the Framework Model physical simulation components, and identifies the water quality effects and compares the cost-effectiveness of the alternative areawide strategies. The conclusions and recommendations from the overall study are contained at the beginning of this report.

CURRENT APPLICATION OF FRAMEWORK MODEL

Many portions of the Framework Model have been tested and used for planning within the Metropolitan Washington Council of Governments and other organizations during various stages of the Model's development. Where this has happened, it has been possible to test the assumptions and procedures discussed in this report.

Initial water demand and sewage flow estimates have been used extensively by the water agencies of the states of Maryland and Virginia and the District of Columbia as part of the Washington Area Interstate Water Resources Program.[3,4] The U.S. Army Corps of Engineers has used the water demand estimates in its water supply study of the Washington Metropolitan area,[5] as has The Johns Hopkins University in a study for the Maryland Power Plant Siting Program.[6] Such estimates are also useful in the preparation of Environmental Assessments and Impact Statements as required under Section 102 of the National Environmental Policy Act.[7] Examples of studies utilizing results from the Framework Model are those undertaken by consultants for the Washington Suburban Sanitary Commission[8] and the Baltimore District of the U.S. Army Corps of Engineers.[9]

The results and estimating techniques of the Stormwater Runoff Component have also found widespread application. A stormwater management study for the District of Columbia by an engineering consultant utilized some of the findings of the stormwater runoff component.[10] An Environmental Impact Statement prepared by EPA for North Fulton County, Atlanta, Georgia[11] applied an urban runoff estimating technique developed by MWCOG for use in the Framework Model.[12] In fact, a report prepared by the U.S. Environmental Protection Agency Region IV, and presented at the 1973 Confer-In, cited this method of estimating imperviousness and specific curb length developed by MWCOG as the prime example of currently available stormwater estimating techniques.[13]

Because the Framework Model is the first effort by the Metropolitan Washington Council of Governments to relate projections of future growth to future demands for an essential environmental resource, it provides a useful guide to similar activities underway in the region. The Framework Model has been and is being applied by the Council of Governments in its Reexamination of the Year 2000 Policies Plan[14] and in the preparation of an Air Quality Maintenance Plan for the National Capital Interstate Air Quality Control Region, where the recommended control strategies will be analyzed for both air and water impacts.

The Framework Model is likely to be useful in similar environmental planning in other metropolitan regions in the Country. The EMPIRIC Model, (which serves as the Community Development Component) and, therefore, the rest of the Framework Model, is not restricted to the Washington Metropolitan area. The EMPIRIC Model has been or soon will be in full operation by the Minneapolis-St. Paul Metropolitan Council, the Canadian Council of Urban and Regional Research in the Winnipeg region, the Denver Regional Council of Governments, and the Boston Metropolitan Area Planning Council.[15] Thus, the Framework Model could be linked directly to the EMPIRIC Model in these urban areas as well.

IMPLICATION FOR SECTION 208 AREAWIDE WASTE TREATMENT MANAGEMENT PLANNING

The Framework Model's ability to measure the effect of land use, stormwater management, waste treatment management, and non-structural measures on the region's major water resource, and to analyze fiscal, social, and environmental impacts, is particularly important in light of the Section 208 areawide waste treatment management planning requirements of the Federal Water Pollution Control Amendments of 1972.[17] Section 208 provides for the establishment of a continuing areawide waste treatment management planning process and development of an annual areawide plan in those regions in the country which, as a result of urban-industrial concentrations or other factors, have substantial water quality control problems. Section 208 identifies the mechanisms by which an area and an agency may be designated by EPA for the conduct of this continuing planning process, and specifies what the annual areawide waste treatment management plan must contain.

The Framework Model can serve as a major analytical tool for agencies designated to conduct areawide waste treatment management planning. The Framework Model has been designed to satisfy or to assist with satisfying the following requirements of the Section 208 planning process:[64,65]

- Identifying future development patterns and sewage flows, including infiltration/inflow
- Testing alternative structural waste treatment control techniques
- Testing alternative non-structural control techniques, such as land use regulation and water conservation practices
- Evaluating alternative waste load allocations
- Identifying water quality impacts of alternatives
- Identifying costs and financial arrangements including user charges
- Comparing cost-effectiveness of alternative strategies
- Assessing the environmental and social impacts of plan implementation
- Assisting public participation and plan review

The remainder of this section illustrates how the Framework Model can be applied to meet the above requirements.

Identifying Future Development Patterns and Sewage Flows

The Framework Model physical simulations begin with the Community Development Component, which for metropolitan Washington includes as the basic computational tool the EMPIRIC Activity Allocation Model. EMPIRIC is designed to distribute regional "control totals" of future households and employment among a set of small sub-areas based on alternative public policies and market forces. Sub-models are used to generate estimates of population, land use by type, income by group, and other desired characteristics by small area. The EMPIRIC model can be used, and has been used in metropolitan Washington, to test the effects of alternative future metropolitan development patterns; i.e., corridor cities vs urban sprawl.

Using output from EMPIRIC, the Water Demand Component estimates future water requirements by small area for various usage categories, such as single-family domestic (in-house) demands, sprinkling, commercial/industrial demand by major employment category, and public-unaccounted demand. Dry weather sewage flows are derived directly from the residential in-house and commercial/industrial water demands as part of the Sewage Generation Component. *Infiltration/inflow, which* must also be examined in Section 208 planning, is calculated based on EMPIRIC output also, and added to dry weather sewage flows. Pollutant load characteristics of sewage are also calculated.

Testing Structural Control Techniques

The Section 208 planning process is required to satisfy the facilities planning provisions of the Act under Section 201 (so-called Step 1 planning).[8] This facilities planning must include an evaluation of technologies for treating wastewater and disposing of the effluent by: 1) discharging to receiving waters, 2) reusing, and 3) applying to the land. The Waste Treatment Management Component of the Framework Model is designed to test alternative waste treatment management systems by applying user-specified removal efficiencies to the projected sewage flows. The effluent can be discharged to user-specified points of discharge in the Potomac Estuary, or withheld from such discharge (to simulate either re-use or land application).

Testing Non-Structural Control Techniques

According to guidelines prepared by the Environmental Protection Agency,[18] in the required municipal facilities planning under Section 201 of the Act and therefore under Section 208, all measures for preventing, reducing, and abating municipal wastes (including stormwater wastes) other than conventional structural facilities shall be considered. These wastewater management techniques include the regulation of land use and development, a technique which can be tested directly by using the Framework Model. Guidelines published by the Council on Environmental Quality also require consideration of land use control and other non-structural devices in the preparation of Environmental Impact Statements and Assessments.[19]

Another wastewater management technique to be considered in Section 208 planning is the control of surface runoff. The effectiveness of this technique is directly measured by exercising the Stormwater Component of the Framework Model to estimate future runoff, and then applying alternative control strategies such as stormwater storage or treatment in the Waste Treatment Management Component.

Another technique for reducing wastewater flows identified in the EPA guidelines is water conservation. Since the Water Demand Component estimates commercial usage, public-unaccounted usage, and both residential in-house domestic usage and sprinkling separately, the effectiveness of instituting water conservation practices such as water-saving toilets and shower heads can be evaluated. This is important not only for wastewater management analyses under the Act but also for water supply/demand planning in the metropolitan area. In revising its model plumbing code for the region to require water conserving devices[20], the Council of Governments determined by applying the Water Demand Component that up to 25 million gallons of water per day could be saved in residential usage alone by 1992 if local governments adopt the plumbing code revisions.[21]

In addition, the effectiveness of measures to reduce infiltration/inflow can be tested since infiltration/inflow is calculated separately in the Sewage Generation Component. From this estimate a determination can be made as to whether excessive infiltration/inflow will occur, and therefore whether a sewer system evaluation survey must be conducted.[18]

Evaluating Waste Load Allocations

An important requirement under Section 303(e) of the Act is the establishment by appropriate agencies of pollutant load limits for the major water bodies of a region.[24,17] The estuary model which serves as the Receiving Water Component of the Framework Model was developed for and exercised by the Environmental Protection Agency in 1969 to establish effluent limits which are the basis for the current expansion and upgrading of treatment plants discharging to the Upper Potomac Estuary.[25] However, a report prepared in 1973 by consultants for the Maryland Environmental Service challenged the validity of those limits and the current effluent load allocation scheme.[26] This estuary model has been revised and improved by MWCOG for use in the Framework Model, and could be exercised to evaluate other load allocation schemes to meet the Section 303(e) requirements. The Section 208 planning guidelines identify the testing of alternative waste load allocations as a major activity within the Section 208 planning process as well.[65]

Identifying Water Quality Impacts

The ability of alternative control strategies to achieve desired water quality objectives is a necessary and obvious consideration in the areawide water resources planning process. The Receiving Water Component of the Framework Model can simulate the effects of alternative point and non-point sources of pollution, and can produce three-dimensional estuary profiles for each of the water quality constituents of interest. These computer plots are very useful in presenting complicated results in a simplified and understandable format to elected and appointed decision-makers and citizens.

Identifying Costs and Financial Arrangements

To assist in identifying the fiscal impacts of the Section 208 plan, the Fiscal Budget portion of the Framework Model includes a Cost Element and a Financial Arrangements Element. The Cost Element is used to determine and compare the capital and OM&R costs of proposed alternatives, while the Financial Arrangements Element is used to determine the need for Federal/State grants, bond indebtedness, and required user charges.

Various portions of the Framework Model, both in the physical simulation components and in the impact assessment elements, can be used to assist in determining these user charges for operation and maintenance of publicly owned treatment works. Regulations published by EPA under the Act[23] require that the user charge system shall result in the distribution of the cost of operation and maintenance of treatment works in proportion to the user's contribution to the total wastewater loading of the treatment works. Factors such as strength, volume, and delivery flow rate characteristics shall be considered and included as the basis for the user's contribution. If the concentrations for BOD or other pollutants from a user exceed the range of concentration of these pollutants in normal domestic sewage, a surcharge added to the base charge can be levied. The Sewage Generation Component can be used to simulate effects of different strengths to serve as a basis for determination of user charges in the Financial Arrangement Element.

Comparing Cost-Effectiveness of Strategies

The facilities planning portion of the Act requires that a cost-effectiveness analysis of alternatives be conducted, and that Federal grant funds be given only for treatment works found to be the most cost-efficient. A principal objective of this study was to develop a definition of cost-effectiveness applicable in highly complex regions, and to test the cost-effectiveness of alternative areawide water resources management strategies in metropolitan Washington. Under the Water Quality Objectives Element in Chapter III, the definition of cost-effectiveness is explained, while Chapter IV includes the comparison of alternative strategies.

Assessing Environmental and Social Impacts

Regulations published by EPA require the preparation of an Environmental Impact Assessment on the areawide waste treatment management plan by the designated planning agency. This will serve as the basis for development of an Environmental Impact Statement by EPA. The Natural Resources Impact Element and Social Impact Element of the Framework Model have been designed specifically to assist with the identification of environmental and social impacts during the planning process.

Assisting Public Participation

The Act and implementing EPA regulations encourage active public participation during the areawide planning process. The Implementability Element of the Framework Model addresses this need, and emphasizes the responsibility of the designated planning agency to obtain citizen points of view during the program for presentation to the responsible policy board.

These are some of the uses of the Framework Water Resources Planning Model in the Section 208 areawide waste treatment management planning process. The illustrated uses stress that each component or element of this model can be used independently or they can be linked, as was done in the full Framework Model. Either way, the Framework Model is easily the most flexible and comprehensive water resource planning model available in the Washington Metropolitan Area, and will continue to be used by the Council of Governments in its areawide water resources planning program.

TOWARDS A METROPOLITAN GROWTH POLICY

The discussion of the Section 208 areawide waste treatment management planning process would be incomplete without an explanation of where that program fits within the comprehensive areawide planning process of the Council of Governments. A basic reason for this Council of Governments' interest in Section 208 planning is that water resources planning is recognized as an integral and inseparable part of the overall planning program at MWCOG aimed towards development of a metropolitan growth policy for the region.

During the Year 2000 Policies Plan Re-examination (which is discussed in Chapter II) over the past year and a half, the need for developing a metropolitan growth policy has been reiterated by many local governments, citizens, and technical staff representatives in the Washington area. Public discussions have gone beyond the question of whether there should be a metropolitan growth policy for the region. The questions now being asked include: What should this policy address? How should it be developed?

As this study was being completed (summer of 1974), the MWCOG staff had begun an attempt to answer these questions and to structure a proposed Metropolitan Growth Policy Program for consideration by the region's officials. Preliminary staff analysis identified the need for a cooperative forecasting process as a foundation for the development of the growth policy, an emphasis on impact analysis, and a series of action programs including a Metropolitan Capital Improvements Program and fair-share interjurisdictional agreements on key growth issues.

It is envisioned that the metropolitan growth policy at MWCOG would integrate a greater extent possible than before, the following functional programs:

- Land Use and Housing programs sponsored by HUD
- Water Resources program sponsored by EPA
- Air Quality program sponsored by EPA
- Transportation planning program sponsored by DOT
- Proposed energy program under HUD sponsorship

The metropolitan growth policy would be intended to serve as the foundation for legal and constitutional defense of local growth management efforts, would assure consistency among the MWCOG functional planning activities noted above, and would increase coordination among local, state, and Federal agencies within the region.

CHAPTER II

IDENTIFICATION OF AREAWIDE WATER RESOURCES MANAGEMENT STRATEGIES

EXPANDING RANGE OF OPTIONS

One of the primary objectives of the project is the identification of water quality management options available to the metropolitan region. Too often in the past this task has been undertaken as a narrow engineering design study of a proposed physical structure to determine the desired treatment units. An option has been defined frequently as simply where to put a wastewater treatment plant, rather than as alternatives to building such a facility at all. The discussions of the interrelated elements of the Metropolitan Washington water resources system in this report reveals that there is justification for broadening this approach. Indeed, several significant actions which have occurred at the Federal and State levels in recent years require that a broader range of water resources management strategies be considered by local communities.

One such action was the passage by Congress of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, which establishes national water quality goals and prescribes the system through which Federal financial aid to municipalities for constructing waste treatement works is channeled. Under the Act the definition of treatment works eligible for Federal grants has been broadened considerably to include any method or system for preventing, abating, reducing, storing, treating, separating or disposing of municipal waste, including storm water runoff, or industrial waste.[17] Waste treatment management techniques which must be evaluated in every case include: (i) biological of physical-chemical treatment and discharge to receiving waters; (ii) treatment and reuse; and (iii) land application techniques.[27] Flow and waste reduction measures such as infiltration/inflow reduction, water conservation techniques, and regulation of land use and construction practices must also be evaluated in every planning effort, as discussed in Chapter I.

Another significant Federal action was the passage of the

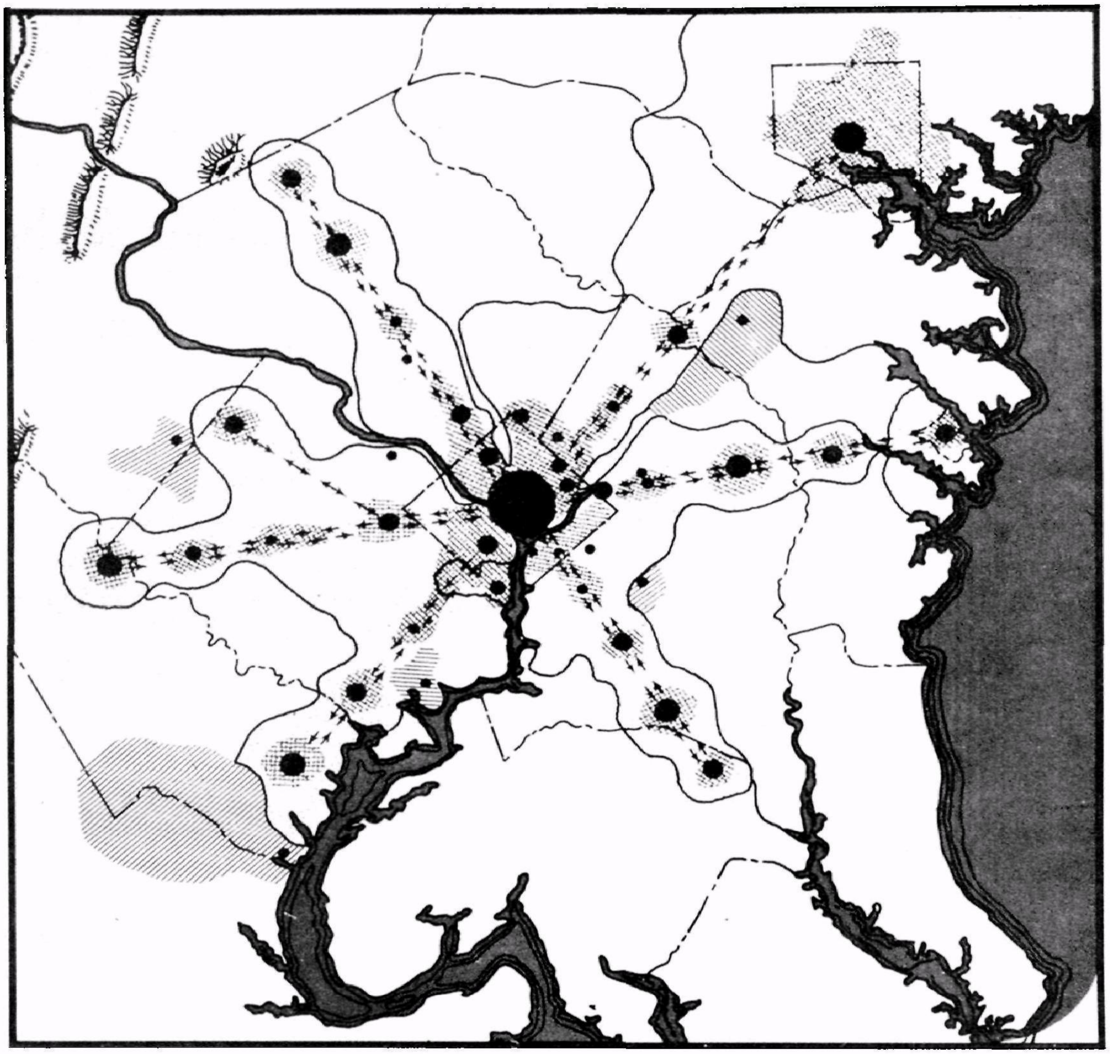
National Environmental Policy Act (NEPA) which requires all Federal departments and agencies to prepare environmental impact statements (EIS) for major Federal actions significantly affecting the quality of the human environment.[7] Thus, before the Environmental Protection Agency can give a construction grant to a community, the EPA must prepare an EIS for the project. Alternatives to the proposed action, including those not within the authority of the responsible agency, must be considered in the EIS, including the alternative of taking no action, or action of a significantly different nature such as non-structural programs.[19]

State action in the form of the imposition in the early 1970's of moratoria on further connections to certain municipal wastewater treatment plants in the metropolitan area has caused the local jurisdictions to actively consider, and in some cases already approve, the construction of "interim" treatment facilities to control public health hazards and to promote orderly growth within the community.[28,29] Local governments have also taken actions which now prohibit certain practices of waste treatment management, such as Prince George's County's recent limited ban on the incineration of sludge within the county.[30]

Thus for a number of reasons, not the least of which has been the inability of traditional treatment facilities alone to achieve desired water quality goals, a much broader range of water resources management options must be assessed than appeared to be necessary even five years ago.

RE-EXAMINATION OF THE YEAR 2000 POLICIES PLAN

The identification of water quality-related management options under this project was achieved as an integral part of a much larger metropolitan effort by MWCOG and its member jurisdictions, commonly referred to as the "Reexamination of the Year 2000 Policies Plan." This Policies Plan[31,32,33,34] has been the basic planning guide for the Washington region since it was published by MWCOG's predecessor, the National Capital Regional Planning Council, in 1961. Sometimes called the "wedges and corridors plan," it recommended development of the Washington area in a series of corridors radiating from a central core along which new communities and towns would be concentrated. Areas between the corridors ("wedges") would be preserved as open space as shown in Figure 1.



Source:" A Policies Plan For The Year 2000" NCRPC & NCPC, 1961.

Figure 1 YEAR 2000 RADIAL CORRIDOR PLAN

Since the late 1960's a continuing review and comparative evaluation of existing plans has been conducted by MWCOG in three phases.[14] Phase One included a series of qualitative evaluations of metropolitan development trends culminating in a Metropolitan Conference on the Year 2000 Plan held in July, 1971. In Phase Two, four alternative development patterns, including the original wedges and corridors concept, were evaluated and discussed in an extensive process of public briefings and hearings before local governing bodies and in meetings with technical staffs and the public. This discussion resulted in a re-affirmation in mid - 1972 of public preference for the wedges and corridors concept and a refinement of the plan's basic goals.

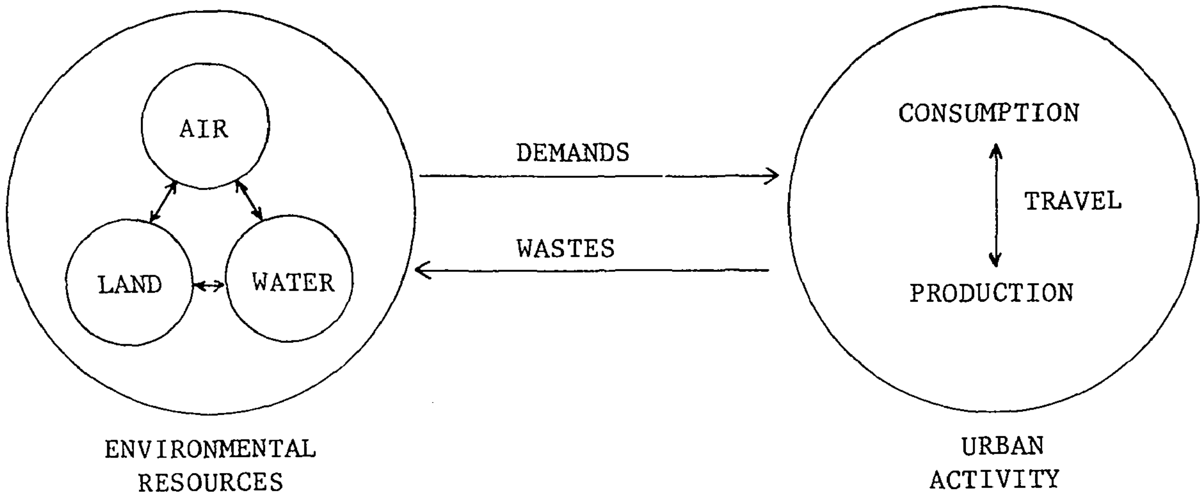
Beginning in early 1973, Phase Three of the plan review, through a series of workshops and public meetings and intensive staff effort, concentrated on extending the subject areas dealt with in metropolitan policy beyond the relatively narrow confines of the original year 2000 Policies Plan and into such areas as health, criminal justice, and natural resources planning including water resources planning.

WORKSHOP ON PHYSICAL ENVIRONMENT

A workshop during Phase III which established the context within which the water resources management options would be identified in the Year 2000 Policies Plan Reexamination was held in June of 1973. This "Joint Workshop on the Physical Environment" was conducted by the Land Use Policy Committee and the Health and Environmental Protection Policy Committee of MWCOG to discuss environmental resources management issues through discussion of issue papers. In one of the issue papers,[121] the environmental resources management system was depicted to these elected officials of the region in the simplified manner shown in Figure 2, where urban activities place demands on and generate wastes to environmental resources in a closed cycle.

Drawing from research conducted by Resources for the Future,[122] it was emphasized that management techniques could be grouped into four major types based on the "loci of control" where they are imposed. These groupings are:

1. Reduce waste emissions within urban activity (such as changing generation patterns and limiting growth)



Source: MWCOG Joint Workshop on the Physical Environment, Environmental Management Issue #4, June 18,1973.

Figure 2 ENVIRONMENTAL RESOURCES MANAGEMENT SYSTEM

2. Reduce or transform wastes after generation (such as treating sewage and incinerating or recycling solid wastes)

3. Decrease demand - increase supply (such as water-saving home fixtures and reservoirs)

4. Affect environmental resources directly (such as instream aeration to increase assimilative capacity).

The issue paper noted that a major problem which the region faces is where and to what extent in the environmental resources management system the management techniques should be introduced.

The need to manage the area's natural resources within the limits of their "capabilities" or "carrying capacities" was highlighted throughout the workshop. Environmental resource capability or carrying capacity means the measured ability of a resource to support use and development commensurate with desired environmental quantity and quality of that resource.[23] It was recognized that these resource carrying capacity limits which make up the area's natural resource budget have not yet been fully determined. The most current expression of resource carrying capacity is the air and water quality standards adopted or approved by the States and the Environmental Protection Agency.

During the workshop it was noted that in recent years local jurisdictions have attempted to "trade" land quantity for improved air and water quality. Through use of block diagrams such as those in Figure 3, the staff demonstrated how resource tradeoffs can and do occur. The figure illustrates that between 1967 and 1973 the region had achieved a decrease in particulates in the air from open burning and solid waste incineration (by banning them in local ordinances) to the point that Federal-State particulate air quality standards are now being met. However, as a result the amount of land required to landfill material which had previously been burned or incinerated has increased substantially.

Through use of these block diagrams, the sources of waste emissions or resource demands can be depicted by parameter, and potential tradeoffs among media can be highlighted. Emerging from the workshop was a consensus that there is

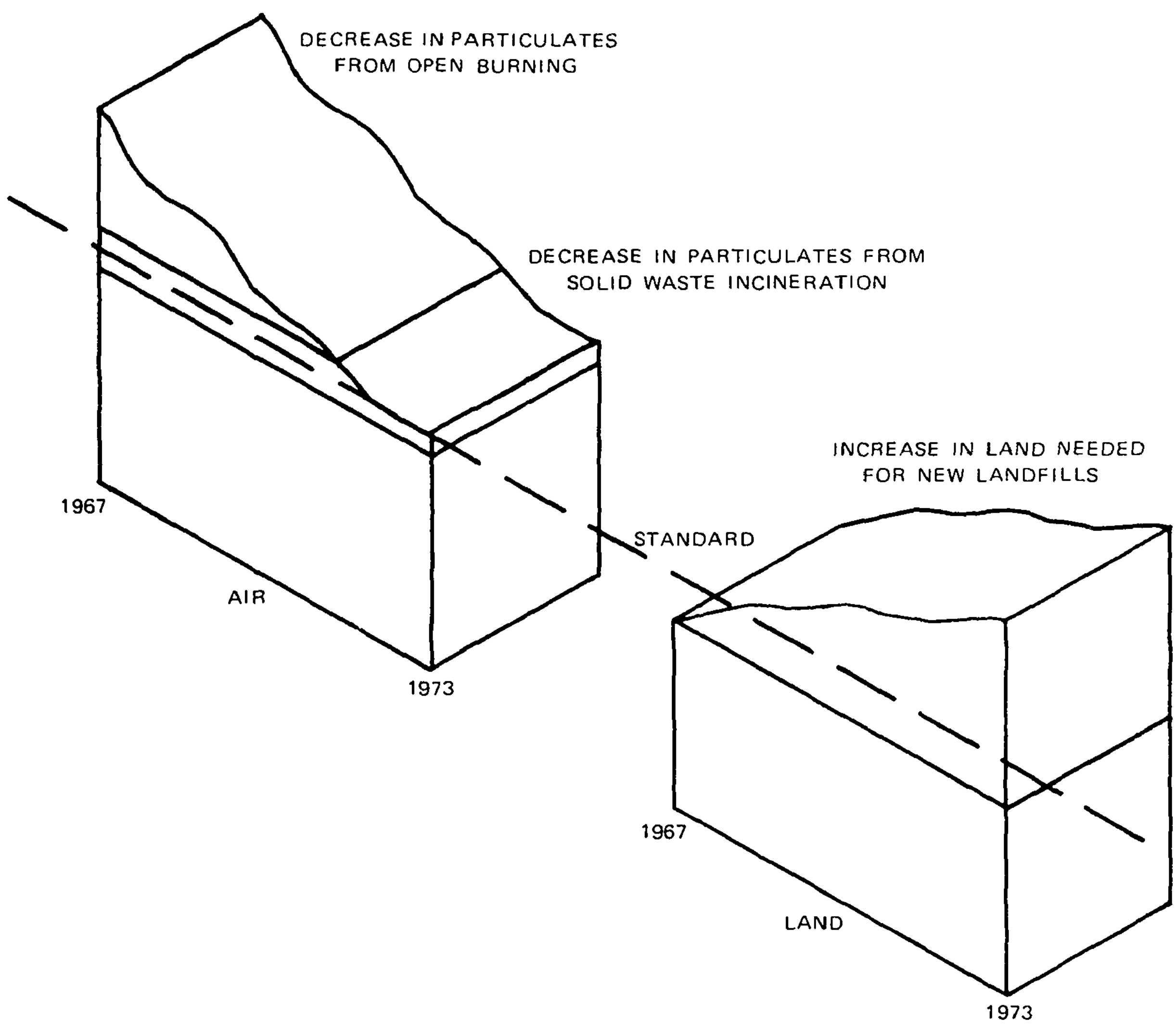


Figure 3 RESOURCE TRADE-OFFS

a need for intensifying efforts to develop a natural resources budget for the metropolitan area which is more sophisticated and meaningful than the current set of Federal-State air and water quality standards.[14]

OPTIONS FOR ACTION

As a direct result of the workshop and this study, a much broader and more useful range of water quality-related management options has been prepared and incorporated, as part of a comprehensive set of "options for action" for each problem topic, into the two-volume "Reexamination of the Year 2000 Policies Plan" published by MWCOG in early 1974.[14] This document identifies the water quality-related "target" for the metropolitan area as: "maintain or achieve by 1983 existing state-adopted standards for protection and propagation of fish and wildlife and for recreation in and on the water." This target is entirely consistent with the stated goals of the Federal Water Pollution Control Act and of Section 208 areawide waste treatment management planning.

To achieve this target, a set of "options for action" have been identified and generally grouped according to the loci of control identified in the workshop. These options for action are as follows:

1. Reduce sewage flows by:

    a. Water demand reduction through:

        1. watersaving devices required by codes
        2. use restrictions during water shortages
        3. water rate changes
        4. public education
        5. water service moratoria

    b. Reduction of infiltration/inflow into collection systems

    c. Moratoria on sewer connections

2. Transfer residuals to air or land by:

   a. Interim package treatment plants

   b. Expansion and upgrading of the treatment efficiencies of existing waste treatment plants

   c. Construction of new advanced waste treatment plants

   d. Land application of secondary effluent from treatment plants

   e. Septic tanks

   f. Multi-residual processing (such as sewage and solid waste recycling)

   g. In-house devices to transfer residuals or to withhold wastes from water-carried systems (such as chemical or incinerating toilets or holding tanks)

3. Improve stormwater management by:

   a. Erosion and sediment control during construction

   b. On-site retention of stormwater (after construction)

   c. Collection and removal of residuals from stormwater

4. Utilize assimilative capacity of water resource by:

   a. In-stream aeration

   b. Extension of effluent outfalls

Although most of these options are structural, there are several others on the list, such as public education and water pricing, which seek to change people's habits and consumption patterns. Each of these options share a common characteristic in that each has received serious consideration in Metropolitan Washington by one or more local jurisdictions in recent years. Even though there are perhaps other water quality-related options which may be added during the public review process, and there are water supply-related options in the Year 2000 Policies Plan Reexamination not shown here, this list provides a basis from which to assess the relative benefits and costs to the metropolitan region of the options available to it.

IMPLICATIONS FOR FISCAL, NATURAL RESOURCE, AND COMMUNITY RESPONSE BUDGETS

Another objective of this study was the identification in qualitative terms of the associated costs and benefits of the various water quality-related management options. This has been accomplished in part also during the Year 2000 Policies Plan Reexamination. In his study for MWCOG of the concepts of optimum growth and balanced communities, a consultant suggested that the decision-making process, whereby problem solving occurs on an incremental basis, can generate new problems because, without an appreciation of the resources available, relative priorities cannot be thoroughly examined.[35] He suggested that the decision-making process use as a tool three "budgets" -- natural resource, fiscal, community response -- as a method of weighing the various and sometimes conflicting considerations that must be included in resolution of growth-related problems.

In its Year 2000 Policies Plan Reexamination, MWCOG has evaluated in a qualitative fashion each of the "options for action" in housing, jobs, safety and justice, juvenile delinquency, health and education, recreation, general welfare, natural resources including water resources, community balance, and transportation relative to the three-budget system. Under the budget concept, the available resources (whether monetary, natural, or human) at any given time that can be devoted to the solution of a problem such as water quality are finite.[14] For this reason, it is necessary to weigh social, economic, and environmental factors and to make difficult tradeoffs in allocating limited resources to the solution of the problem. The fiscal budget includes economic considerations such as tax base and public revenues, costs of services, and impact upon the private sector economy. The natural resources budget is defined by the "carrying capacity" of the air, land and water. The community response budget encompasses not only the social impact on a neighborhood but also current public values and the local government decision-making process.

It is believed that the budgets can be useful at two points in the planning process. First, they can be used in evaluat-

Table 2

WATER QUALITY-RELATED OPTIONS FOR ACTION

(Extracted from Metropolitan Washington Council of Governments Re-examination of Year 2000 POlicies Plan, Volume I, January, 1974)

Problem	Target	Options for Action	Implications for: Fiscal Budget	Implications for: Natural Resources Budget	Implications for: Community Response Budget	Need for Metropolitan Agreement on Implementation Prog.	Responsibility	Key Criteria for Monitoring and Evaluation
Water Resources The Upper Potomac Estuary, the Occoquan, and the Patuxent regularly experience high bacterial counts, low dissolved oxygen levels, and nuisance algae growths such that adopted state water quality standards are regularly violated.	Maintain or achieve by 1983 existing state-adopted standards for protection & propagation of fish and wildlife and for recreation. (PO-8) (72-13)	1. *Reduce sewage flows by Demand Reduction through:*						
		a. *Water saving devices required by codes.*	New developments will bear cost which will likely be passed on to the consumer.	Reduce requirements for new water facilities. Reduce flow to water pollution control facilities.	Permit consumer to feel he is participant in effort to help environment.	Modification of COG Model Plumbing Code.	Completed.	Number of devices installed by type.
						Adoption of code change to require water-saving devices.	WSSC, D.C. Council, Va. State Housing Board, City of Rockville Council.	
		b. *Use restrictions during water shortage.*	Place hardship on selected commercial enterprises such as car washes.	Permit water to be available for longer duration.	Require sacrifices on water use by public.	Water shortage emergency plan.	Water utilities, local governments, state water agencies, COG and other regional planning agencies.	MGD of water saved during restrictions.
						Adoption of ordinance as part of emergency plan.	Water utilities, local governments.	
		c. Water rate changes.	Rates generally set based on revenue needed to operate at no profit.	Reduction in demand that could be achieved in question.	Could adversely affect low and moderate income families.	Resolution of question of effects of rate changes on demand.	Water utilities, local governments, state water agencies, COG and other regional planning agencies, consultants.	Change in rates vs. MGD of water saved.
						Modification of rate schedules.	Water utilities, local governments.	
		d. *Public education.*	Source of funds for such a program would be needed.	Assist in reducing demand for water.	Purpose is to change people's water consumption habits.	Determine whether metropolitan-wide program is needed.	COG and other regional planning agencies, water utilities.	Number of people informed.
						Develop program.	COG and other regional planning agencies, water utilities, local governments.	MGD of water saved as direct result.
		e. Water service moratoria.	Tax base affected. Builders/developers restricted.	Reduce future demand for water. Reduce future sewage flows.	Housing stock diminished.	Interim solution to balance construction with supply development.	Local governments, COG and other regional planning agencies, developers and building associations, chambers of commerce.	Number of housing and commercial units affected by type.

b. *Reduction of infiltration/inflow into collection systems.*	Trade-off of repairing collection mains versus expanding capacity of water pollution control plants.	Increase removal efficiency of plants by concentrating load.	Public inconvenience of construction and repair.	Undertake studies on infiltration/inflow required by EPA.	Local public works depts., state water agencies, local governments, COG and other regional planning agencies, EPA.	MGD of infiltration/inflow reduced.
c. Sewer moratoria.	Builders/developers restricted. Tax base affected.	Reduce future sewage flows.	Housing stock diminished.	Interim solution to balance construction with plant capacity.	State water agencies, local governments, COG and other regional planning agencies, developers and builders associations, chamber of commerce.	Number of housing and commercial units affected by type.
2. Transfer Residuals to Air or Land by:						
a. Interim package plants.	Financial responsibility not established.	Performance of plants to protect water bodies questioned. Assist in eliminating overflows.	Lack of qualified and available operations personnel.	Compatibility of performance standards across jurisdictional lines and financing.	Local governments, state water agencies, developers and buidling associations.	MGD processed by plants. Removal efficiencies. Pounds of residual transfered.
b. *Expansion and upgrading to AWT of existing water pollution control plants (Arlington, Alexandria, Prince Georges County, Fairfax County, D.C., Loudoun Co.*	Economies of scale. 90% Federal-state funding availability based on cost-effectiveness.	Effectiveness of AWT to reduce loads. Transfers residuals to air by incineration or land by sludge processing.	Protect public health. Effect of plant on surrounding community. Response to Federal enforcement action.	Receive Federal-state funding and construct and operate facilities.	Contractors, local public works depts. EPA, state water agencies.	MGD processed by plants. Removal efficiency. Pounds of residuals transfered.
c. *New AWT plants (Occoquan, Prince William County, Montgomery County).*	Cost-effectiveness versus upgrading existing plants. 90% Federal-state funding availability.	Effectiveness of AWT to reduce loads. Effect of new discharge to use of water bodies as potable water source. Transfers of residuals to air or land. Energy requirements.	Protect public health. Effect of plant on surrounding community. Failsafe requirements. Difficulty of sludge disposal.	Ensure new plants will perform as expected. Obtain Federal-state approval and financing. Construct and operate facilities.	EPA, state water agencies, local governments, COG and other regional planning agencies, citizens' groups, contractors.	Same as above.
d. Land application of secondary effluent from plants.	Developable land removed from use. Cost-effectiveness. Land cost allowable under grant.	Possible groundwater contamination. Increased quantity of groundwater. Effect on surface topography and vegetation. Recycling of valuable nutrients.	Public health risks not fully investigated.	Investigation of feasibility of pilot project. Obtain Federal-state approval and financing. Construct and operate facilities.	Local governments, state water agencies, local public works depts., COG and other regional planning agencies, EPA, citizens' groups.	MGD transfered to land. Amount of nutrients discharged to land.

Problem	Target	Options for Action	Implications for Fiscal Budget	Implications for Natural *Resources* Budget	Implications for Community *Response* Budget	Need for Metropolitan Agreement on Implementation Prog.	Responsibility	Key Criteria for Monitoring and *Evaluation*
		e. Septic tanks.	Cost borne by consumer directly.	Possible effect on groundwater. Many soils not suited to septic tanks.	Potential health hazard in future. Permit development without sewers.	Identify areas with septic tank potential or problems.	Local public works, state water agencies.	Number of septic tanks.
		f. Multi-residual processing (sewage and solid waste).	Cost-effectiveness versus transfering residuals in separate processes. Economies of scale. Cost allocation among participants	Reuse and recycling of residuals. Energy conservation.	Multiple use of facilities.	Identify positive returns to jurisdictions, economic incentives, management efficiencies.	EPA, state water agencies, local governments, public service utilities, COG and other regional planning agencies, citizen groups.	MGD processed. Amount of residuals reused and recycled.
		g. In-house device to transfer residuals (such as chemical or incinerating toilets and garbage disposals).	Eliminate or minimize need for collection system and pollution control facilities.	Transfer residuals to air or land.	Public health risk associated with breakdown of equipment.	Encourage research to determine feasibility of installing as pilot such as in a "new town".	Developers, local governments, COG and other regional planning agencies, local health depts., state water agencies, manufacturers.	Amount of residuals transfered.
			Technological state-of-the-art availability questioned. Could increase private cost to developers, reduce public costs.					
		3. Improve stormwater *management by:*						
		a. *Erosion and sediment control during construction.*	Requires expenditures by developers.	Eliminate sedimentation of water resources from scarified land.	Improve aesthetics of water resources.	Insure ordinances are compatible and enforced.	Local public works and other depts., state water agencies, COG and other regional planning agencies, developers, soil and water conservation districts.	Amount of silt discharge. Number of violations of ordinances reported and prosecuted.
		b. *On-site retention of stormwater (after construction).*	Requires expenditures by developers.	Minimize impact of storm loads on water resources.	Minimize flooding of streets during storms. Requires maintenance.	Development, adoption of enforcement of compatible ordinances.	Local public works depts., COG and other regional planning agencies, developers, property owners, local governments, soil and water conservation districts.	Amount of stormwater flow reduced during peak periods.

c. Collection and removal of residuals from stormwater.	Tradeoff of controlling stormwater versus sewage flow.	Transfer residuals to air or land. Provide source of nonpotable water for reuse and recycling.	Temporary disruption of neighborhood during construction.	Investigation of feasibility as a pilot project.	COG and other regional planning agencies, local government depts., state water agencies, soil and water conservation districts.	Pounds of residuals removed.
4. Utilize assimilative capacity of water resource by:						
a. Instream aeration.	Cost-effectiveness. Pumping costs.	Increase dissolved oxygen level of water.	Effect on recreation and navigation. Aesthetic effects of fountains.	Investigation of feasibility.	State water agencies, local governments.	Change in dissolved oxygen level of water resource.
b. Extension of effluent outfalls (such as Piscataway plant).	Cost-effectiveness. Availability of Federal grant.	Permit better dispersion of effluent. Impact during construction.	Image of reducing pollution by dilution.	Investigation of feasibility for each treatment plant.	COG and other regional planning agencies, state water agencies.	Change in dissolved oxygen level and eutrophication in water resource.

ing the desirability of each individual option for action. Then, they are useful in facilitating the tradeoff process that must occur when proposed solutions to one problem are evaluated in relation to other problems. An example is given in the Year 2000 Policies Plan Reexamination where the most desirable solution to a water resource problem such as prohibiting new connections to overloaded treatment plants may prove detrimental to efforts to solve a human resource problem such as the need for increasing the supply of reasonably priced housing.

Table 2 on the preceding pages presents, in abbreviated form, the implications for the three budgets of the water quality-related management options listed earlier. The table and others like it included in the Year 2000 Policies Plan Reexamination constitute a written guide for the conduct of a decision-making process that leads toward solution of the problems facing the Washington metropolitan area. They illustrate a process in which:

1. Problems are identified. (See column headings that appear on the following tables.)

2. Targets are established for solving the problem.

3. A series of options for action are identified including all known, reasonable alternatives.

4. The options are explored and evaluated in terms of three sets of criteria or three "budgets": fiscal, natural resource, and community response.

5. The necessary extent of metropolitan agreement on an action program is discussed and agreed upon.

6. Responsibility is agreed upon for all necessary actions designed to carry out the option and to reach the target.

7. Key Criteria (quantitative measures) for monitoring and evaluating progress toward reaching the target are established.

It is interesting to note that when participants at an EPA Conference on the Quality of Life (QOL) concept were asked during an experiment to develop a consensus list of QOL factors, the component headings which resulted -- economic, political/social, and environment -- are parallel to those of the MWCOG three-budget system. And, when the specific QOL factors in each heading were then weighted and totalled, the three component headings ended up being rated relatively equal to each other in importance.[36]

SIX STRATEGIES FOR DEMONSTRATION OF FRAMEWORK MODEL

It is neither necessary nor within the resources available to the study to undertake a more detailed analysis of all of these options for action. Rather, since the primary purpose of the project is the development of systematic tools and techniques for use in the areawide planning process, a lesser number of water resources management strategies incorporating a variety of options will be used to demonstrate these tools in later chapters.

Six possible strategies for the year 1992 in metropolitan Washington have been selected for detailed discussion. They were formed by combining various options for action from Table 2. These strategies have been termed "areawide water resources management strategies" because they are tested for application across the entire metropolitan region, because treatment works are not site-specific (except for outfall location), and because they include options beyond simply wastewater treatment. These six strategies are summarized in Table 3 and include:

Strategy No.1 - Secondary Waste Treatment. The level of wastewater treatment in all municipal treatment plants discharging into the estuary is assumed at only secondary treatment. Water demand and sewage flow estimates predicted by the Framework Model are used with no control of stormwater runoff.

Strategy No.2 - Advanced Waste Treatment. Wastewater entering the Potomac Estuary in 1992 is assumed treated to advanced standards (AWT). The remaining strategies are alternative extensions of this strategy.

Strategy No.3 - Stormwater Treatment. This strategy assumes AWT, as well as operation of structural options

Table 3. SUMMARY OF AREAWIDE
WATER RESOURCES MANAGEMENT STRATEGIES

Areawide Strategies	All plants at secondary treatment only?	All plants at advanced waste treatment?	Stormwater runoff created?	Water saving plumbing in new construction and stricter sewer construction specifications after 1976?	Non-water carried waste removal in new construction after 1976?	Water use restrictions under Emergency Plan invoked?	Estuary used for water supply during emergencies?
1. Secondary Waste Treatment	Yes	No	No	No	No	No	No
2. Advanced Waste Treatment	No	Yes	No	No	No	No	No
3. Stormwater Treatment	No	Yes	Yes	No	No	No	No
4. Water Conservation	No	Yes	No	Yes	No	No	No
5. Dry Waste Collection	No	Yes	No	Yes	Yes	No	No
6. Indirect Estuary Re-use	No	Yes	No	Yes	No	Yes	Yes

All strategies assume same projected 1992 metropolitan development pattern.

resulting in 50% average reduction in waste load reaching estuary from stormwater runoff.

Strategy No.4 - Water Conservation. This strategy incorporates plumbing code changes requiring water-saving devices for all new construction after 1976. A 20% reduction in new residential domestic (in-house) water demands and sewage flows, and equivalent reductions in commercial/industrial sectors is simulated to reflect this. Advanced waste treatment for all wastewater is also simulated, while treatment of stormwater is not simulated. Sewer infiltration/inflow is assumed to be reduced by seven percent by stricter construction specifications and programs.

Strategy No.5 - Dry Waste Collection. This strategy assumes non-water carried waste removal of residential and commercial wastes in new construction after 1976 resulting in 50% reduction in residential domestic and commercial/industrial water demands and elimination of sewage flows in new construction while assuming AWT for existing sewage flows. This strategy also assumes water conservation measures are required for new construction causing an additional 10% reduction in residential domestic and commercial/industrial water demands. Reduced sewer infiltration/inflow as in Strategy No.4 is also assumed.

Strategy No.6 - Indirect Estuary Reuse. This strategy envisions obtaining a portion of the needed water supply from the Potomac Estuary during emergencies. This strategy also assumes water conservation and sewer infiltration/inflow reduction measures and AWT from Strategy No.4 are in effect, and that emergency water use restrictions are also imposed.

The six strategies were chosen to reveal the impacts of different treatment efficiencies, and different public policies that influence the use of water resources. With the exception of Strategy No.5, these strategies are in various stages of consideration within the metropolitan Washington region. A detailed description of the assumptions made in operating the Framework Model for these six strategies is included in Appendix A. A comparison of the results of the Framework Model simulations is presented in Chapter IV.

CHAPTER III

COMPONENTS AND ELEMENTS OF THE FRAMEWORK WATER RESOURCES PLANNING MODEL

OVERVIEW

The Framework Water Resources Planning Model can be depicted as a series of components and elements relating to one another in the manner shown in Figure 4. A major objective of the study was to describe the interrelationships among the components of the metropolitan scale water resources system. The physical simulation portion of the Framework Model begins with a Community Development Component which projects the nature and distribution of future growth in the metropolitan area for various forecast years, producing estimates of numbers of households, employment by type, and other socio-economic and demographic data by small geographic area.

The Water Demand Component is designed to estimate water demand by usage category for each combination of development plan and forecast year provided by the Community Development Component. Water requirements are estimated by small area separately for the residential, commercial/industrial, and public-unaccounted sectors. Within these sectors, requirements are further estimated for individual categories of usage such as apartment domestic (in-house), apartment sprinkling, single-family domestic, single-family sprinkling, commercial use by type, distribution losses, and free service. The Water Demand Component also provides essential information for the Sewage Generation Component.

The Sewage Generation Component projects the burden future growth imposes on the sanitary sewer and sewage treatment system of the region. It provides estimates by small area of average daily sewage flow and average daily pollutant loads by parameter based on appropriate output from the Water Demand Component, exogenously-calculated infiltration/inflow based on output from the Community Development Component, and user-specified pollutant load coefficients.

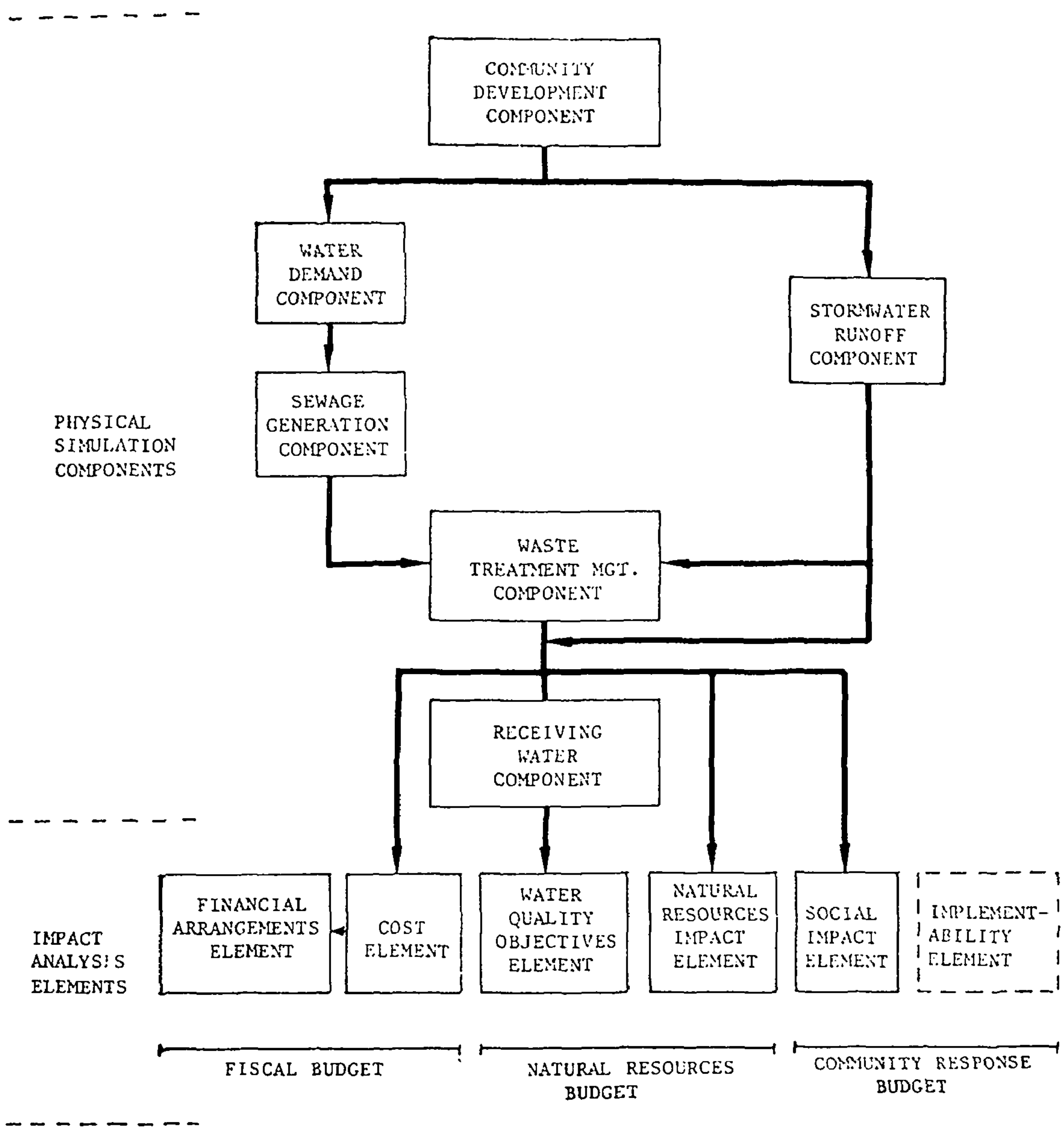


Figure 4 COMPONENTS AND ELEMENTS OF THE FRAMEWORK MODEL

The Stormwater Runoff Component projects the impacts of non-point sources of pollution for future patterns of urban development. This component also uses output from the Community Devleopment Component to calculate runoff volume and hydrographs by watershed for each storm selected for analysis. In addition, the Stormwater Runoff Component produces associated biochemical oxygen demand (BOD) washoff and BOD pollutographs by watershed.

The Waste Treatment Management Component next simulates the application of alternative waste treatment management techniques to the wastewater and stormwater flows and loads generated by the Sewage Generation Component and Stormwater Runoff Component respectively. The results are effluent flows and loads by parameter for all sewage service areas in the region.

These projected flows and loads are then simulated as discharges at selected points in the receiving water. These flow quantities and pollutant loads, along with initial conditions and constant data, are the inputs to the Receiving Water Component, which simulates the water quality response, in this case, of the upper Potomac Estuary. The estuary simulation can be performed on three different types of inputs: (a) "dry weather" sewage discharges only; (b) sewage discharges and treated stormwater runoff; or (c) sewage discharges and untreated stormwater runoff. Output from the Receiving Water Component consists of a computer-printed three-dimensional estuary profile for each pollutant or parameter simulated, with axes including the extent of Potomac Estuary affected (length in statute miles), time (in hours), and the concentration of parameter under investigation (such as milligrams per liter of dissolved oxygen).

It was the intent of the study to integrate existing physical simulation models into the Framework Model wherever possible, rather than developing new and untested models. Thus, the Community Development Component consists of the EMPIRIC Activity Allocation Model utilized by the Council of Governments for several years in other planning areas such as transportation. The basic computational model used in the Water Demand Component is the "MAIN II System", which was developed by Hittman Associates based on extensive research conducted by The Johns Hopkins University during the 1960's. The Stormwater Runoff Component incorporates portions of the

EPA Stormwater Management Model, while the Receiving Water Component includes the Potomac Estuary Model developed for the U.S. Environmental Protection Agency.

The following section of this chapter describes in detail each of these Framework Model components used to simulate the metropolitan water resources system. A flow diagram is presented for each component to illustrate how it operates and how the various submodels interrelate. Methods used to validate the results of the Framework Model components are also discussed.

The final section of the chapter describes the framework for analyzing the fiscal, environmental, and social impacts of alternative water resources management strategies. This framework is presented schematically in Figure 4 as the impact analysis elements of the Framework Water Resources Planning Model. The approach used was derived directly from the Year 2000 Policies Plan Reexamination discussed in the previous chapter, where three hypothetical budgets, a fiscal budget, a natural resources budget, and a community response budget,were shown to describe limits to resource use. Every allocational decision made by government, whether it be in water resources planning or another functional area, impacts upon or consumes a portion of each of these budgets. For each of these three budgets, existing methodologies for analyzing impacts of water resources management strategies are discussed and proposed procedures for their use in the Framework Model are presented.

FRAMEWORK FOR PHYSICAL SIMULATIONS OF THE WATER RESOURCES SYSTEM

Each of the major physical simulation components of the Framework Water Resources Planning Model, presented schematically in Figure 4, is discussed in detail in this section. The purpose of this section is to provide a better understanding of the development and applicability of the Framework Model for areawide waste treatment management planning. A demonstration of the entire physical simulation portion of the Framework Model for six areawide water resources management strategies for 1992 in metropolitan Washington is contained in the next chapter.

Community Development Component

The Community Development Component of the Framework Model provides estimates of detailed socio-economic and demographic characteristics for future years as input to the Water Demand and Stormwater Runoff Components. The "EMPIRIC" Activity Allocation Model, developed by the Council of Governments and its consultants, Peat, Marwick, Mitchell & Co., serves as the Community Development Component[37] although any model which provides the necessary socio-economic and demographic data can be used for this purpose. EMPIRIC* is one of a family of regional planning models which are designed to allocate projected metropolitan population, employment and land use totals among a set of smaller subregions or districts.

The model is designed to perform three specific functions:

- To allocate metropolitanwide control totals of future population, employment, and land use growth among a set of small subregions or districts, based upon exogenously specified metropolitan planning policies;

- To estimate the probable impact of alternative public and private planning policy decisions on the future distribution of metropolitan growth; and

*A detailed explanation of the design and use of "EMPIRIC" is contained in references [37] and [38].

- To provide an analytical foundation for the evaluation and coordination of public policy decisions in many functional areas.

In essence, the EMPIRIC Model is a set of simultaneous linear equations used to evaluate the effect of public policies and public investments on private market forces and development trends. The market forces are expressed by:

- Patterns of subregional household and employment development over a past period of time

- Future employment and population projections by time period for the entire metropolitan area

- Large scale private and public developments

The public policies are expressed in the following ways:

- <u>Transportation Service</u>: the accessibility of a given area to activity centers, via both automobile and public transportation for specific future points in time;

- <u>Water and Sewer Service</u>: the land area to be served by public systems in each portion of the area, as of stated points in time;

- <u>Density Constraints</u>: the density at which new development will take place is specified for various categories of residential and employment-oriented activities. Additionally, it is possible to place activity "ceilings" upon small areas in simulating moratoria or holding capacity constraints.

Household and employment levels divided into various categories are called "activities" in the modeling terminology. The EMPIRIC model allocates these activities to subregional areas called "Policy Analysis Districts" (or PAD's). The Washington metropolitan area is divided into 146 of these Policy Analysis Districts as shown in Figure 22. In addition to the EMPIRIC "Main" module which estimates household and employment distribution, there is a land consumption submodel which estimates future acreage, by type of land use, for each PAD, and supplementary submodels which divide "Main" model outputs into component distributions of population by age, household size, and so forth. Listed in Appendix C are the outputs available from the full EMPIRIC model.

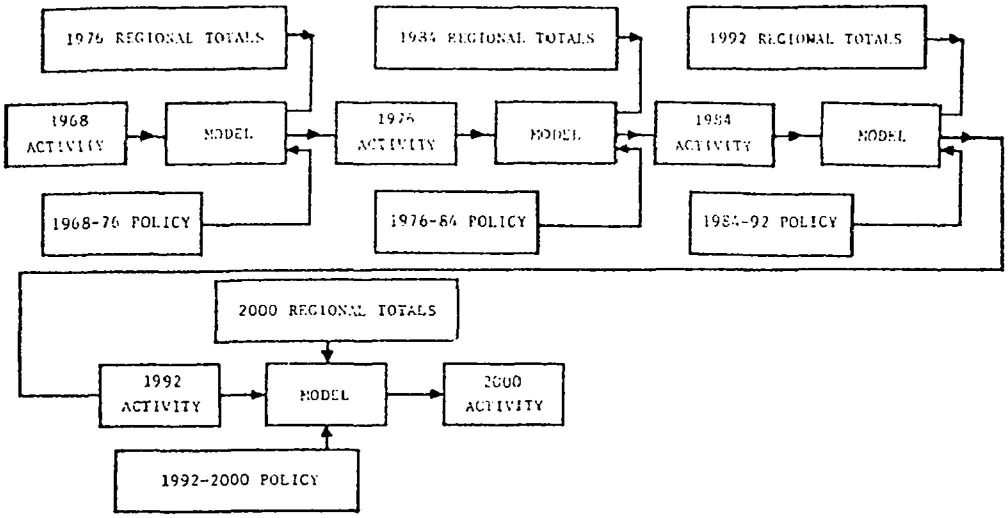
The EMPIRIC Model has been "calibrated" (adapted to the Washington metropolitan area) using activity and policy data developed for two points of time, in this case 1960 and 1968. Forecasts of the future metropolitan distribution of activity are then generated by specifying anticipated metropolitan wide control totals of households and employment, together with a set of future development and planning policies for the forecast intervals 1968-1976, 1976-1984, and 1984-1992, and by operating the model recursively to generate future activity distributions by small geographic area. A demonstration of the EMPIRIC model for the metropolitan Washington area as the base from which to estimate water resource impacts is contained in the final chapter of this report.

The EMPIRIC Model may be used both as a straight-forward forecasting device and also as a mechanism for comparing the efficacy of alternative planning policies over one or more specific time periods. Both of these methods are illustrated in Figure 5. EMPIRIC, or a substitute planning system for predicting the distribution of growth in an area, should be identical to the system used in developing metropolitan-wide transportation, air quality, housing and other related plans. This will ensure that the accepted basis for planning is used as input to the Water Demand Component and Stormwater Runoff Components of the Framework Model.

Water Demand Component

The Water Demand Component of the Framework Model is designed to estimate water demand by usage category for up to 200 user-specified geographic areas for each combination of development plan and forecast year provided by the Community Development Component. In addition, these water demand estimates serve as a basis for inferring uninfiltrated waste flows in the Sewage Generation Component.

RECURSIVE FORECAST PROCEDURE



EVALUATION OF ALTERNATIVE POLICIES
(FOR A SINGLE FORECAST PERIOD)

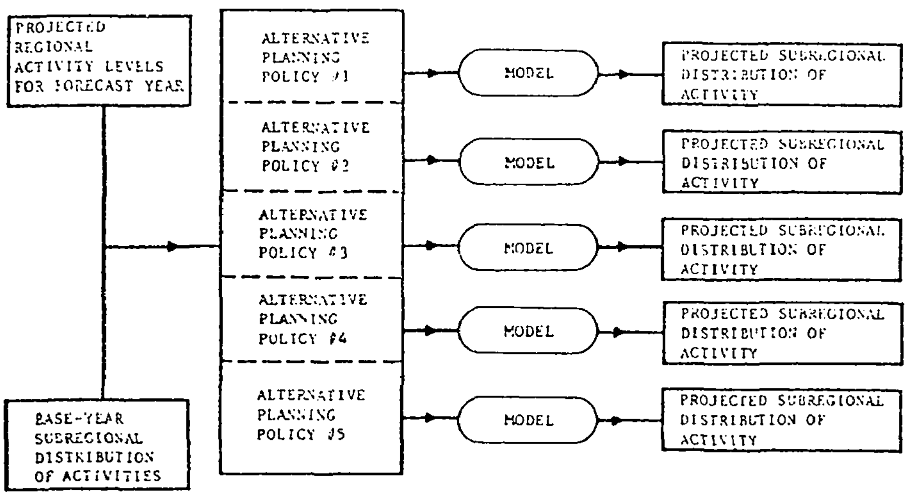


Figure 5 FLOW DIAGRAM OF ALTERNATIVE WAYS TO EXERCISE COMMUNITY DEVELOPMENT COMPONENT

A schematic representation of the Water Demand Component is presented in Figure 6. The basic computational model is the "MAIN II System", which was developed by Hittman Associates, Inc. based on extensive research conducted by The Johns Hopkins University during the 1960's. The system itself is a set of formalized precedures, approaches, and equations which have been developed specifically for use in planning for municipal water supply. Water requirements are estimated separately for the residential, commercial/ industrial and public/unaccounted sectors for each of the 50 "planning units" identified in the study and illustrated in Figure 22 as aggregated EMPIRIC Policy Analysis Districts. Within these sectors, requirements are further estimated for individual categories of water uses such as apartment domestic use, apartment sprinkling, single-family household domestic use, single-family sprinkling, commercial use by type of establishment, free-service, and distribution losses. Estimates are made of average daily, maximum day, and peak hour requirements for each category. Complete verification and documentation of the "MAIN II System" has been completed by Hittman Associates, Inc.[39,40]

To estimate water demands for each combination of development plan and forecast year, the MAIN II System as utilized in the Framework Model requires one hundred and five data elements for each planning unit. Because over 5000 data elements are therefore required to exercise the MAIN II System each time, a new computer program identified as the "Interface" program has been developed to manage this data. To accomplish this interfacing, the new program constructs a matrix of planning units by data elements for each combination of development plan and forecast year. These matrices can be formed, manipulated and revised as necessary.

Figure 6 indicates how data is entered into the Interface Program from three sources - a "constants" data file, an EMPIRIC output file from the Community Development Component, and user-specified data elements on cards. Sixty-five of the 105 data elements required by the MAIN II System for each planning unit are considered to remain constant throughout all development plans and forecast years for metropolitan Washington. These data elements, such as latitude, longitude, and home value range, are stored in the "constants" data file. The remaining forty-two data elements vary for each development plan and forecast year. The values for all of these

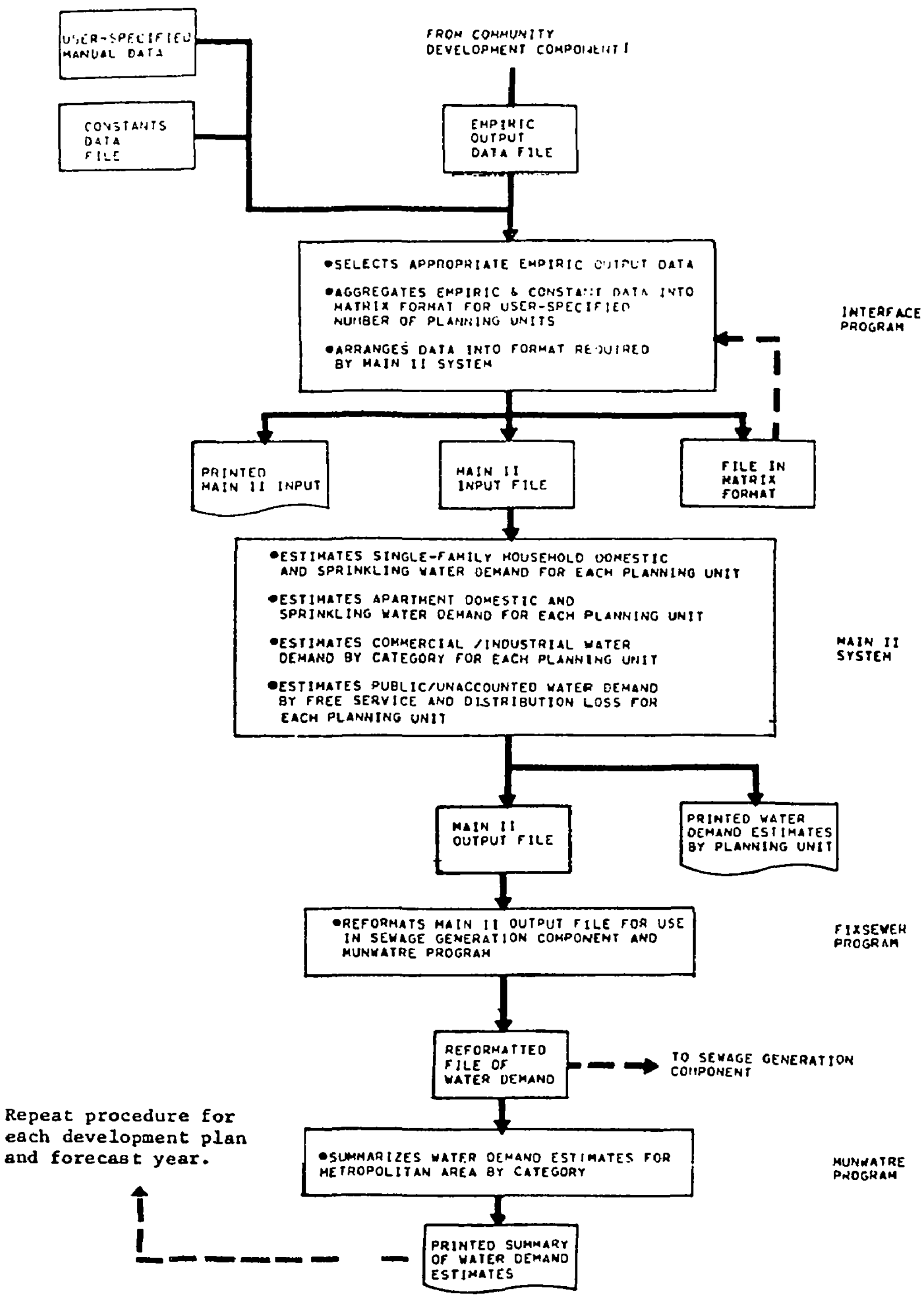


Figure 6 FLOW DIAGRAM OF WATER DEMAND COMPONENT

variables are either direct EMPIRIC output or are computed from EMPIRIC data produced by the Community Development Component. For each combination of development plan and forecast year an unmodified EMPIRIC data file is obtained and input to the Interface program. In addition, user-specified data elements on cards may be used to override any of the 'constant' or 'variable' data elements.

The Interface program reformats these inputs to produce three different outputs illustrated in Figure 6. One is a printout of data elements. The second is a data file disc that can be input directly to the MAIN II System to estimate water demands. The third is the same data file in matrix format convenient for revising the MAIN II input if necessary by rerunning the "Interface" program. The final two programs in the Water Demand Component serve to reaggregate MAIN II output for use in the Sewage Generation Component and to produce a printed metropolitan summary of water demand estimates.

As indicated earlier, the rationale behind the estimating procedures of the MAIN II System is based on extensive studies of residential, commercial and industrial water use conducted by The Johns Hopkins University. The research of residential water use conducted by Johns Hopkins[41,42,43,44] revealed that the principal factor influencing total annual water use in residential areas is the total number of homes. Thus, the EMPIRIC Model, which distributes the number of households throughout the metropolitan area based upon alternative development policies, provides ideal projections of this parameter. In addition to the number of households, the Johns Hopkins study identified three other important factors which affect water use in residential areas. These are the economic level of consumers as indicated by the market value of their homes, the climate, and whether customers are metered (single-family households) or are billed on a flat-rate basis (apartments).

Since the EMPIRIC Model projects the number of single-family and multi-family households separately, the latter factor is directly indicated by EMPIRIC. Similarly, since EMPIRIC distributes total families into four income quartiles, and based on an analysis by MWCOG to relate home value ranges and income quartiles,[128] another important factor is accounted for by EMPIRIC. Finally, as part of the original MAIN II

System, a Library of Water Use Coefficients contains the required climatic data.

The MAIN II System permits the commercial/institutional and industrial segments of the community to be divided into categories by type of establishment or industry, and water demand to be estimated for each type. Commercial establishments in the model include businesses of all kinds, mostly retail, which are not included in the Bureau of the Census Standard Industrial Classifications. Because of the similarity of the MAIN II computational techniques for the commercial/institutional and the industrial categories (i.e. multiplying each parameter by a water usage coefficient) the format of the EMPIRIC data to be used, and the fact that there is little industry in the Metropolitan Washington area, these two categories were under a commercial/industrial heading. Because commercial/industrial usage is relatively less important than residential usage in Metropolitan Washington and because EMPIRIC distributes employment into five major categories as indicated in Appendix C, eight commercial/industrial categories are used in the Water Demand Component. These consist of the five employment categories by EMPIRIC along with three of the original 28 commercial categories included in the basic MAIN II Model. Appropriate water usage coefficients were developed for these categories by MWCOG[129] based on the results of the commercial and industrial studies by The Johns Hopkins University[45] and the County Business Patterns published by the Bureau of the Census.[46]

The public-unaccounted submodel computes water which is pumped without subsequent recovery of revenue from a residential, commercial, or industrial customer. This usage is divided into the following three categories: free service, losses (probably due to leakage), and usage by airports. Computation is based on national average per-capita usage coefficients. For free service and losses categories the usage is determined within the model by multiplying the appropriate usage coefficient by the total population of the planning unit. For the airport category the average daily number of passengers at National Airport is input. Projections of passengers at other area airports are under development in the MWCOG Air Transportation System Plan and Program, and can be incorporated into the Water Demand Component when available.[130]

To demonstrate on a macro-scale the validity of the MAIN II model for application in Metropolitan Washington, published water consumption data for 1968 was first collected by MWCOG and tabulated by the water service areas indicated in Figure 22 in the following chapter. This recorded information was then compared by MWCOG to the output from the Water Demand Component exercised for 1968.[109] For the metropolitan area as a whole, the model results are within four percent of the recorded water demands for 1968. Because individual wells prevalent in the outer portions of the region are not included in the recorded information, the model output actually was closer than four percent. Model estimates by individual usage category for the metropolitan area were generally within seven percent of the recorded data. A more detailed demonstration of the model has also been performed by MWCOG for the water resource planning units within the District of Columbia, with excellent results.[110]

Sewage Generation Component

The Sewage Generation Component provides estimates of average daily sewage flow and average daily pollutant loads by parameter based on appropriate output from the Water Demand Component, exogenously-calculated infiltration/inflow based on output from the Community Development Component, and user-specified pollutant load coefficients. Sewage flow and load estimates serve as input to the Waste Treatment Management Component along with appropriate Stormwater Runoff Component output. A schematic representation of the Sewage Generation Component is presented in Figure 7. Uninfiltrated average daily sewage flows are inferred by planning unit directly from the Water Demand Component output of domestic (in-house) residential water demand and commercial/industrial water demand. Since they do not contribute to sewage flow, residential sprinkling and public-unaccounted water estimates are not used in the Sewage Generation Component. It is interesting to note that no agencies in the metropolitan Washington area, including local jurisdictions, state agencies, water utilities, or wastewater treatment plant operating agencies, calculate sewage flows based directly on water demand.

Infiltration/inflow is calculated exogenously for each planning unit by multiplying the Community Development Component output of developed acres in the forecast year by a user-specified infiltration/inflow factor. In the initial runs

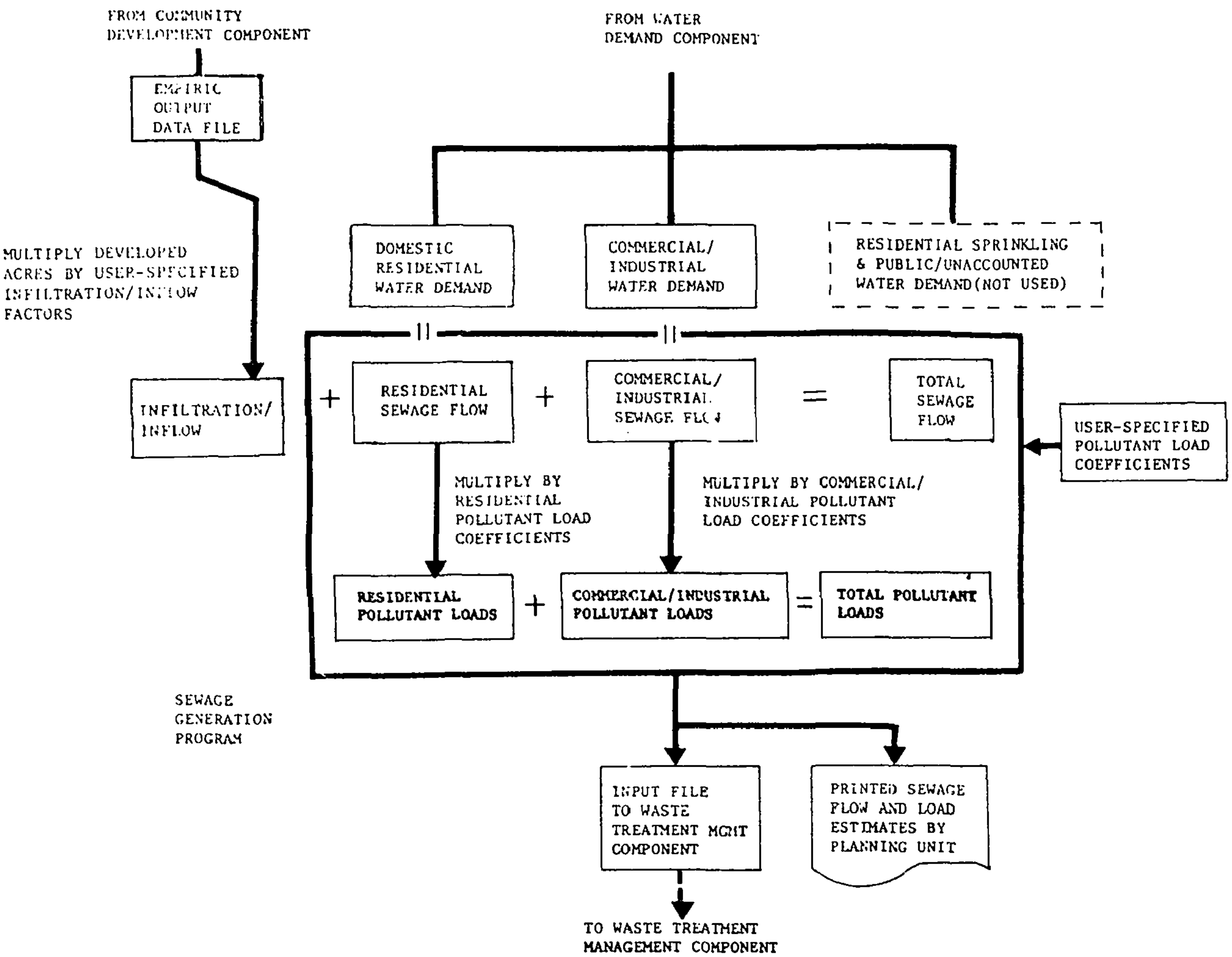


Figure 7 FLOW DIAGRAM OF SEWAGE GENERATION COMPONENT

of the Sewage Generation Component an infiltration/inflow factor developed by the Washington Suburban Sanitary Commission of 200 gal/developed acre/day is used.[47] In many areas more sophisticated information from formal infiltration/inflow studies may be available. Total average daily sewage flow by planning unit is thus the sum of the residential sewage flow, commercial/industrial sewage flow, and infiltration/inflow. An option available within the Sewage Genration Component is to calculate infiltration/inflow by applying an adjustment factor to the uninfiltrated flow produced by the Water Demand Component instead of calculating it exogenously. The method of calculating infiltration/inflow could perhaps be improved by linking it to runoff generated in the Stormwater Runoff Component.

It is assumed in the Sewage Generation Component that the effect of infiltration/inflow is to dilute the pollutant strength of sewage generated by households and businesses, and that the pollutant contribution from infiltration/inflow is minimal on an average daily basis when compared to other sources of wastewater. Thus, pollutant loads for such parameters as biochemical oxygen demand (BOD), nitrogen, and phosphorus are calculated by the Sewage Generation Component by multiplying, in turn, the residential sewage flow and the commercial/industrial sewage flow by user-specified pollutant load coefficients. Based on a survey of water pollution control plants in the metropolitan area, concentrations in milligrams per liter for each pollutant were determined and used in initial runs of the Sewage Generation Component.[108] Output consists of the total pounds per day for each pollutant by planning unit. The Sewage Generation Component exercised for 1968 using MAIN II output and infiltration/inflow based on EMPIRIC output predicted 314.6 MGD. The value actually recorded in the region for that year was 319.4 MGD, representing accuracy well within the expectations of the model.[108]

Stormwater Runoff Component

The Stormwate Runoff Component is made up of four models: the Prestorm Model, the EPA Stormwater Management Model, the Split Runoff Model, and the Rainfall Analysis Model. The flow diagram of the Stormwater Runoff Component is illustrated in Figure 8. The Community Development Component, the source of population and growth forecasts used in estimating water demand, is also used as an input to the Stormwater

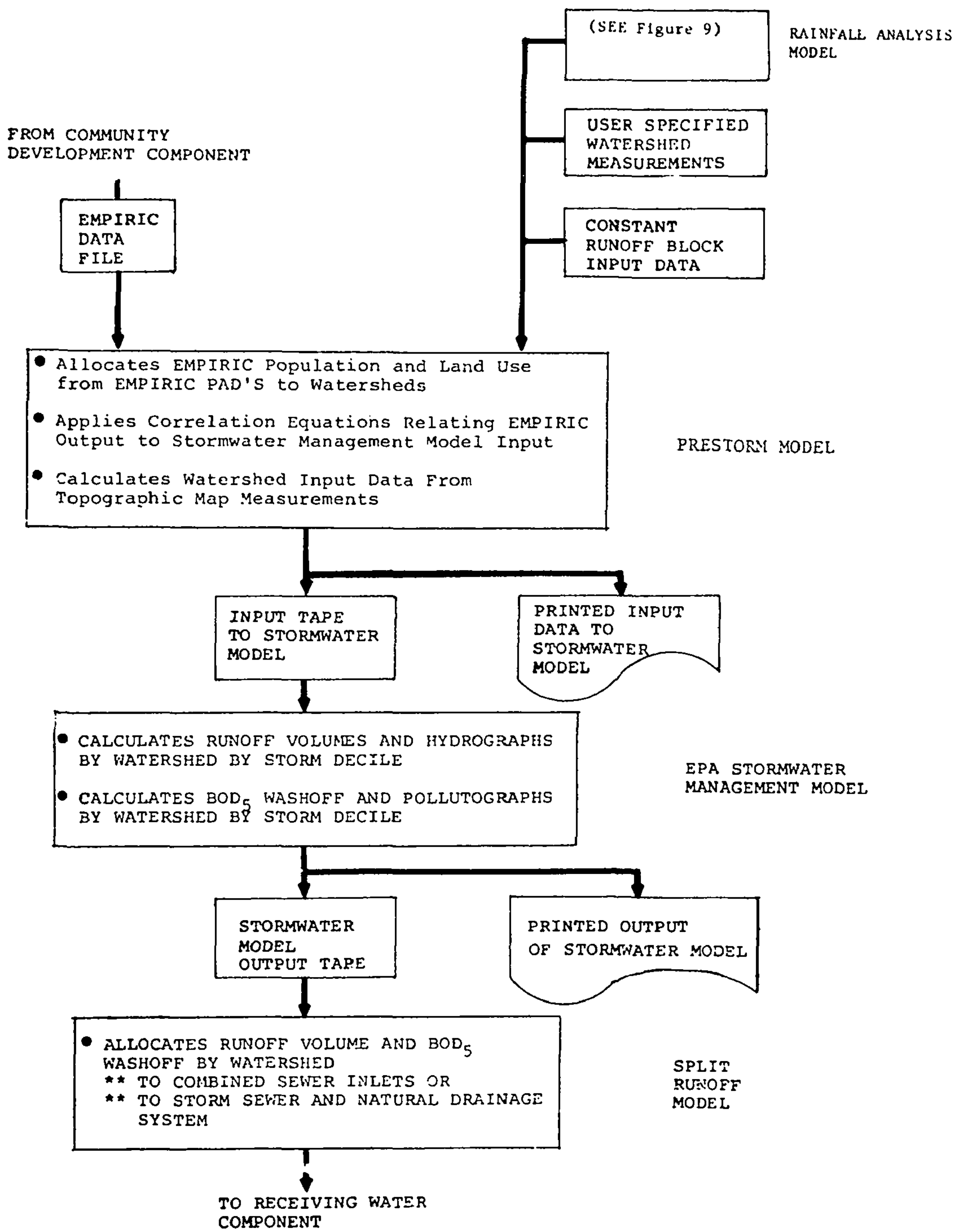


Figure 8 FLOW DIAGRAM OF STORMWATER RUNOFF COMPONENT

Runoff Component. Stormwater runoff is linked, in research conducted as part of this project[12] to the measures of urban growth which come from the EMPIRIC Model. The effects of growth on the accumulation of pollutants and subsequent washoff from the ground surface are linked in the Prestorm Model. This link provides an essential interface between the variables commonly projected by urban planners (population, employment and households) to variables required in stormwater forecasting models. It allows the element of urban planning to be related to the management of stormwater. The Stormwater Management Model[48] developed for the U.S. Environmental Protection Agency serves as the major element of the Stormwater Component of the Framework Model. In the EPA Stormwater Management Model, the pollutant accumulation is related to the length of curbs in an area. MWCOG staff research developed the relationship of population, households, and employment to curb length,[12] providing the key to the connection between the predictive EMPIRIC and the EPA Stormwater Management Models.

In order to project the changes in the volume of runoff carrying pollutants from impervious surfaces, a sensitivity analysis was performed by MWCOG to determine the relative importance of the twenty-one parameters (shown in Appendix D, representing watershed, stream hydraulics and land use) in the EPA Stormwater Management Model[49] on runoff volume per storm and BOD washoff per storm. The greatest impact on stormwater runoff volume for a given storm was found to be watershed imperviousness. Estimating this parameter over time required that EMPIRIC be used to project changes in a variable related to imperviousness. The correlation between impervious surfaces and population density by MWCOG allowed this link between projected growth forecasts and the stormwater runoff quantities. The equations correlating EMPIRIC output parameters and inputs required by the EPA Stormwater Management Model were applied in the Prestorm Model. The remaining variables required to project runoff were processed by the Prestorm Model either as inputs passed directly to the EPA Stormwater Management Model or as an input that requires further calculation or allocation before being passed on to the EPA Stormwater Management Model.

Watershed geographic parameters are based on three topographic map measurements: longest stream length, its change in elevation, and the average change in elevation from stream to ridge measured at the midpoint of stream length. The Prestorm Model then calculates the required slopes and overland flow distances from these measurements and watershed areas by land use. Watershed areas by land uses are obtained from the output of the Community Development Component from an allocation by the Prestorm Model of one hundred and forty-six policy analysis districts (PAD's) to sixty-five watersheds. Only those watersheds directly tributary to the Potomac River have been studied in this project.

The EPA Stormwater Management Model calculates runoff volume and hydrographs by watershed for each storm selected and, in addition, produces the associated BOD washoff and BOD pollutograph. During the initial runs of the Framework Model a storm with a two year return frequency[50] was used to simulate the rainfall in the region. Because antecedent dry periods (during which ground pollutants accumulate) and detailed intensities during a storm are required by the EPA Stormwater Management Model, a more sophisticated analysis has been made of rainfall actually experienced in the region[51].

The objective of the rainfall analysis was to produce a small set of storms representative of an actual series of many storms. The storm characteristics that are important include the rainfall intensity variation with time, the duration of the period antecedent to the storm event, and the duration of the period succeedant to the storm event. The antecedent duration is important in the EPA Stormwater Management Model[48] because the constituent accumulation rate is directly proportional to antecedent duration. The rainfall intensity variation is important in the EPA Stormwater Management Model because the constituent washoff fraction is simulated as an exponential function of rainfall intensity. The succeedent duration is important for estimating available treatment time.

The flow diagram of the Rainfall Analysis Model is presented in Figure 9. Storm events were formed from continuous hourly rainfall records obtained from the U.S. Weather Bureau[52]. Storm deciles were formed by dividing all of the series of storms of record into ten groups called deciles containing the same number of storms. The first decile storm group contained the largest storms on a volume basis. Each storm decile was then grouped by hour from start of storm and ten intensity groups were formed for each of the hours. The highest tenth intensity group was then interpreted to repre-

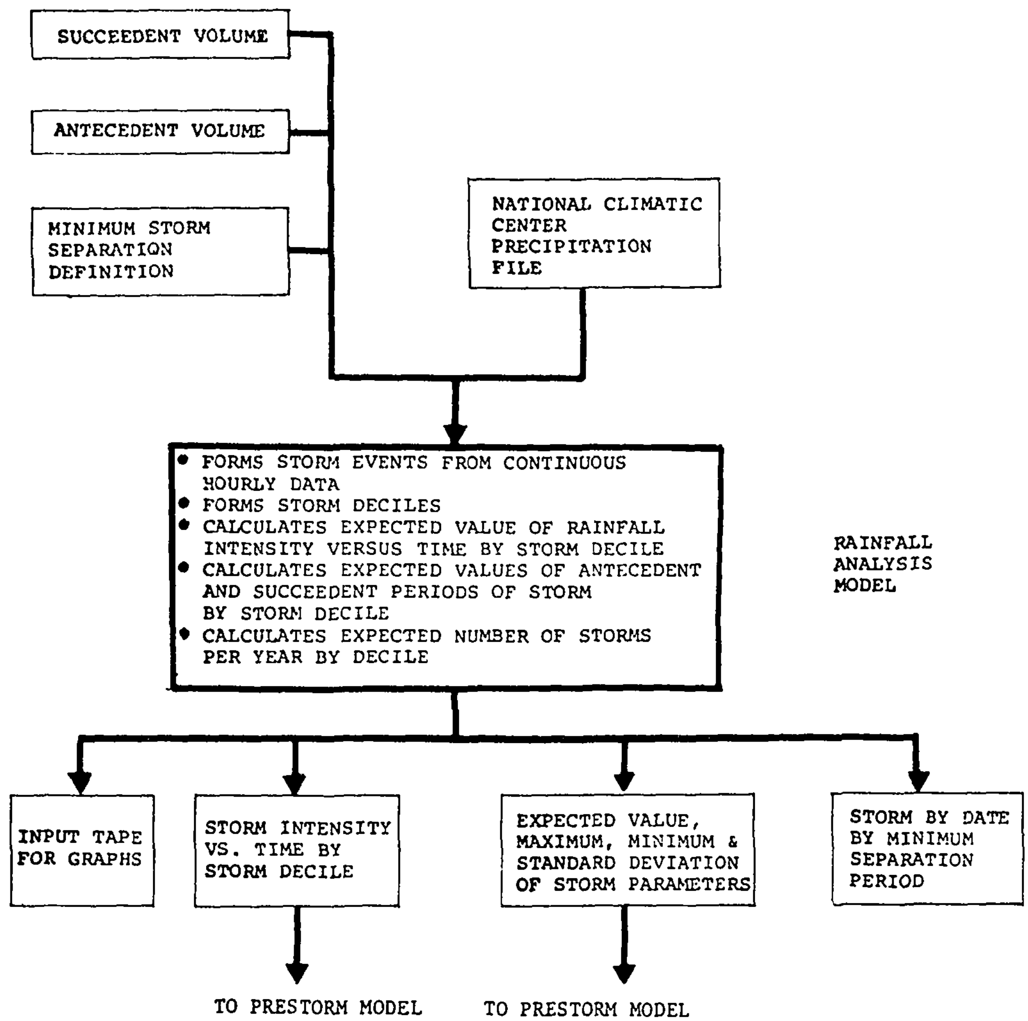


Figure 9 RAINFALL ANALYSIS MODEL SCHEMATIC

sent the intensity that applies during the first tenth of each hour; the second highest tenth intensity group is similarly interpreted to represent the second highest tenth of each hour - and so on through the remainder of the hour. This form of analysis preserved the proportion of the various hourly intensities for each storm decile. Because of this analysis, simulations of stormwater runoff resulting from more frequent storms than those normally considered when solving the more conventional stormwater piping problems can be made by the Framework Model.

The Split Runoff Model is used to allocate the runoff volume and BOD washoff by watershed to either combined sewer inlets (for subsequent treatment) or to the storm sewer and natural drainage system. These results are used directly as input to either the Waste Treatment Management or to the Receiving Water Components. In this study combined sewerage was assumed to be completely treated. At the time of the study, no data correlating the rainfall to combined sewer overflows existed. When such data becomes available, it can be introduced into the simulation at this point.

The projections of the Stormwater Management Component consist of the expected runoff volume and BOD_5 washoff by storm and by annual total. The area studied is 737,000 acres divided in the model into fifty-three watersheds. These fifty-three watersheds are expected to have a population density greater than 0.5 persons per acre in 1992. The specific ground pollutant accumulation rates used to produce these BOD_5 washoff results are 5.73, 28.3, 36.3, and 12.3 grams/curb meter/day, respectively, for residential, commercial, industrial, and undeveloped or parkland user. In order to operationally apply the Stormwater Management Model 48 to the 737,000 acre area of the Metropolitan Washington Region directly tributary to the Potomac River only one of the two sources of pollution used in the model was utilized. The catchbasin source of pollution is included with the curb accumulation of ground pollutants. The resulting annual average BOD concentration of stormwater runoff ranges between 2 and 39 mg/l depending roughly on the watershed population density. The resulting fifty-three watershed average BOD concentration of stormwater runoff ranges between 11 and 18 mg/l depending on storm decile.[2]

Waste Treatment Management Component

This Component, depicted in Figure 10, simulates the application of alternative waste treatment management options to the wastewater and stormwater flow and loads generated by the Sewage Generation Component and Stormwater Runoff Component respectively. An earlier chapter has mentioned the various management options available to the metropolitan community, many of which do not involve "treatment" of flows by conventional structural facilities. However, this component is designed to test load reduction by structural facilities where applicable.

Operation of the NEWTREAT program of the Waste Treatment Management Component permits the user to simulate the performance of existing or proposed facilities designed to remove pollutants from stormwater or wastewater by inputing user-specified levels of treatment. Within the Component the appropriate outputs of the Sewage Generation Component by planning unit and Stormwater Runoff Component by watershed (important for watersheds served by combined sewers or for which stormwater is "treated") are first aggregated into a user-specified set of sewage service areas. Figure 22 in the following chapter depicts the service areas used in the initial runs of the Framework Model. An option available in the Waste Treatment Management Component but not used in the initial runs is to put portions of a single planning unit's flow into more than one sewage service area.

For each sewage service area, a set of user-specified pollutant removal efficiencies (which indicate the actual or desired level of treatment) are applied by the Waste Treatment Management Component. The results are effluent flows and loads by parameter for all sewage service areas. If the effluent will be discharged to the Potomac Estuary, this data is transferred to a data file for input to the Receiving Water Component. If an option such as land application of partially treated effluent is being simulated, then the effluent loads and flow for direct discharge to the Potomac Estuary will be zero.

Receiving Water Component

The Receiving Water Component of the Framework Model is comprised of a Preestuary Model developed by MWCOG and two sub-

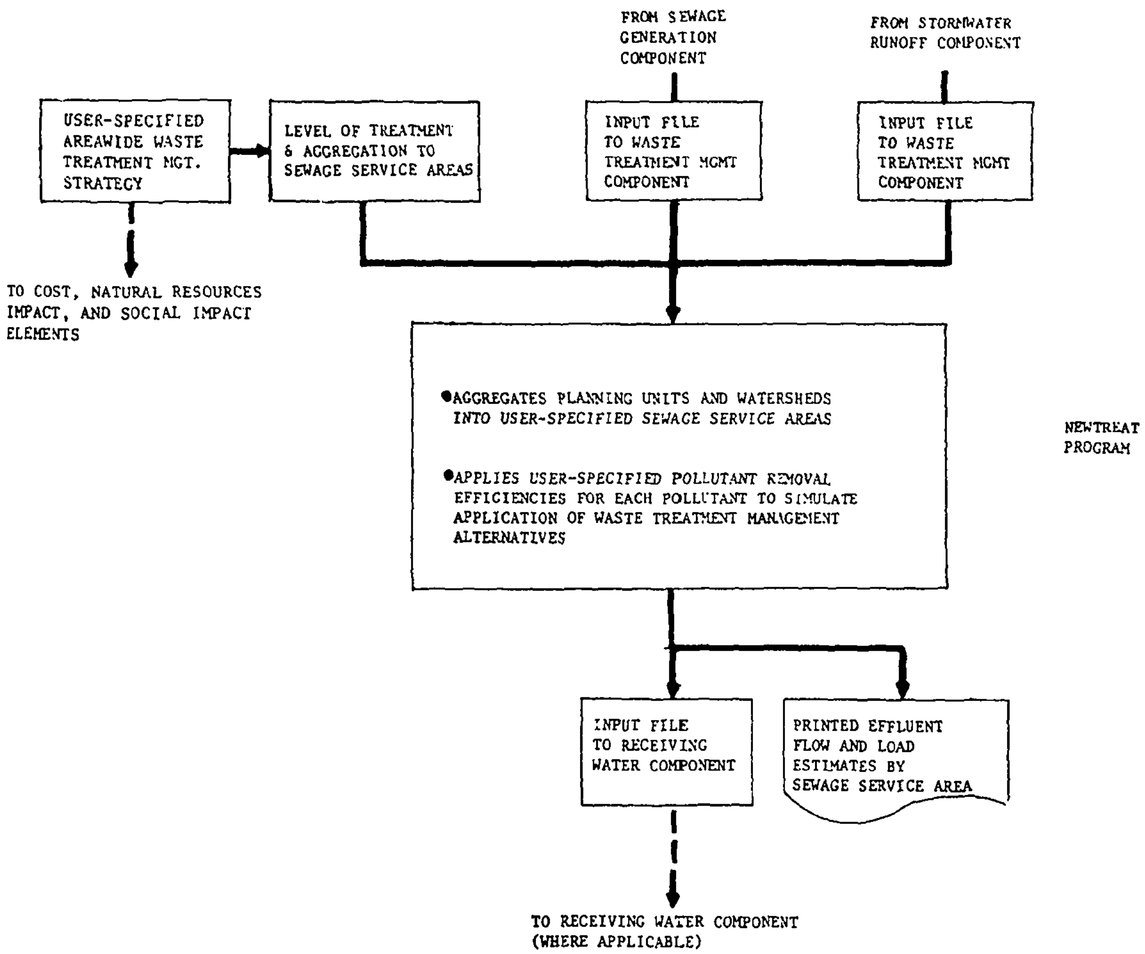


Figure 10 FLOW DIAGRAM OF WASTE TREATMENT MANAGEMENT COMPONENT

models of the Potomac Estuary Model developed by the U.S. Environmental Protection Agency[53,54]. The Preestuary Model is used to facilitate data preparation for use in the EPA Estuary Model. The EPA Estuary Model as applied in the Framework Model produces dissolved oxygen profiles of the Potomac River from statute mile 116 at Chain Bridge to statute mile 18 at Piney Point, Md., in response to the biochemical oxygen demand, ammonia, and dissolved oxygen loads from tributary streams and wastewater treatment plant discharges. The EPA Estuary Model was modified by MWCOG[55] so that storm flows and constituent loads to the estuary are superimposed for the duration of the storm event on a background dry weather estuary condition.

A further modification of the EPA Estuary Model was made by MWCOG to produce three-dimensional estuary profiles of constituent concentration vs river mile vs time and to calculate in tabular format the extent and duration of receiving water dissolved oxygen response. These outputs are used in the Water Quality Objectives Element of the Framework Model. During a storm simulation, constituent profiles by river mile are produced for a series of times from the start of a storm simulation. The Receiving Water Component can be used to investigate alternative treatment levels for both wastewater and stormwater as provided by the Waste Treatment Management Component for comparison to state standards applicable to each water quality segment in the Water Quality Objectives Element.

Estuary simulation using three different types of inputs can be performed by the Receiving Water Component. In Figure 11, the flow diagram of the Receiving Water Component, these types of inputs are designated as Option A, Option B, and Option C which represent (a) "dry weather" sewage flow discharges only, (b) sewage flow discharges and treated stormwater runoff; and (c) sewage flow discharges and untreated stormwater. Also identified in Figure 11 are the calculations performed by the Preestuary, Estuary Hydrodynamics, and Estuary Quality Models comprising the Receiving Water Component. The input shown as "impact of extra-regional policies" represents the incoming water quantity and quality upstream of the Washington metropolitan area. The incoming water quantity is adjusted for the effect of power plant comsumptive uses and water supply withdrawals in the Potomac Basin. This is a very important input to this model as will be seen in later

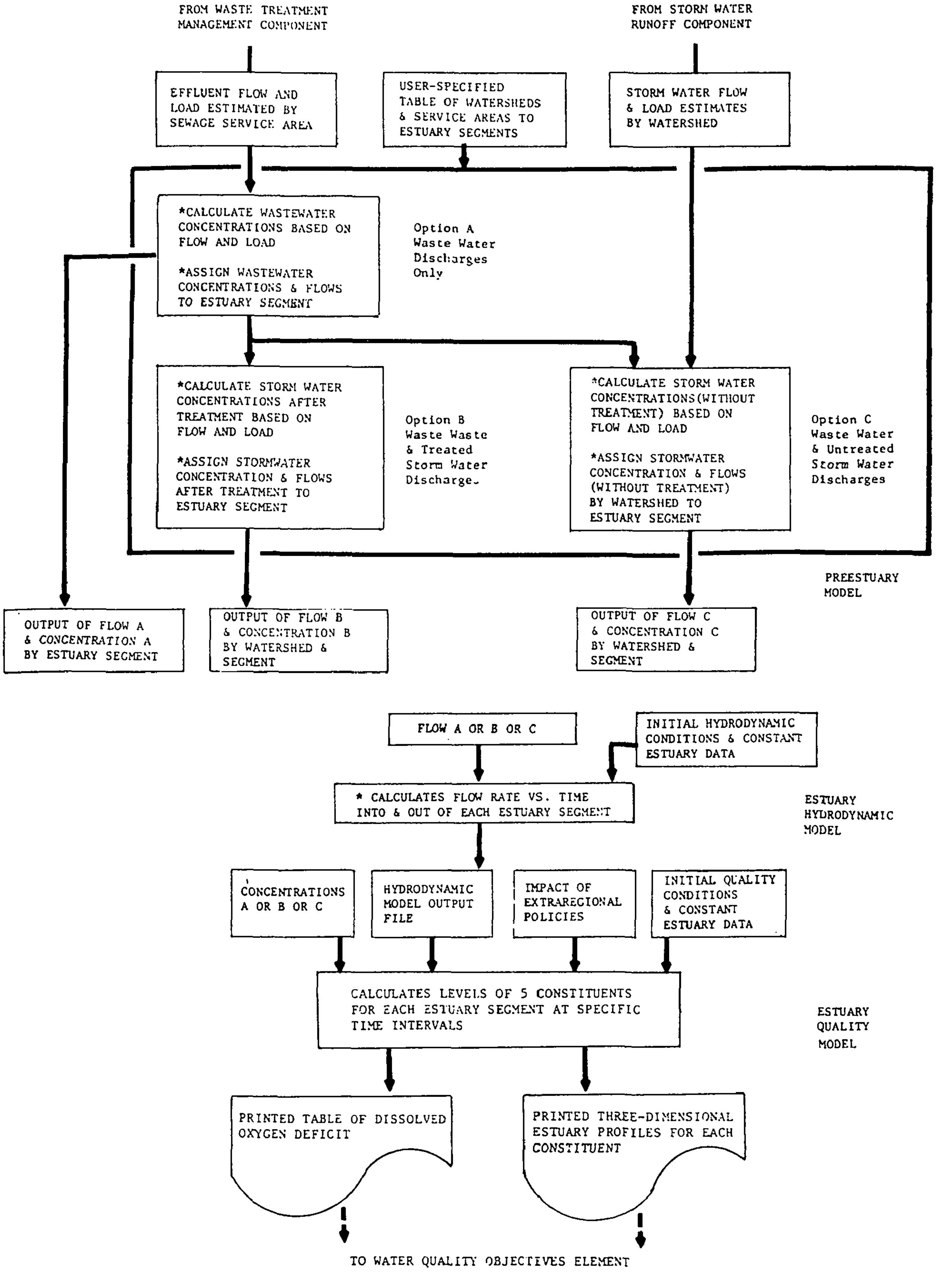


Figure 11 FLOW DIAGRAM OF RECEIVING WATER COMPONENT

discussions of the river flows modeled.

The Preestuary Model is used to assign effluent flows and constituent concentrations calculated by the Waste Treatment Management Component, with or without treated or untreated stormwater runoff flows and associated constituent concentrations, to the appropriate segment of the estuary to simulate waste treatment plant outfall locations.

The Estuary Model is comprised of two blocks, the Estuary Hydrodynamic Block and the Estuary Quality Block. The Estuary Hydrodynamic Block is used to calculate the flow rate versus time into and out of each segment of the Potomac Estuary, based on stated inflows, tidal conditions, and withdrawals by segment.[56] The output of the Hydrodynamic Block is used in the Quality Block to transfer constituents between segments and to calculate dissolved oxygen transferred between the atmosphere and the estuary.

The Estuary Quality Model is used to calculate the constituent concentrations for each segment of the Potomac Estuary. The five constituents chosen for analysis in the study are five day biochemical oxygen demand (BOD), ammonia(NH_3), nitrate(NO_3), chlorophyll 'a' of photosynthetic phytoplankton and dissolved oxygen. The interaction of these constituents is shown in Figure 12. The dissolved oxygen constituent is depleted by oxidation of carbonaceous and nitrogenous matter. The product of the oxidation of nitrogenous matter in the nitrification process is nitrate. The nitrate is used as a nutrient source by photosynthetic phytoplankton; whose population is depleted by predation and sinking. The photosynthetic phytoplankton, measured as a concentration of chlorophyll 'a', alternately perform photosynthesis by day adding oxygen to the water and respiration by night depleting the dissolved oxygen level of the water. Depressed oxygen levels are counteracted by aeration at the air-water surface.

Similarly, oxygen levels in excess of the equilibrium saturation concentration result in a transfer of excess oxygen to the atmosphere. An additional consumption of oxygen is removed by reaction with the benthos in a proportion to the bottom area. The interactions of these constituents take place at different rates which vary with temperature. At a temperature of 20° C the half-life of ammonia used in the

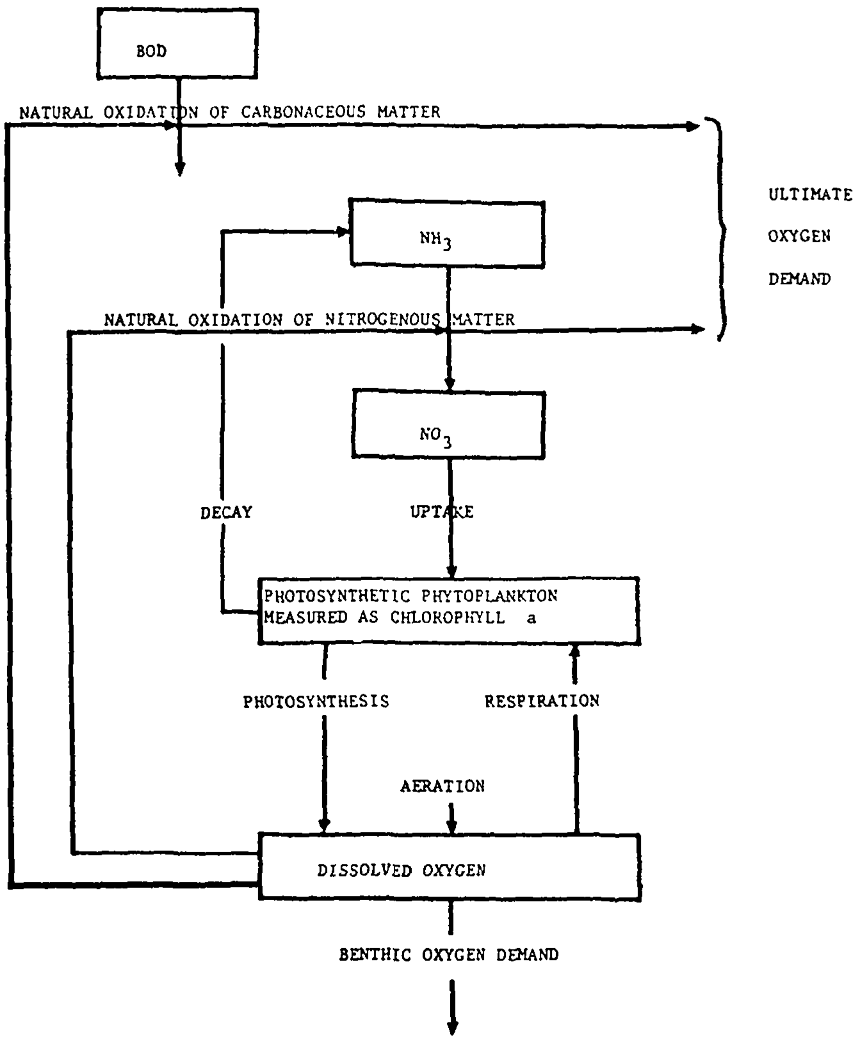


Figure 12 ESTUARY QUALITY MODEL SCHEMATIC

simulation due to its reaction with oxygen is 3.0 days. The half-life of BOD in the simulation due to its reaction with oxygen is 4.0 days. The half-life of nitrate in the simulation due to uptake by photosynthetic phytoplankton is 7.7 days. The half-life of chlorophyll 'a' in the simulation due to predation and sinking is 17.3 days. All of these half-lives are adjusted when simulations are conducted at other than 20°C. In addition to these chemical and biological reactions, the physical processes of advection of the constituents in the direction of flow, and diffusion of the constituents in the direction of lower concentration are simulated in the Estuary Model.

The results of the operation of the Estuary Model are presented as constituent concentrations versus river mile by time from simulation start. Simulation length is set to approximate three times the BOD half-life or about 12 days at 20°C. Initial conditions for storm and non-storm simulations are held constant so that the additive effect of a storm event is determined even if the initial constituent concentrations set at the start of the simulation are not at equilibrium flow and quality conditions averaged over a tidal cycle. The timing of the arrival of the storm loads from the various watersheds is assumed to occur evenly over the same twenty-four hour period. This is an operational decision as the more distant and least developed watersheds from the uppermost estuary segment have the smallest constituent washoff amounts. Additionally, from an examination of the constituent half-lives, it is thought that a difference of twenty-four hours in arrival time of watershed BOD washoff amounts to the uppermost segment is small relative to the BOD half-life of 4 days.

Besides intermediate outputs used to link the various submodels, output from the Receiving Water Component is computer-printed in two readily-useable formats. First, three-dimensional estuary profiles are produced for each of the five constituents modeled. Axes on each plot include the extent of Potomac Estuary affected (length in statute miles), duration (in hours), and the concentration of the constituent under investigation (such as milligrams per liter of dissolved oxygen). The first section of Chapter IV presents a typical three-dimensional estuary plot. The second section includes the profiles for each of six areawide water resources management strategies analyzed in Chapter IV.

A second output from the Receiving Water Components is a table summarizing the three-dimensional estuary profiles for dissolved exygen. The table shows the extent in area, estuary length, and estuary volume affected by various levels of dissolved oxygen for stated durations. Examples of these tables are included in Chapter IV and Appendix A.

Both the three-dimensional estuary profiles and the tables for dissolved oxygen are utilized in the Receiving Water Component of the Framework Model to assist in defining the "capability" and the "effectiveness" of each areawide water resources management strategy.

FRAMEWORK FOR ANALYZING THE FISCAL, ENVIRONMENTAL, AND SOCIAL IMPACTS OF ALTERNATIVE STRATEGIES

The Need for the Framework

That a water quality management option must be formally assessed for not only its fiscal impact, but also for its environmental and social effects beyond meeting water quality standards, is a relatively new requirement in local water resources planning, stimulated in large part by state and Federal regulations.[58] To date the most influential Federal legislation in this regard has been the National Environmental Policy Act of 1969 which requires that Federal agencies prepare detailed statements on "major Federal actions significantly affecting the quality of the human environment",[7] including such actions as providing Federal financial assistance to construct treatment works and preparing the Section 208 areawide waste treatment management plans.[17] In addition, fifteen states including Virginia and Maryland now require impact statements for a wide range of state government, local government, or private industry activities significantly affecting environmental quality.[59,60,61] These requirements do not appear out of the ordinary. According to results of an extensive survey conducted in 1973 by the International City Management Association, 30% of cities and 35% of counties responding also have formal requirements for environmental impact statements.[58]

Thus, in a four year period the preparation of environmental analyses has become a major activity at all levels of government. However, despite federal guidelines defining uniform procedures for EIS preparation, a recent study conducted for EPA concludes that an obstacle to meaningful review of environmental impacts has been the "general lack of adequate methodological tools" actually being put to use in the governmental decision-making processes.[62]

The development of a framework within which such existing and emerging tools can be used in assessing and displaying the fiscal, environmental, and social impacts of water quality managementalternatives as required by Federal, state and local law was a major objective of this project. There are several reasons for employing such a framework in the water resources planning and impact assessment process of the Washington Metropolitan Area. First, many levels of government and groups of citizens are involved in arriving at any water resource management decision. For example, a wastewater treatment plant in Maryland must receive local government and state health approval as an amendment to the county's "Ten Year Water & Sewer Plan", undergo public hearings, and receive local permits. The treatment plant must also be included in the state basin water quality management plan and any Section 208 areawide waste treatment management plan. If it is to be funded by a Federal grant, it must also undergo review by other local governments and the metropolitan planning agency as part of OMB Circular A-95 procedures, qualify for and receive state and federal grant funds where applicable and obtain an NPDES permit. It is expected that an acceptable framework for identifying and analyzing background information and planning assessments might facilitate decision making processes as complicated as this one.

It was also throught that the framework could serve as a major tool for agencies designated to conduct areawide waste treatment management planning under Section 208 of PL 92-500, by being designed to satisfy or assist with satisfying the following regulatory requirements under Section 208:

- Cost-effectiveness analysis[22]
- User charge determination[23]
- Financial arrangements to implement the plan[17]
- Facilities planning requirements[27]
- Impacts of plan implementation[17]
- Public participation and plan review[63,64]

Perhaps more importantly, however, the framework can be used to present the relevant data and points of view to an areawide waste treatment management agency's policy board in a manner which will aid the board's decision as to whether a particular strategy should or should not be part of the annual areawide plan.

The same basic premise used in developing the framework for simulating the water resources system was used to structure the impact analysis; i.e., to link existing methodologies wherever feasible into a framework for use by the area's decision makers, rather than developing all-new and thus untested techniques. As discussed earlier, there has developed during the Year 2000 Policies Plan Reexamination a growing consensus that conceptually there are three budgets which define the limits or constrain the range of resource allocation choices that can be made by elected officials in the Washington Metropolitan area. These three budgets are the fiscal budget, the natural resources budget, and the community response budget. While only the first budget deals in a recognized currency (dollars), it is recognized that every allocational decision made by local governments impact upon or consume a portion of each of these budgets. In this chapter existing methodologies for analyzing the impacts of water quality management options will be discussed and the proposed procedures for use in the Framework Water Resources Planning Model will be described.

Fiscal Budget

The community fiscal budget is well known to urban managers. On the revenue side it is defined as the fiscal capacity of the jurisdiction, whether local, state or Federal, to generate from its income and from intergovernmental transfers (i.e., revenue sharing) adequate revenues to support its wide-ranging capital and operating programs. On the expenditures side it is a process of buying the services and use of capital required to support the needs of the community. Expenditures are made with the administrative and often legal requirement that the desired product or service be purchased at the lowest attainable price following a program to guarantee that costs will be equitably shared and that long-term expenditures are carefully programmed. In this report the fiscal budget will be discussed as two elements, a "cost" element and a "financial arrangements" element. EPA guidelines suggest that the evaluation of monetary costs for water pollution control projects should not be influenced by adopted financial arrangements,[65] thus lending credence to the separation of these two elements.

Cost Element-

Existing Methodologies - In waste treatment management planning, local governments in Metropolitan Washington and their engineering consultants have extensive experience in estimating and comparing the direct costs of proposed capital facilities using methods long known to engineering economics and specified in Federal cost-effectiveness analysis guidelines.[17,22] Direct costs consist of both capital construction costs and annual costs for operation, maintenance, and repair (OM & R), with the latter divided between fixed annual costs and costs which would be dependent on the annual quantity of wastewater processed. The cost of an alternative water resources management strategy is computed by discounting its costs over the selected planning period to "present worth values" or the "average annual equivalent values." Table 4 illustrates in simplified form the derivation of present worth and average annual equivalent cost for a hypothetical sewage treatment plant. Alternative systems are then compared by ranking the estimated present worth values, or to identify where estimated values are identical within the accuracy of the analysis. An example of this for a recent study in Montgomgery County, Maryland, is shown in Table 5. The approach is relatively straightforward once the appropriate interest rate and planning period are selected, although there may be a need to give special treatment to elements of operating costs that are projected to inflate in cost at a rate well above any inflation experiences by the rest of the economy. This can be done by discounting them in present worth analysis at a rate less than that chosen for other items of cost. The cost of chemicals, fuels, or power may qualify for such treatment in present value analysis.

Most water quality management alternatives chosen in the past have been capital-intensive, thus lending themselves to straightforward engineering economic analysis. As more comprehensive water resource management strategies are considered, it will be necessary to consider such things as flow reduction devices and use of pricing to reduce water consumption. These programs do not fit easily into conventional cost analyses. Therefore the framework must be designed to permit calculation and comparison of the costs associated with these alternatives as well.

As emphasized by the MWCOG three-budget system, local governments are faced with providing other community services such as roads, schools and police in addition to water resource facilities. Each of these have direct costs as well which

Table 4. *EXAMPLE OF PRESENT WORTH AND*
AVERAGE ANNUAL EQUIVALENT COST CALCULATION
(adapted from example by EPA in reference 18)

GIVEN:

sewage treatment plant #2

capacity: 10 mgd

average flow through plant: increases linearly from 2 mgd to 10 mgd over 20 years

planning period: 20 years (as required by EPA guideline[22]

salvage value at end of 20 years: $0

initial cost of plant: $3,000,000

constant annual operation and maintenance cost: $126,000

variable annual operation and maintenance cost: increases linearly from $0 to $68,000 in year 20

interest rate: 7.0% (as established by Water Resources Council[22]

DETERMINE:

Present worth and average annual equivalent cost of this plant over 20 years.

METHOD:

Present worth equals the sum of initial cost, present worth of constant O&M cost, and the present worth of the gradient series of the variable O&M cost. Average annual equivalent cost equals the present worth times the appropriate capital recovery factor. Use engineering economics textbook to find table at 7.0% compound interest factors (present worth of a gradient series)

Step 1

Initial cost = $3,000,000

Step 2

To find the present worth of operating costs it will be necessary to calculate the present worths of the constant costs and the variable costs separately.

a. Present worth of constant annual costs equals that cost times the uniform series present worth factor @ 7.0% for 20 years. Thus:

$126,000 (10.594) = $1,335,000

b. Present worth of a variable cost increasing linearly is found by first finding the amount of increase per year. This amount is $68,000/20 years or $3,400 per year. This increase is known as a gradient series This series times the correct gradient series present worth factor @ 7.0% for 20 years yield the present worth of the variable cost. Thus:

$3,400 (77.5091) = $ 264,000

Step 3

Sum of numbers obtained in the steps above yields present worth:

present worth of constant O&M costs = $1,335,000

present worth of variable O&M cost = $ 264,000

present worth = $4,599,000

Step 4

To find average annual equivalent cost multiply present worth obtained above times the capital recovery factor @ 7.0% for 20 years. Thus:

$4,599,000 (.09439) = $ 434,100

which is the average annual equivalent cost of the plant for 20 years.

Table 5. ECONOMIC COMPARISON OF AWT ALTERNATES IN MONTGOMERY CO., MD.
(All Values in Thousands of Dollars)

SITE	INITIAL CAPITAL COSTS*	RANGE OF ANNUAL O&M COSTS	TOTAL CAPITAL COSTS 1973-2000	PRESENT VALUE OF COSTS O&M	PRESENT VALUE OF COSTS CAPITAL	PRESENT VALUE OF COSTS TOTAL	RATIO OF PRESENT VALUE TO LOW COST SITE
S-1	$125,398	$3,615-$13,493	$224,309	$83,897	$154,917	$238,314	1.03
M-2	$122,627	$3,613-$13,410	$218,358	$83,036	$151,327	$234,362	1.01
W-2	$129,350	$3,676-$13,663	$227,878	$84,487	$158,906	$243,393	1.05
R-2	$129,784	$3,665-$13,650	$225,761	$84,549	$159,148	$243,697	1.05
M-2/R-2	$146,945	$3,777-$13,913	$245,744	$86,414	$176,784	$263,198	1.13
W-2/R-2	$151,983	$3,828-$14,070	$256,610	$87,379	$183,701	$271,080	1.17
AWT at PEPCO	$124,521	$3,342-$11,502	$229,247	$75,426	$156,841	$232,267	1.00
M-2, Clear Water Line to PEPCO	$130,978	$3,882-$13,645	$226,664	$85,785	$158,857	$244,642	1.05

*Expenditure for 1973-1976 period exclusive of local lateral collector sewers. Initial AWT plant capacity is 60 mgd. Assumed 27 year planning period and 5.5% interest rate.

Adapted from Reference 66.

will influence the decisions of local elected officials. EPA guidelines recognize that waste treatment works must be evaluated on the basis of "opportunity costs", which means that when funds are invested in any particular capital goods, the opportunity is foregone to obtain a return from the investment of funds elsewhere. The Framework Model should have the capability for describing these competing programs whenever desired by decision makers.

Finally, it is universally recognized in urban areas (particularly in metropolitan Washington where sewer moratoria continue) there will likely be large "private" expenditures by developers or industry for new development within the community in a metropolitan area where additional waste treatment capacity is provided. Guidelines from EPA indicate that these types of "indirect" costs or benefits should be included, as appropriate, in the social and economic impact evaluations rather than in the direct cost calculations.[65] The justification for this is the fact that these costs cannot be accurately quantified, although, it can be argued, that the costs of infrastructure and service systems induced by sewer systems are more important than differences between most engineering choices. Lacking detailed quantitative tools for assessing induced costs, they will be considered later in this chapter under the Community Response Budget.

Proposed Cost Element - The Cost Element is used to compare the costs of alternative management strategies. The technique involves the reduction of anticipated resource costs of an alternative- capital, operations, maintenance, fuel and utilities - to a present value. To do this, a planning period must be chosen, cost estimates must be made, and the time value of money must be estimated.

The cost element is used only to compare alternatives. Certain simplifications are made during the process that make the selection process inappropriate for use in programming implementation or in determining mechanisms for covering the costs of the alternative chosen by this selection process. Cost estimates made to compare two or more alternatives may be only approximate. The effects of inflation or of varying interest rates are ignored since they are considered to affect each alternative with equal uncertainty. The overhead costs to be experienced by the agency or grant subsidies to be obtained by the agency responsible for the operation of the planned facility, while important components of costs, are ignored in cost comparisons. These costs are considered in the Financial Arrangements Element.

Figure 13 presents a flow diagram of the Cost Element. It is used to calculate the total present value cost per planning period at a specified date and to show the incremental present value cost differential among alternative strategies. To apply the Cost Element to alternative water resource management strategies, each strategy is first segmented into devices. The cost of each device is then determined.

The total planning period capital cost element requires the following information: the total capital cost at a stated cost index, the length of the construction period, and the life of the capital structure. The equation for performing the calculation is presented in Appendix B as Equation (1).

Operation and maintenance costs are divided into a fixed and variable portion with the variable portion further divided into a base component and a growth component. Thus the elements of operation and maintenance cost are a fixed element, a variable-base element, and a variable-growth element. The total planning period fixed operations and maintenance cost element requires an estimate of the fixed annual operations and maintenance cost at the end of the planning period, and is therefore based on the design capacity at the end of the planning period. The fixed portion of the total planning period operation and maintenance cost is calculated using Equation (2) of Appendix B.

The total planning period variable operation and maintenance base element cost requires an estimate of the annual variable operations and maintenance costs which are based on the capacity of each device in use at the start of the planning period and on a variable operations and maintenance cost per unit capacity for each device evaluated at the midpoint of the planning period. This variable-base element equation is shown as Equation (3) of Appendix B.

The total planning period variable operations and maintenance variable element requires an estimate of the annual variable operations and maintenance costs which are based on the amount of growth in used capacity of each device during the

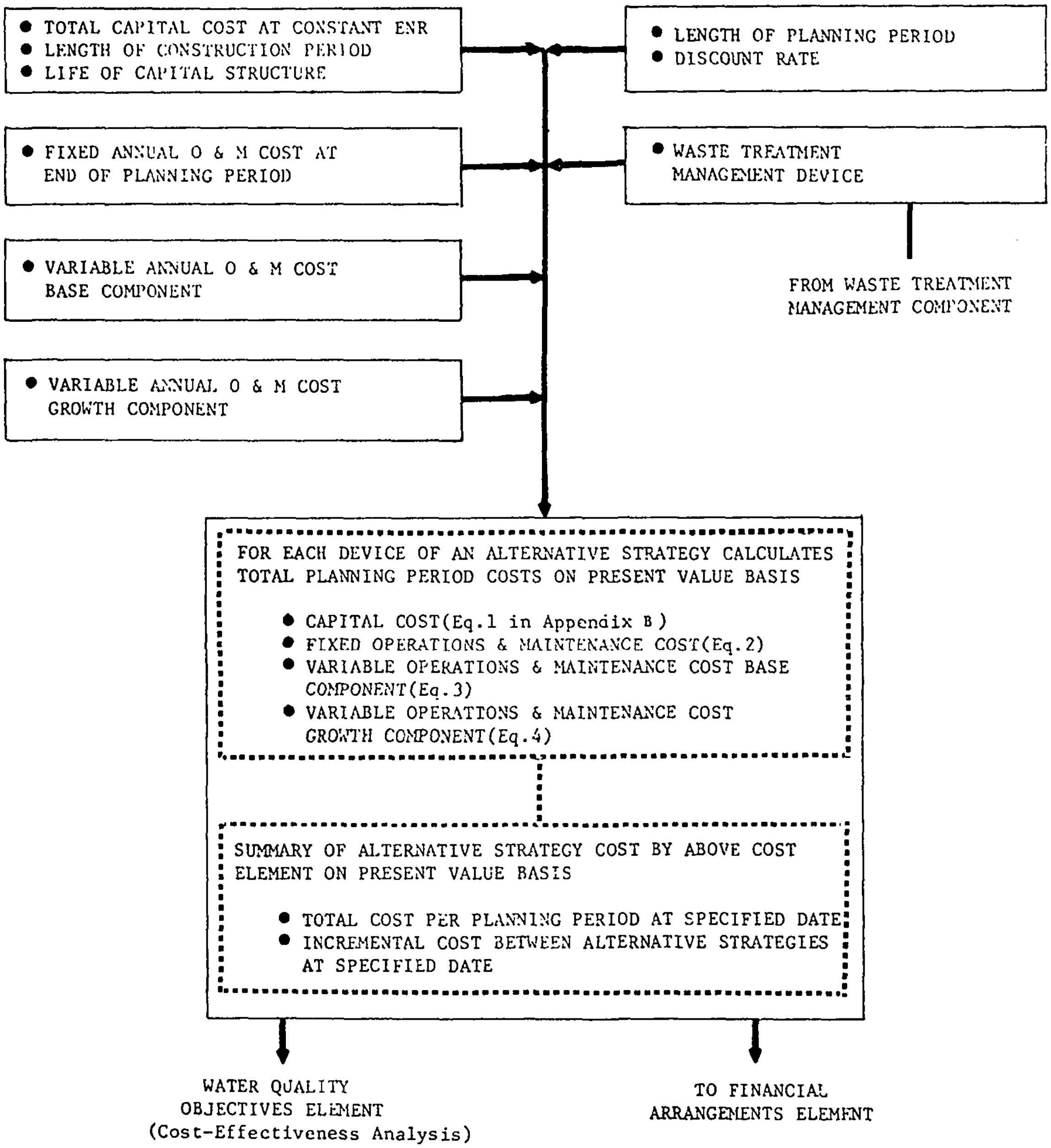


Figure 13 FLOW DIAGRAM OF COST ELEMENT

planning period and on the above mentioned variable operations and maintenance cost per unit capacity for each device evaluated at the midpoint of the planning period. This variable-growth component is calculated from Equation (4) of Appendix B. Use of this equation implies an assumption of a linear growth rate in used capacity of each device.

The results produced by the Cost Element are used in conjunction with the Water Quality Objective Element during comparisons of both the cost and the effectiveness of alternative water resources management strategies. The results produced by the Cost Element are also used in conjunction with the Financial Arrangement Element for comparison of alternative methods of covering these resource costs.

Financial Arrangements Element

Existing Methodologies - The other portion of the fiscal budget consists of financial arrangements for meeting the direct resource costs of proposed facilities and to otherwise carry out the areawide waste treatment management plan as required by Section 208(b)(2)(E) of PL 92-500. This is far more complicated than simply choosing between alternatives as was done in the Cost Element.

For example, from data obtained as a result of interviews with technical and financial personnel representing a sample of the water resources utilities in the Washington region,[131] it was discovered that a third component of cost beyond capital and OM & R costs must be recognized in water resources planning. This is the indirect operation, maintenance, and overhead costs associated with the utility itself but not associated with an particular project.

It was found that such costs ranged between twenty-five percent and thirty-five percent of a utility's budget. The Financial Arrangements Element must in some fashion deal with this "third" cost. Such "general overhead costs" are often assumed common to all alternatives and therefore are excluded in the cost analyses,[66] but cannot be ignored when considering required financial arrangements.

Sources of revenue for local jurisdictions include intergovernmental transfers from state and local agencies, and local revenues primarily through property taxes[67] and user charges. Property taxes are a primary source of local revenues, but user charges are more often used to finance sewage treatment works. Normally, local jurisdictions seek Federal grants for 75% of the costs for design and construction of such facilities as provided by PL 92-500, and meet the remaining construction costs by a combination of state grants and municipal bonds. In turn, jurisdictions generally utilize user charges to customers to pay annual operating, maintenance, and repair costs and debt services for the principal and interest on the non-grant funded portion of the capital. Local delivery and collection systems to individual homes are paid for through other charges such as front-foot benefit assessments and house connection fees.[68]

A consultant to Montgomery County, Maryland, explained the method used to analyze financing arrangements for proposed facilities to serve that county as follows:

> To finance construction costs, bonds are assumed to be sold as needed during the 1973-76 period, for the initial costs of development (less expected grants), and at later dates, as required by the construction schedules. Payment of interest but no principal is assumed during the 1973-76 period. Further, principal payments, together with interest are assumed to begin in 1976, the first year of system operation. Level debt service, a term of 35 years, and a rate of 5.5 percent is assumed on the bonds. Bonds issued in years subsequent to the initial development, for phased construction, are also assumed to have the same terms as the bonds issued in the initial development period. Federal and state grants are assumed available to cover 80 percent of eligible project costs. Possible effects of legislation affecting grants are illustrated. Alternative grant assumptions are 90 percent of eligible project costs and 80 percent of all project costs, including land costs.
>
> A "revenue-requirement", or "cash basis", is used in estimating user charges for the alternative plans. User charges are defined for this study as the amount of revenue required to pay debt service on bond amounts required after deduction of grants, plus the additional revenue required to pay

operation and maintenance costs. Bond sales and operation and maintenance costs are for only the part of the sewerage system considered in this study. Therefore, the user charges are for only the "sewer use charges", which are billed to households and others on the basis of water consumption.[66]

Annual user charges for alternative waste treatment options can be compared just as present values were in a previous table. This approach to presenting alternative financial arrangements can easily mislead the public, however, by showing relative costs to be confused with absolute costs. If construction and operating costs are increased by inflation or if an interest rate different from that assumed in the Cost Element is actually paid for borrowed capital, or if the proportion of grant support changes, the user charge may increase substantially.

Several added points concerning financial arrangements are necessary. First, Section 204(b)(2) of PL 92-500 requires that each industrial and nonindustrial recipient (such as another local jurisdiction) of waste treatment services must pay its proportionate share of operation and maintenance costs based on guidelines published by EPA.[17,23] The framework developed under this project must therefore incorporate methods recommended in such guidelines.

Next, as noted earlier there are non capital-intensive alternatives which must be evaluated under the areawide planning process. Most are not eligible for Federal Title II grants under PL 92-500, and therefore may be lower total cost alternatives, yet because they are unsubsidized be more costly to individual users of the system. Table 6 illustrates that "subsidies" for such alternatives may range substantially. As the final column indicates, however, the costs will be passed on to the consumer in some fashion. Therefore, it is important that the framework display the expected cost to the consumer of every alternative considered with appropriate explanation to avoid the impression that these charges will not change.

Thirdly, waste treatment management agencies in the past have operated on the basis that revenues must be collected to equal, but not to exceed, costs. Section 201(e) of PL 92-500

Table 6. CATEGORIZATION OF WATER-SEWER FINANCING BY TYPE

Type of financing	Examples in waste treatment management where this would apply	How cost passed on to consumer
A. 100% local financing	Street sewer lines, operating costs of treatment plants	Increase in customer water-sewer rates, increase in front-foot assessments
B. 100% local-state financing	Sanitary landfills, resource recovery	Increase in customer rates, state income tax
C. 75% federal - 25% local and state financing	Municipal treatment works capital costs	Title II grant by Federal income tax, state income tax, increase in customer rates
D. 100% developer financing	"Interim" treatment plant, water saving devices, "dry collection" facilities	Increase in price of housing
E. 100% industry financing	Industrial treatment works, industry contribution of flow to municipal treatment plant	Price of product produced or service rendered
F. 100% private citizen financing	Pricing policy to encourage water conservation	Surcharge on customer user rates
G. "no" financing	Water use restrictions during water shortages, individual water conservation practices	Loss of revenues by selected commercial establishments

now provides that integration of facilities for sewage treatment and other municipal and industrial wastes is encouraged, and that such integrated facilities shall be designed and operated to produce revenues in excess of capital and operation and maintenance costs. Such revenues are to be used to aid in financing other environmental improvement programs. Thus this concept of reinvesting the "profits" must be introduced into the financial planning framework.

Finally and inevitably, the budgets of individuals, local governments, states, and the Federal government must each "balance" in some fashion. There will be constraints placed on local government budgets, such as Maryland state limit on chartered counties of maximum of 25% of local assessed valuation allowed for sewerage facilities bonds, which must be recognized in the fiscal budget portion of the framework to ensure that it is of assistance to decision makers.

Proposed Financial Arrangements Element - Under this element the financial arrangements for meeting the direct costs of proposed capital facilities and non-capital programs are identified. Figure 14 depicts the procedure to be used. The procedure would be repeated for each alternative water resources management strategy and comparative tables prepared accordingly.

For capital facilities, the financial arrangements to cover construction costs generally consist of a combination of grants from the Federal and State governments as provided for by PL 92-500 and general obligation bonds by the local government or special district. Construction cost estimates are obtained directly from the Cost Element. User-specified information includes the determination of which portions of this construction cost are expected to be borne by grants and which by bonds. Alternative grant assumptions should be used for comparative purposes, such as 80% grant-20% bond vs. 100% bond. Additional user-specified information includes the type of debt service (i.e. level), payment period, expected interest rate, year interest payment begins, year principal payment begins, and any constraints imposed. An example of a constraint would be the limitation on municipalities by the Commonwealth of Virginia of an 18 percent bond rate limit applied against assessed property values.[67] For that portion of construction costs to be financed by bonds, the debt service is calculated for user-specified years.

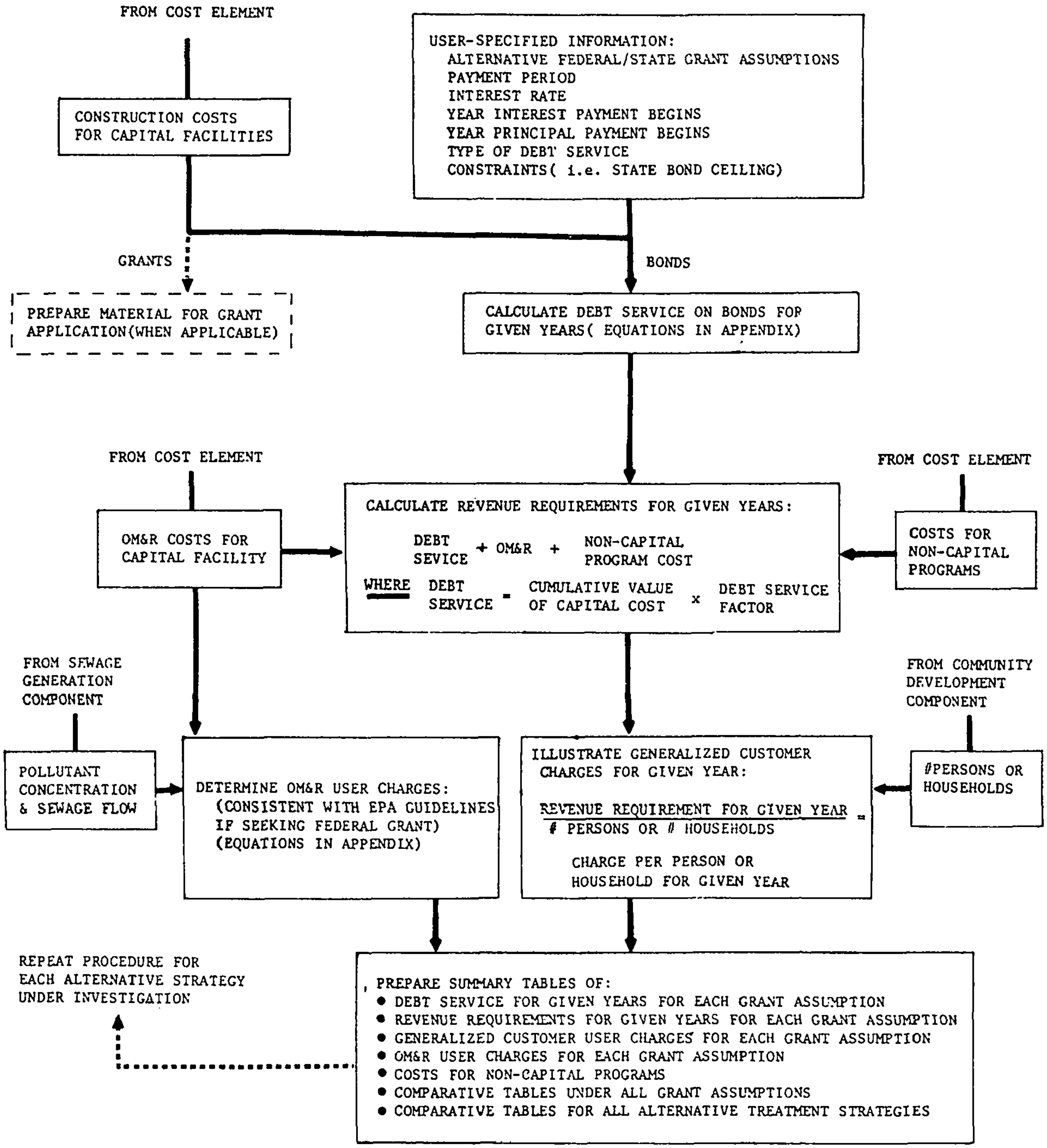


Figure 14 FLOW DIAGRAM OF FINANCIAL ARRANGEMENTS ELEMENT

The equations used are presented in Appendix B. The time periods are often in annual or five-year increments.

Next, revenue requirements are calculated for given years. This is done by summing the debt service previously calculated, the operations, maintenance and replacement costs and the costs for non-capital programs obtained from the Cost Element. The revenue requirements represent the amount of income which the local jurisdiction or special district must collect for each specified year to cover costs associated with the proposed facility or program. This income is generally obtained through the imposition of customer charges, although some functions such as planning may not be fully covered by these charges. Generalized customer charges accurate enough for comparing alternative waste treatment management systems are calculated for given years by dividing the revenue requirement by the number of persons or the number of households to be served. These later numbers are generated by the Community Development Component.

Under PL 92-500 an applicant for a Federal construction grant must adopt a system of user charges to assure that each recipient of waste treatment services will pay its proportionate share of operations, maintenance and replacement.[23] Guidelines published by the U.S. Environmental Protection Agency present alternative formulas for determining these user charges encorporating such factors as strength, volume, and delivery flow rate characteristics. As part of the Financial Arrangements Element, operations, maintenance and repair user charges can be calculated based on the OM&R costs developed in the Cost Element and the pollutant concentration and sewage flow resulting from the Sewage Generation Component of the Framework Model.

Summary tables are then prepared for each set of calculations made in the Financial Arrangements Element. Typical tables for a single waste treatment management system would include debt service, revenue requirements and generalized customer user charges for given years for each alternative grant assumption, OM&R user charges, and costs for non-capital programs. Comparative tables under all grant assumptions and for all alternative water resources management strategies would complete the Financial Arrangements Element.

Natural Resources Budget

The "Natural Resources Budget" is the second of the three budgets identified by the Council of Governments during the Year 2000 Policies Plan Reexamination. It includes consideration of the limits or "carrying capacities" of the region's land, air, and water resources, and other environmental impacts. Because of the emphasis on water quality considerations in this study, the Natural Resources Budget has been divided into a Water Quality Objectives Element, and a Natural Resources Impact Element.

Water Quality Objectives Element

Existing Methodologies - Waste treatment management plans and practices are required by PL 92-500 to assist in achieving the goals of the Act in restoring and maintaining the chemical, physical, and biological integrity of the Nation's water. Thus, waste treatment works are required by Federal law to demonstrate a beneficial influence on a natural resource media.

Since passage of the Federal Water Pollution Control Act of 1965, this beneficial effect has been defined for treatment works as contributing to the attainment of water quality standards adopted by each state and approved by EPA (or its predecessors). These standards consist of (1) a set of planned water uses, (2) quality criteria, expressed as limiting numerical values assigned to various water quality indicators, selected to protect planned water uses, and (3) a plan for implementation and enforcement of the criteria.[69] A significant feature of the 1965 Act was the absence of a requirement that the states establish criteria governing the quality of effluents, and non-point sources of pollution. Enforcement efforts against alleged polluters during the late 1960's were therefore often hampered by the difficulty in tracing each pollutant back to a discharger or proving that the discharger was causing sufficient damage to the river or to public health to warrant special restrictions.[70]

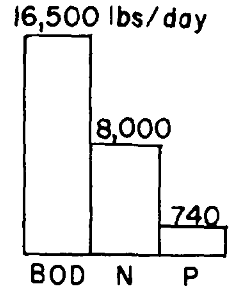
To remedy these difficulties, the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) established minimum effluent limitations to apply to industries and municipalities nationwide, while retaining the former system of state-adopted water quality standards. However, the Act also recognized that there were water bodies in the nation, such as the Upper Potomac Estuary, where these effluent limitations alone would not be adequate to achieve desired water quality. Therefore, the Act permits more stringent limitations to be imposed by the states in those instances. The Act also requires each state to classify its waters into those segments by basin which will, and those which will not, meet applicable water quality standards after the application of the effluent limitations prescribed by the Act. Those which will meet standards are termed "effluent limitations" segments. Those which will not meet standards are termed "water quality" segments.[71]

This distinction is important to the development of the Framework Model for two reasons. First, Section 208 area-wide waste treatment management planning may occur in those areas of the nation with substantial water quality control problems. EPA regulations provide that classification of substantial portions of major receiving wastes in an urban-industrial area as "water quality" segments will meet the definition of having substantial problems. Secondly, these regulations also require that each basin plan prepared by the states shall include for each "water quality" segment the total maximum daily loads of pollutants allowable for each specific criterion being violated or expected to be violated, with these maximum loads at least as stringent as necessary to implement applicable water quality standards. These loads are then to be allocated among significant discharges and, whereever possible, other sources including non-point sources.[72] These allowable loads are then incorporated into the National Pollutant Discharge Elimination System (NPDES) permits required under Section 402 of the Act for all dischargers.

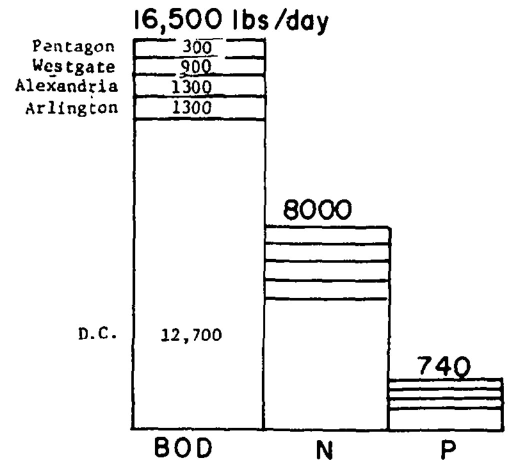
Even before passage of the Act, the essentials of this procedure had been utilized in the Washington Metropolitan area. As indicated in Figure 15 total maximum daily loads for biochemical oxygen demand (BOD), total nitrogen (N) and total phosphorus (P) were determined in 1969 for the Upper Potomac Estuary by the U.S. Department of the Interior utilizing the forerunner of the computer model which serves as the Receiving Water Component of the Framework Model. Then, waste load allocations for each pollutant were made in May of 1969 by

LATE 1960's - WATER QUALITY STANDARDS ADOPTED BY STATES OF MARYLAND AND VIRGINIA AND THE DISTRICT OF COLUMBIA AND APPROVED BY THE DEPARTMENT OF THE INTERIOR PURSUANT TO FWPCA OF 1965. (111, 112, 113,*)

EARLY 1969 - ANALYSIS OF UPPER POTOMAC ESTUARY CONDUCTED BY THE DEPARTMENT OF THE INTERIOR USING MODEL WHICH SERVES AS RECEIVING WATER COMPONENT. TOTAL MAXIMUM DAILY LOADS RECOMMENDED (114:)



MAY 1969 - TOTAL MAXIMUM DAILY LOADS ACCEPTED BY POTOMAC ENFORCEMENT CONFERENCE WASTE LOAD ALLOCATIONS ADOPTED BY CONFERENCE (25:)



1969- 1973 - DESIGN DRAWINGS AND GRANT APPLICATIONS PREPARED FOR UPGRADING OF FACILITIES TO ACHIEVE WASTE LOAD ALLOCATIONS.

1973 - UPPER POTOMAC ESTUARY IDENTIFIED AS A "WATER QUALITY" SEGMENT BY STATES OF MARYLAND AND VIRGINIA AND THE DISTRICT OF COLUMBIA PURSUANT TO FWPCAA OF 1972 . (115, 116, 117.)

1974 - NPDES PERMIT ISSUED BY USEPA TO THE DISTRICT OF COLUMBIA BASED ON WASTE LOAD ALLOCATION (118.)
REMAINING PERMITS TO BE ISSUED BY END OF YEAR.

* NUMBERS REFER TO REFERENCES AT END OF REPORT

Figure 15 CHRONOLOGY OF ESTABLISHMENT OF WASTE LOAD ALLOCATION FOR UPPER POTOMAC ESTUARY the Potomac Enforcement Conference* to the five wastewater treatment plants discharging into the Estuary. These load limits have served as the design target for the upgrading of the facilities, and are being incorporated into the NPDES permits being issued. Since 1969, however more sophisticated models have shown that different load limits[73] may be applicable to the estuary but these revised "budget limits" have not been recognized by those responsible for planning. The two load limits for the upper fifteen miles of the estuary are shown in Table 7. Newer models will doubtless allow the estuary load allocation to be further revised.

This concept of a finite limit for given water bodies, to be apportioned among discharges, is entirely consistent and compatible with the concept of natural resources "budget limit" which emerged during the Year 2000 Policies Plan Reexamination. The budget limit is, in effect, a "carrying capacity." The concept of carrying capacity or natural resource budget limit has received considerable support by local governments and citizens as a major element of metropolitan Washington growth policy.

It must be remembered, however, that the apportionment of discharge rights to various sources is little more than a goal if the technology to treat waste discharges is insufficient to provide the degree of treatment needed to remain within the discharge limit, and therefore to attain water quality within standards. In these cases, the strategies for the control of any source of pollution must be carefully justified as cost effective steps in a wider strategy of water quality improvement. In regions such as metropolitan Washington where application of the effluent limitations required by the Act (i.e., secondary treatment) will not achieve compliance with water quality standards, the definition of the term "effectiveness" in a cost effectiveness calculation must be explicit so that a single project can be gauged for its incremental effectiveness on water quality.

---

*Conference in the Matter of Pollution of the Interstate Waters of the Potomac and Its Tributaries in the Washington Metropolitan Area was initiated by the Secretary of the Interior in 1957 and reconvened in 1958 and 1969 under the provisions of Section 10 of the Federal Water Pollution Control Act, as amended (33 U.S.C. 466, et.seq.).

Table 7. COMPARISON OF
SUGGESTED LOAD LIMITS FOR
UPPER 15 MILES OF POTOMAC ESTUARY
(lbs./day)

	BOD	N	P
Potomac Enforcement Conference 5/8/69[25]	16,500	8,000	740
Technical Report No. 35, 4/71[73]	41,800	4,700	1,185

In one sense, the projected effectiveness of a management strategy can be measured in terms of the diminished adverse effects on water quality caused by pollution. The value of the removal of biochemical oxygen demand, as an example, from any source must be gauged by the diminished effects of all oxygen-demanding pollutants on water quality. This is essential when management strategies are applied to different elements of the water resources system and include both structural and non-structural approaches, and programs initiated by many different agencies. This approach appears to also have merit in preventing commitments to technologies that may prove unproductive and that may overcommit the financial resources or community support available without gaining the greatest degree of water quality improvement. The proposed Water Quality Objectives Element of the Framework Model describes how these considerations are dealt with.

Proposed Water Quality Objectives Element - A purpose of the Water Quality Objectives Element is to state a method of reporting the effectiveness of water resources management strategies on receiving water properties, and to provide a basis for cost-effectiveness analysis. The emphasis on receiving water quality is in contrast to the often-used procedure of determining the most cost effective method of providing a given degree of treatment, a practice which is justified during plant design and along effluent limited segments of receiving waters, but is inappropriate in planning and managing a water resource system of interrelated facilities in "water quality" areas.

For this reason, the definition chosen for a control strategy's "effectiveness" incorporates measures of the extent, constituent concentration, duration and annual probability of occurrence of the response of the receiving water to an areawide water resources management strategy.

A strategy can be called an effective one when there is a high probability that constituent concentrations will be within the limits set in standards in all stretches of the estuary and for all time periods.

The first measure incorporated into the definition of effectiveness, the extent of the estuary response, is required to present the length, surface area or volume of receiving water affected by depleted dissolved oxygen or by increased concentrations of harmful constituents. Surface area or length of receiving water affected may be appropriate when water uses for protection or propagation of fish or for recreation are to be evaluated. The volume measure may be appropriate when water uses for industry, agriculture, or public water supply are to be evaluated.

The constituent concentration of the estuary response is measured as less than or equal to a stated beneficial constituent concentration or as greater than or equal to a harmful constituent concentration. Thus, either a beneficial constituent such as dissolved oxygen, or a harmful constituent such as nitrate may be used in the Framework Model.

The duration of the receiving water response is measured as greater than or equal to a stated duration which may be a constant selected on the basis of the effects different constituent concentrations are known to have on aquatic life.

By combining these first three measures, the "capability" of an areawide water resources management strategy can be defined as the extent of a constituent concentration of less than or equal to a stated constituent concentration for greater than or equal to a stated duration. By selecting, for example, the state-adopted water quality criteria for dissolved oxygen as the stated concentration for analysis, the "capability" of an alternative strategy in meeting standards can be described. These three measures can be taken directly from the dissolved oxygen table output by the Receiving Water Component. If a constituent other than dissolved oxygen is utilized, the measures can be derived from the three-dimensional estuary profile for that constituent.

Figure 16 presents a flow diagram of the Water Quality Objectives Element. In this study the capability, C, of a management strategy is defined mathematically as:

$$C = \text{Extent}_{d,c}$$

where Extent is the estuary length, volume or surface area either 1) at or below a chosen beneficial constituent concentration "c"; or

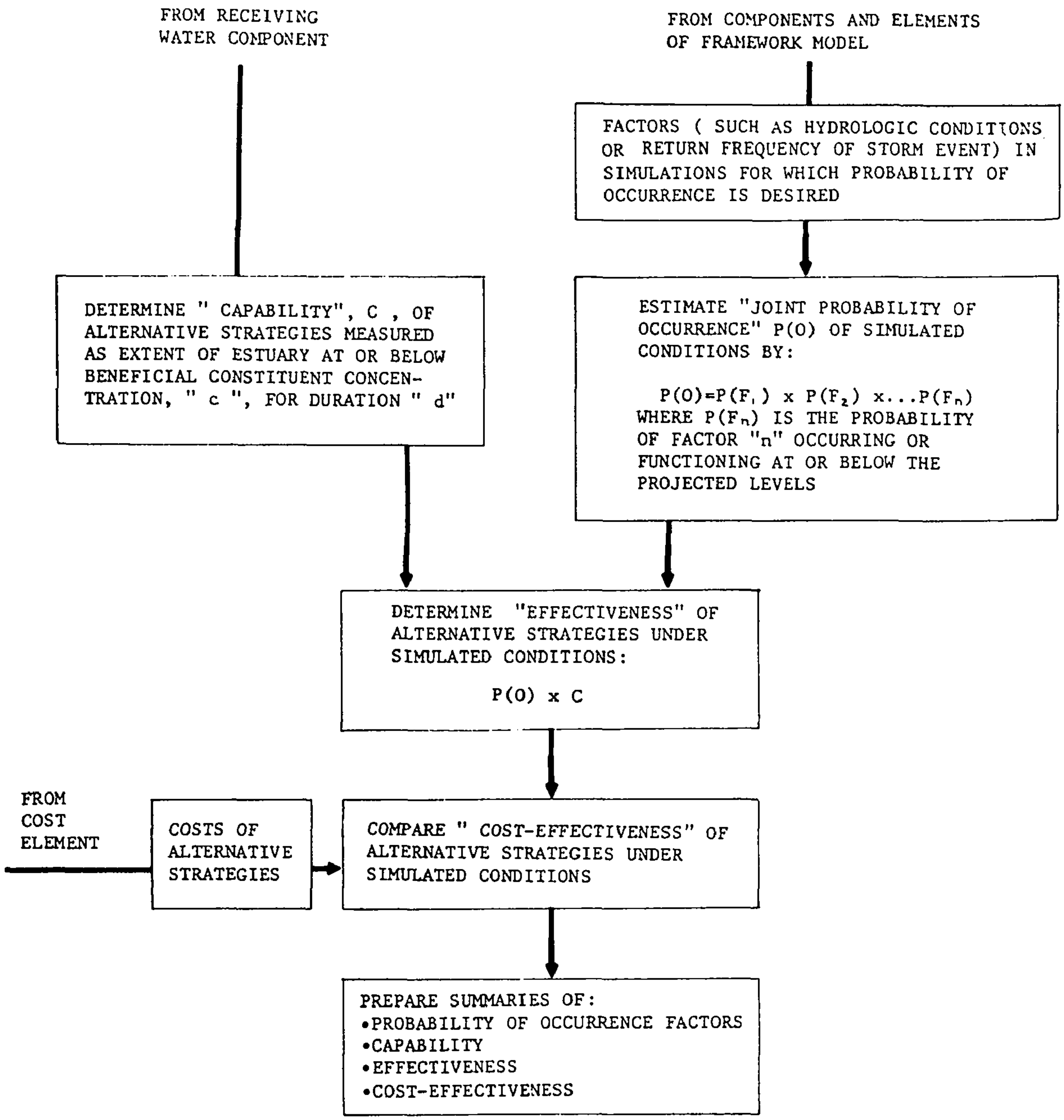


Figure 16 FLOW DIAGRAM OF WATER QUALITY OBJECTIVES ELEMENT

2) at or above a chosen harmful constituent concentration "c"

for a chosen period of time of duration "d"

The definition and use of these terms may seem unnecessary, but they allow an analyst to answer important questions in resource management. What, for instance, is the best measure of "extent" in a given water body? Are future water supply withdrawals going to remove dilution waters needed to assist in abating the impacts of effluents on the estuary? Will untreated stormwater obliterate water quality improvements thcught to be gained from the treatment of point sources? The determination of an areawide management strategy's capability permits analysis of the response of a receiving water body subjected to steady state wastewater flows, intermittent stormwater runoff, and less frequent combined sewer overlfows.

In Chapter IV, the "capability" of alternative areawide water resources management strategies are compared using extent, constituent concentration, and duration measures which are output by the Receiving Water Component.

The fourth and final measure incorporated into "effectiveness" is the joint annual probability of occurrence of the extent, constituent concentration, and duration of estuary quality response. The inverse of the annual probability of occurrence may be called the return frequency in years or the frequency of occurrence in years or the mean time in years between occurrences of the estuary quality response. The annual probability of the estuary response to an areawide water resources management strategy is based on return frequency of storms, river inflows, and water demands, comprising the areawide water resources management strategy, as well as on wastewater and stormwater treatment devices reliability data. This fourth measure is the joint annual probability of all of the above events occurring during a stated time period.

When the "capability" of an alternative areawide water resources management strategy is multiplied by the "joint annual probability of occurrence" of the simulated conditions, the resulting product is the expected "effectiveness". Mathematically, the expected "effectiveness" is represented as:

$$\text{Effectiveness} = P(O) \times C$$

where P(O) is "joint annual probability of occurrence" of conditions upon which the simulation is based. C is the "capability" of the areawide water resources management strategy.

Thus the term "effectiveness" includes the extent, duration, constituent concentration, and joint annual probability of occurrence of the receiving water's response to alternative water resources management strategies.

Of particular significance is that the expected "effectiveness" term provides a link between bioassay results used to evaluate the toxicity of selected chemical constituents or physical parameters to aquatic species which are expressed as a 96-hour-median-tolerance limit, TL_m or TL_{50}. This link is important because it relates the alternative water resources management strategies to their effects on shellfish, fish, and wildlife which are required to be protected by the Federal Water Pollution Control Act Amendments of 1972.

Cost-Effectiveness Determination - Although it is included as the final activity in the Water Quality Objectives Element, the determination of the cost-effectiveness of alternative water resources management strategies links the Cost Element and the Water Quality Objectives Element of the Framework Model.

Section 212(2) of the Act provides that Federal construction grants can only be made for systems which are determined by the U.S. Environmental Protection Agency to be "cost-efficient" as defined by EPA cost-effectiveness guidelines.[22] The EPA guidelines indicate that:

> The most cost-effective alternative shall be the waste treatment management system determined from the analysis to have the lowest present worth and/or equivalent annual value without overriding adverse non-monetary costs and to realize at least identical minimum benefits in terms of applicable Federal, State, and local standards for effluent quality, water quality,

water reuse, and/or land and subsurface disposal.[22]

In the Framework Model the benefits are measured in terms of water quality.

The Cost Element of the Framework Model is used to define the present worth and/or equivalent annual value of the areawide water resources management strategies. The computation of expected "effectiveness" in the Water Quality Objectives Element is the mechanism for comparing the minimum benefits as required by the guidelines. The identification of any "overriding adverse non-monetary costs" is included in the Natural Resources Impact Element discussed next.

A demonstration of the cost-effectiveness analysis methodology proposed under this study is included in the final chapter of this report. The analysis is for several areawide metropolitan Washington water resources management strategies through the year 1992, using dissolved oxygen as the water quality constituent and total planning period capital costs, and operations and maintenance costs, discounted to January 1974 for the cost variable.

Natural Resources Impact Element

Existing Methodologies - Because improved water quality is the objective of water resource planners, other natural resource changes which result from strategies designed to meet water quality objectives are considered to be impacts. The emphasis to date has generally been on trying to identify and minimize adverse impacts of such water quality strategies. The Natural Environmental Policy Act requires that unavoidable adverse environmental effects be identified and that avoidable adverse environmental effects be "mitigated."[19] Cost-effectiveness guidelines by EPA require the recognition of any "overriding adverse" impacts of alternatives.[22] Construction grant regulations specify that treatment works will "comply with" requirements of Clean Air Act and other applicable environmental laws and regulations.

In an earlier chapter the use of adopted air and water quality standards or policies of nondegredation of these resources, as the current expression of environmental resources carrying capacity in the region was noted. A block diagram technique for presenting the current regional conditions versus these standards, and for performing tradeoffs among media was highlighted, as well as the concept of environmental resources as highly related and interdependent. The expansion of this technique into water supply, land and energy considerations was noted.

Natural resources budget limits are relevant at the local and Federal levels as well as at the regional level. In two recent water-related cases in Montgomery County, Maryland, wastewater treatment plant sites were rejected because of overriding adverse impacts. In one instance, the EPA regional office refused to consider locations of outfalls which were within 20 miles of the upstream water supply intakes. In the other case, the proposed location for an "interim" treatment plant was rejected by the County Council after it was learned that brown trout inhabitated the stream where the outfall was proposed. In both cases, however, these factors were discovered after a "firm" decision had been made. In these cases a perceived budget for drinking water quality or for desirable fish population would have been violated.

As in the physical simulation components of the Framework Model, the premise in the Natural Resources Impact Element was to examine and utilize existing methodologies wherever feasible, rather than to develop untested techniques. As a starting point, existing environmental impact assessment methodologies as categorized by Warner and Preston were examined. The categorization of methodologies was into the following five types based on the way impacts are identified:[62]

(1) Ad hoc: Broad areas of possible impacts (i.e., impacts on lakes, forests, etc.) are suggested rather than specific parameters for further investigation being defined.

(2) Overlays: Maps of environmental characteristics are overlaid to provide composites from which impacts can be identified.

(3) Checklists: A specific list of environmental parameters to be investigated for possible impacts is prepared, but direct cause-effect

link to project activities is not established.

(4) Matrices: Two lists, one including project activities and the other potentially impacted environmental characteristics, are related in a matrix which identifies cause-effect relationships between specific activities and impacts.

(5) Networks: Cause-condition-effect networks are prepared to illustrate a series of impacts which may be triggered by a project action.

In the following discussion examples of existing methodologies in each category are presented and then later evaluated.

(1) Ad hoc - The three-budget system developed by MWCOG during the Year 2000 Policies Plan Reexamination and discussed earlier is, in its current state of refinement, representative of the "ad hoc" assessment methodology. Statements such as "reduces particulate matter", "minimizes impact of storm loads", or "improves aesthetics of water resources" are examples of the way impacts are expressed in an ad hoc methodology.

(2) Map Overlays - The use of map overlays as a technique for land use planning has been proposed by McHarg in his well-known Design With Nature.[74] In this approach an individual map is prepared for each environmental characteristic of interest. These maps are then overlayed to expose areas which are conducive to certain types of development. McHarg explains this urban suitability selection process as follows:

Phase I: Exclusion of flood plains, woodlands for erosion control, steep slopes, row-cropland, cropland

Phase II: Exclusion in addition to Phase I of aquifer outcrops, noise zones, existing forest cover

Phase III: Exclusion in addition to Phases I and II of scenic and historic corridors.

Ranking of urban suitability based upon bearing capacities of soils and suitability for septic tanks

Phase IV: Identification of aggregations of urban suitable land.

In Design With Nature the Potomac River Basin and portions of the metropolitan Washington region served as test cases for application of this approach.

The Metropolitan Washington Council of Governments has utilized the map overlay approach in two planning efforts to date. In 1968, COG prepared an "ecological reconnaissance" of major natural features of the metropolitan area in the form of 1:8000 scale mylar maps. The natural features included geology, minerals, elevation, slope, soils, streams and drainage basins, flood plains, ground water, and woodlands. Several of these maps were then overlayed to form the "natural featurescomposite."[75] Where two or more features overlap, only the most limiting one is shown. Although highly generalized, the map illustrates how environmental interpretation and evaluation could help shape metropolitan development policies.

Map overlays were also used by COG in its open space planning program. One of the purposes identified for preserving open spaces in the region was the protection of irreplaceable and ecologically sensitive natural resources. The areas not yet publicly owned or controlled which were specified for primary preservation considerations were designated as "Areas of Maximum Environmental Quality" (AMEQ's), which comprise approximately 176,000 acres within the metropolitan area as shown in Figure 17. They were determined by superimposing maps of streams, flood plains, slopes (over fifteen percent) and woodlands. The resulting composite is a pattern of continuous, corridor-like lanes embracing the greatest concentration of features contributing to environmental diversity. AMEQ preservation is currently a major element of the COG open space program.

Overlaying can also take the form of computer mapping. Data on a large number of environmental characteristics are collected and stored in the computer on a grid system. Alternative composite maps can be generated by giving subjective weights to the various parameters. This technique has been

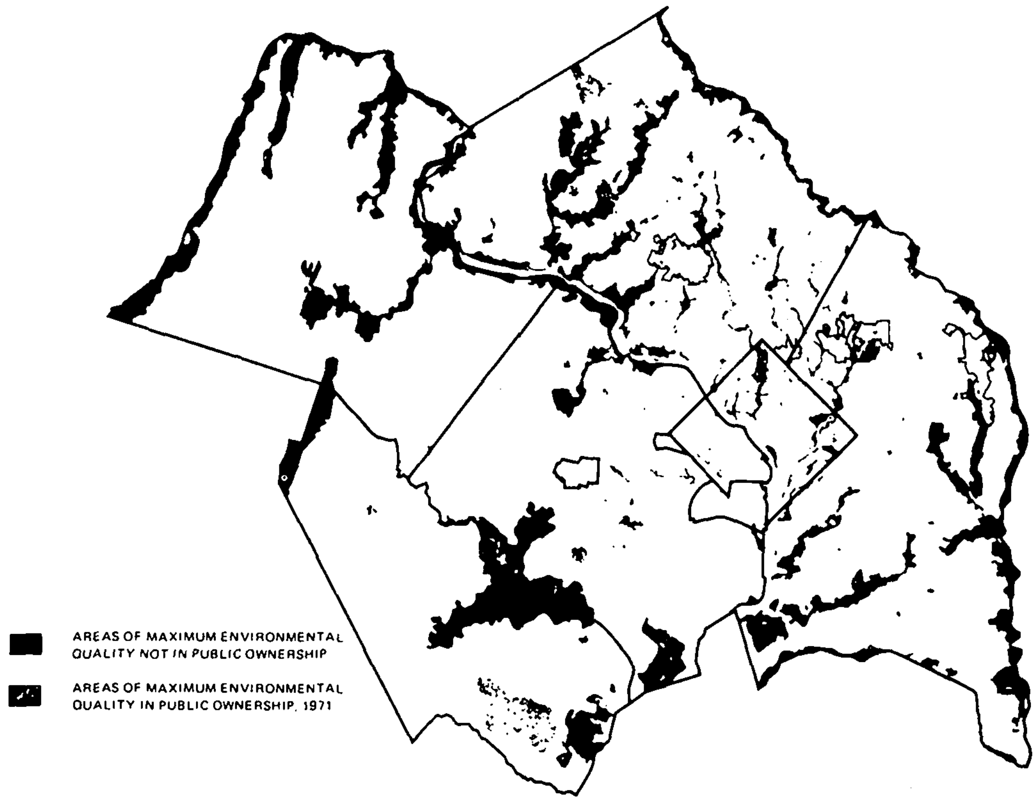


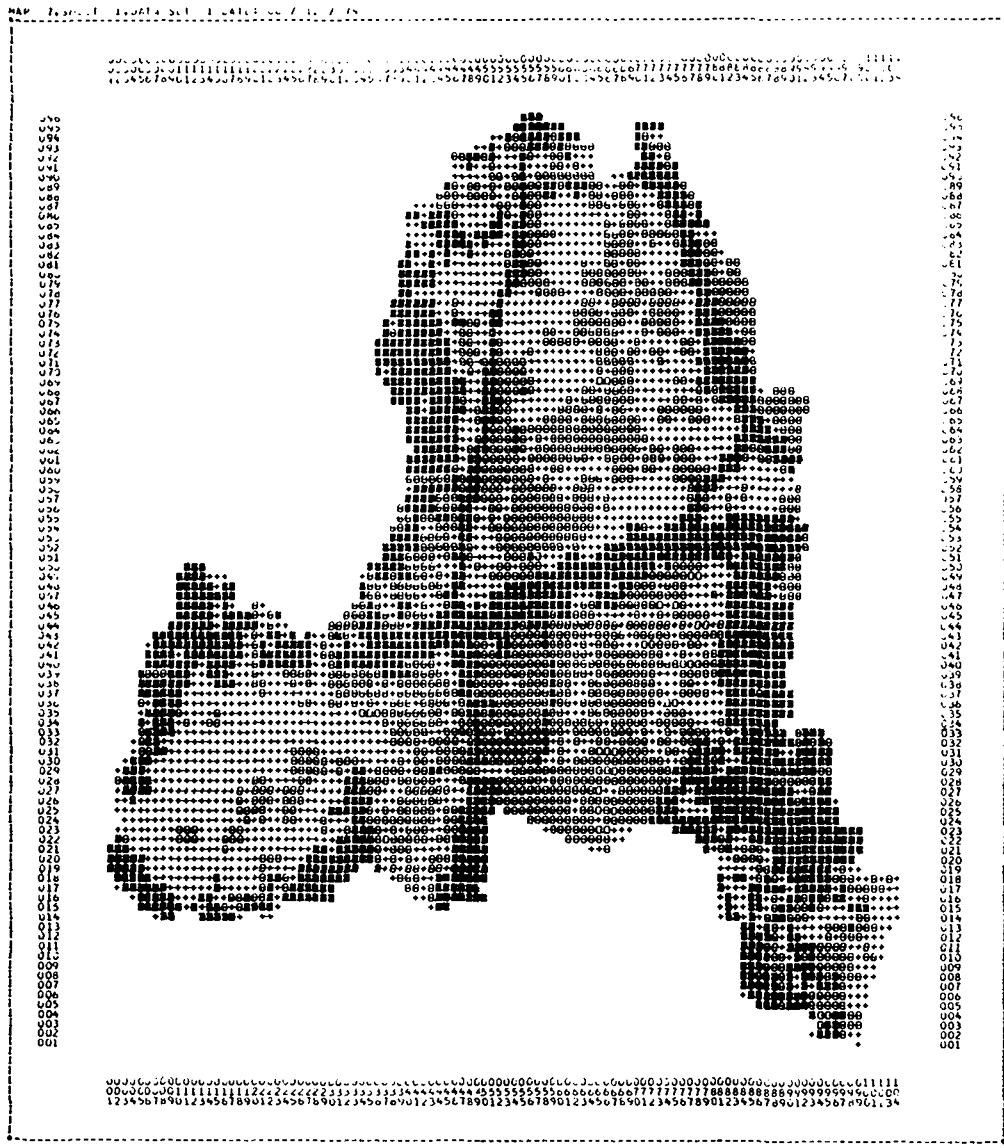
Figure 17 AREAS OF MAXIMUM ENVIRONMENTAL QUALITY

used in highway impact assessments.[76] The Northern Virginia Planning District Commission has been undertaking a study to define a population carrying capacity for an urbanizing watershed in the Metropolitan Washington area based on a computer-compatible ecological data inventory.[77] Data which was collected by 10-acre grid cells included physiographic, pedologic, geologic, hydrologic, climatic factors as well as man-made features and influences. Interrelationships of ecological factors depicting vulnerability to development were then displayed. Figure 18 presents a typical computer-printed map of these features for a portion of the Broad Run Watershed. The maximum population definition of population carrying capacity of the watershed will be determined by the limit imposed by the quantity of environmentally suitable land.

(3) Checklist - The most prominent example of an impact assessment methodology which could be classified as a "checklist" is the hierarchial Environmental Evaluation System (EES) developed by Dee, et.al., at Battelle Columbus Laboratories.[78] The environment is divided into the four general categories of ecology, environmental pollution, aesthetics, and human interest. Under these categories a total of 78 environmental parameters are identified representing a "unit or an aspect of environmental significance worthy of separate consideration in water resource development." To permit net environmental effects to be evaluated and tradeoffs made all parameters are transformed into commensurate units. The technique consists of:

Step 1: Transforming parameter estimates into environmental quality by determining the environmental impacts of each parameter on a scale of 0 (extremely bad) to 1 (very good). Value function graphs are used for this purpose.

Step 2: Assigning relative weights to each parameter as indicators of the relative importance to the environment. A total of 1000 parameter importance units (PIU) is distributed among the parameters.



SHRINK-SWELL POTENTIAL OF SOIL

ECOLOGICAL INVENTORY OF THE BROAD RUN WATERSHED

NORTHERN VIRGINIA PLANNING DISTRICT COMMISSION

3=LOW SHRINK-SWELL POTENTIAL(LOW LIMITATION)
6=MODERATE SHRINK-SWELL POTENTIAL (MODERATE LIMITATION)
9=HIGH SHRINK-SWELL POTENTIAL (HIGH LIMITATION)

SOURCE: USDA SOIL CONSERVATION SERVICE SOIL SURVEY, 1960
CLASSIFICATION BASED ON INTERPRETED DATA AND INFORMATION
SUPPLIED BY THE SCS IN THEIR "GUIDE FOR INTERPRETING ENGINEERING USES OF SOILS."

LEVELS	0	1	2	3	4	5	6	7	8	9
FREQUENCY 4893	0	0	1627	0	0	1730	0	0	1734	

Figure 18 ECOLOGICAL INVENTORY BY TEN ACRE GRID CELL

Step 3: Obtaining commensurate environmental impact units (EIU) by multiplying the environmental quality from step 1 by the PIU in step 2 for each parameter.

The EIU's are used to trade-off beneficial and adverse environmental effects by comparing each parameter with and without a proposed project. The approach can also be used as a warning system to "red flag" parameters that change significantly in an adverse direction. The EES has been field-tested for the proposed Oneida Narrows reservoir portion of the Bureau of Reclamation Bear River project. The approach has not yet been used in the Metropolitan Washington area, although the U.S. Corps of Engineers as part of its ongoing water supply study for the region has identified the list of parameters in the EES as a checklist for its environmental consultant to utilize.[79] As part of the Montgomery County wastewater study, the checklist approach was used to determine the existence of habitat with special scientific or educational value or unique or fragile character at each of the sites under consideration.[66]

(4) Matrix - An example of the "matrix" impact assessment methodology is the procedure developed by Leopold, et.al., for the USGS.[80] A matrix of 100 possible project activities and 88 environmental characteristics or conditions is filled out for a proposed project in the following way:

a. Those activities from the top of the matrix which are relevant to the project under analysis are identified.

b. For those cells in the column where a possible environmental characteristic could be affected, a slash is made.

c. For each box with a slash, a number between 1 (least) and 10 (greatest) indicating the magnitude of the possible impact is placed in the upper left corner of the box. Before the number a "+" is placed if the impact is expected to be beneficial.

d. In a similar fashion, a number is placed in the lower right corner of each box representing the imprtance of the possible impact.

e. A narrative on environmental impacts is prepared for those rows and columns with large numbers of boxes marked or with large numbers in boxes.

(5) Network - The final category of environmental impact methodologies is the "network." Under this approach, cause-condition-effect networks are prepared in an attempt to identify the primary and secondary impacts which may be triggered by a project as well as to expose opportunities for controlling waste loads at points other than at treatment plants. As part of the Year 2000 Policies Plan Reexamination, the Metropolitan Washington Council of Governments utilized a generalized network to trace the sources and the paths which phosphorus takes as it passes through the ecosystem in Metropolitan Washington. This materials flow analysis is shown in Figure 19.

Through this technique the various points of interception of the residual and the allocation of the "ultimate" disposal can be displayed in a relatively straightforward framework of choice. This technique also emphasizes inter-media considerations and is supportive of the carrying capacity approach of the Natural Resources Budget.

<u>Evaluation</u> - These five types of impact assessment methodologies differ markedly in such characteristics as comprehensiveness, data needs, and manpower requirements. However, a review of the methodologies reveals the following similarities important to the Framework Model:

1. Natural resource parameters are selected for investigation

2. The natural resource setting without waste treatment management systems can be identified

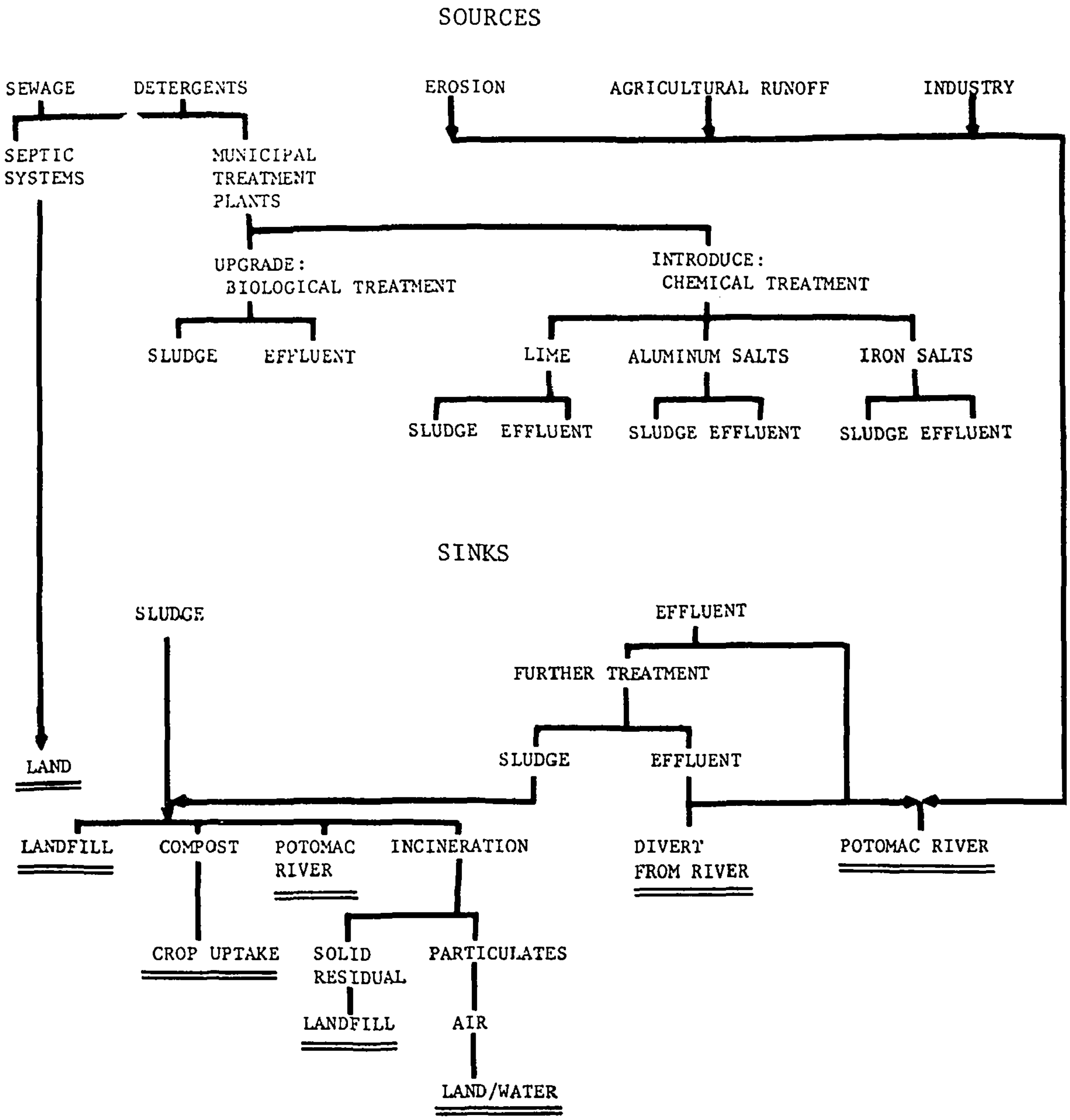


Figure 19 PHOSPHORUS ROUTES

3. The magnitude of changes resulting from implementation of alternatives is assessed for specified parameters

4. Whether subjectively or "objectively", the relative importance of these changes is recognized

5. Potential adverse impacts of alternatives are highlighted

Recent water resource studies conducted in the Washington Metropolitan area* have been analyzed by MWCOG to identify the methodologies used during their performance and other significant characteristics as a guide for the Framework Model development. These studies and several others were classified by the type of impact assessment methodology used in the study development. Several significant findings have emerged from this analysis. These include:

1. Environmental impact analyses are conducted by organizations other than local government staffs (i.e., consultants, regional planning agencies, EPA) although they may be commissioned by the local government.

2. The environmental impact analysis techniques employed by these organizations differ markedly in content and scope but generally fall into the "ad hoc" and "checklist" categories. The level of detail is often considerably less than that suggested in "textbooks" on the subject.

3. Most studies emphasize the mitigation and minimization of possible adverse impacts.

4. The impacts assessed are primarily from capital-intensive structural treatment facilities.

---

*Studies analyzed include references 15, 66, and 81 through 88.

5. Methodologies which lend themselves to "carrying capacity" considerations (i.e., overlays and networks) are not being used in impact studies or in large scale planning development.

6. Significant decisions have been made by local governments based on the results of many of these studies.

From this discussion, the following conclusions regarding the Natural Resources Impact Element have been made:

1. No single impact assessment methodology yet developed is appropriate to all metropolitan regions under all conditions. Therefore, the Element should not be restricted to only one methodology.

2. There are significant similarities in the five types of impact assessment methodologies which should serve as the major steps in the Natural Resources Impact Element.

3. The Element should permit the ready identification of adverse impacts to be minimized, eliminated, or recognized as unavoidable or overriding.

4. Because of limited reserves of air, land and energy resources, impact assessment methodologies which assess the carrying capacity of these resources should begin to be utilized in metropolitan Washington.

<u>Proposed Natural Resources Impact Element</u> - Under this element, the natural resource impacts which would result from the implementation of alternative waste treatment management systems and water resources management strategies can be assessed. The approach presented schematically in Figure 20 is designed to assist in satisfying the requirements of the Federal National Environmental Policy Act (NEPA) and state-adopted Environmental Policy Acts, and to fulfill the environmental impact analysis requirements of the Section 208

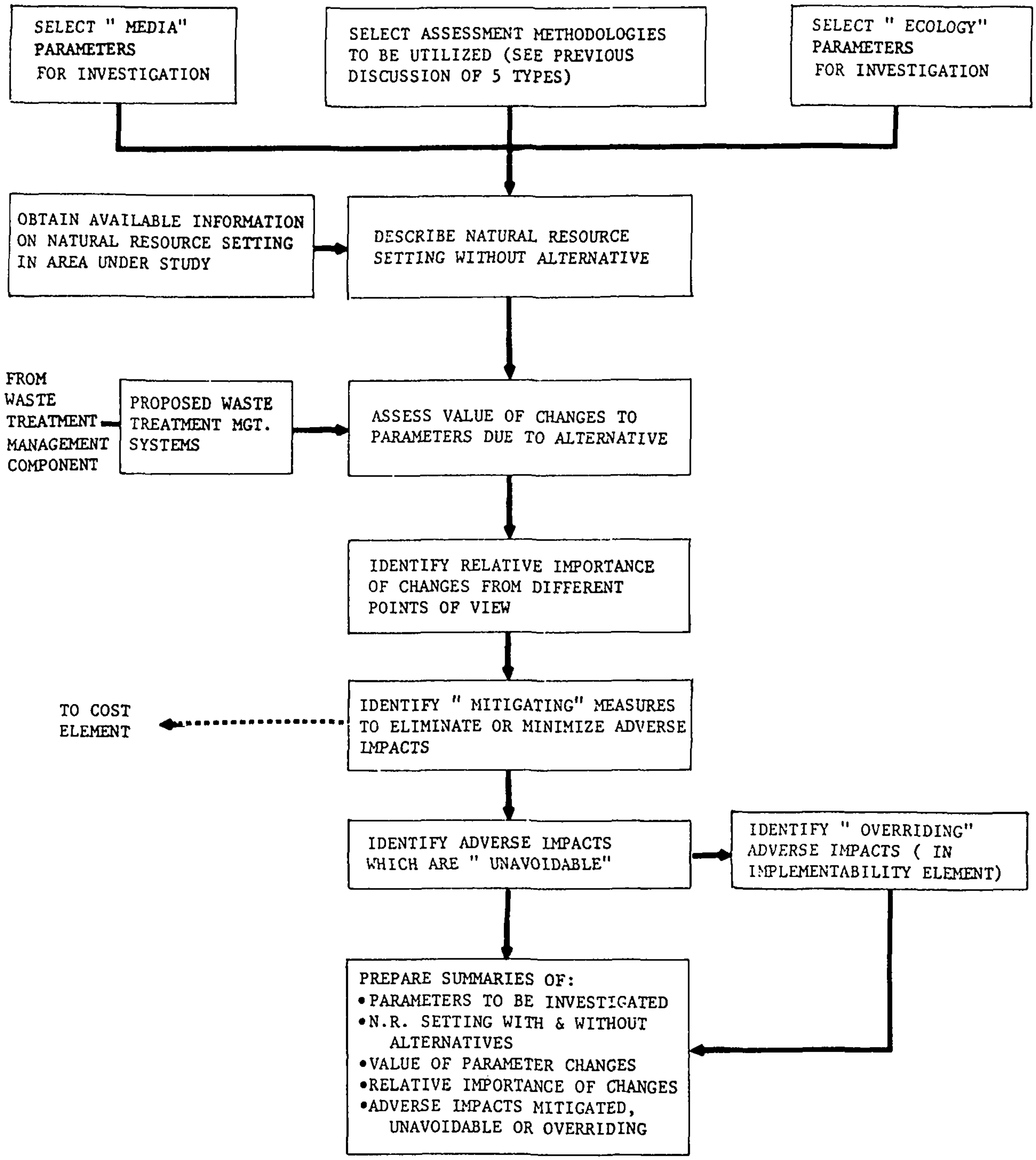


Figure 20 FLOW DIAGRAM OF NATURAL RESOURCES IMPACT ELEMENT

areawide waste treatment management planning process. So-called "social" impacts are discussed separately in the Social Impact Element of the Community Resource Budget.

As discussed earlier, there are at least five different types of environmental impact assessment methodologies which have been developed during the last four years. The most commonly used technique in the Washington Metropolitan Are for detailed comparison of waste treatment management strategies is the "checklist." Therefore, this technique will be highlighted in the remaining discussion. However, the Natural Resources Impact Element procedure permits the user to select and combine detailed assessment methodologies which are most compatible with the area's ongoing planning process. For example, a region where a set of overlays for natural surface features at the desired scale has already been prepared, may choose that technique to analyze land parameters. However, the "checklist" approach still could be used to identify significant ecological features.

Thus, the first step in the Natural Resources Impact Element is to select the combination of assessment methodologies most suitable for the region's planning process. Criteria to use in making this choice are contained in several recent publications.[62,89,90] In all cases the user should select the natural resource parameters which are to be investigated. Based partially on the delineation developed by Batelle Columbus Laboratories,[78] parameters are placed into two groups. The first, "media" parameters, include physical/chemical factors such as air pollution criteria, hydrology, and land surface and subsurface features, and critical environmental areas such as wetlands and "Areas of Maximum Environmental Quality." The second, "ecological" parameters, include plant life, wildlife, and biotic community species and habitat, with particular attention to rare or endangered species and fragile ecosystems. For the latter grouping, checklists for birds of the Metropolitan Washington region and for plants and animals of the Chesapeake Bay Estuarine system have been prepared by the Audubon Naturalist Society of the Central Atlantic States, Inc.[66] and the Chesapeake Research Consortium, Inc. respectively.[91] The user should identify whether similar types of checklists have been prepared for the area under study for use in the Element.

Perhaps the most common "media" parameters examined in environmental impact analyses, besides those for water quality discussed in the Water Quality Objectives Element earlier, are air quality criteria contained in Federally-adopted standards.[92] Many metropolitan areas with substantial water quality control problems also have existing or potential air quality problems as well. Where such air quality problems exist, recent regulations published by the U.S. EPA[93] require that "air quality maintenance plans" be developed during the next several years to ensure that standards are not violated as growth occurs. Thus, the ongoing air quality planning process should be integrated wherever possible with the Section 208 areawide waste treatment management planning process.

The next step in the Natural Resources Impact Element is to describe the natural resource media setting without the alternative waste treatment management systems (i.e., the no-action alternative) by obtaining values for the parameters previously identified. Much of the necessary information may be readily available. For ecology parameters this may be accomplished in a generalized fashion by describing the existing terrestrial and aquatic environments for the area under study. For media parameters such as air quality the adopted implementation plans and maintenance plans should be consulted. Hydrologic information can be taken from the Receiving Water Component. Land surface and subsurface data is available for most metropolitan regions from the United States Geological Survey. Areas that have been designated as Critical Environmental Areas should be identified. It is important, however, that information be obtained for the particular parameters under investigation wherever possible, rather than simply describing the natural resource setting for factors not relevant to the discussion.

The next activity is to assess the value of changes to the natural resource parameters due to the alternative waste treatment management systems. Most often in Metropolitan Washington, this task is performed by consultants hired by the involved local government or planning agency. The purpose of the activity is to obtain quantitative estimates of changes wherever possible. However, often two "experts" will arrive at different conclusions regarding the numerical change to be expected in a given parameter by a water resources management strategy, especially where advanced and sometimes untested technology is being suggested. Thus, it is extremely important that whatever findings are developed in this task be subjected to extensive public scrutiny as part of the Implementability Element. For example, wherever wetlands would be impacted by an alternative, the EPA EIS guidelines require review by the Departments of Interior or Commerce.[94] The points of view expressed during this review process should be used to identify the relative importance of parameter changes from different perspectives. For example, the air pollution effects of an alternative may be relatively "insignificant" when viewed as part of the entire metropolitan area,but may be critically important to those citizens in whose neighborhood the treatment system is to be placed.

Several different "ranking" schemes are available. A common one which is required by the Maryland Environmental Policy Act,[60] is to separate impacts that are "beneficial" from those that are "adverse". Another is to give subjective weights to the importance of each parameter as in the Battelle EES, and then to determine cumulative weights for each alternative. A third is to signify which impacts are more "significant" than others by such classes as "little", "moderate", and "great" concern. Again, the method to be employed by the user will depend on the region under study, the alternatives under consideration, and the personal preferences of the decision-making bodies and citizen organizations. Undoubtedly, however, some subjective method of indicating the relative importance of parameters will be chosen if only by classifying them into "beneficial", "adverse", and "no change".

A major purpose of the Natural Resources Impact Element is, in fact, to "red flag" those parameters which may be "adversely" affected by implementation of a given alternative. Based on federally-promulgated regulations adverse impacts evidently can be grouped into three categories:

1. Adverse impacts which can be minimized or eliminated by introduction of "mitigating" measures (from NEPA)

2. "Unavoidable" adverse impacts which do not in themselves eliminate an alternative from selection (from NEPA)

3. "Overriding" adverse impacts which by

themselves eliminate an alternative from selection (from EPA cost-effectiveness guidelines)

For each impact identified as "adverse" in the Natural Resources Impact Element, the user should first attempt to identify any mitigating measures to minimize or eliminate the adverse effects, including not only changes to any physical portions of the waste treatement management system, but also changes in monitoring, maintenance, replacement, operation, and other follow-up activities. The costs of the proposed mitigating measures should be included in the analysis conducted in the Cost Element. Those adverse impacts which cannot be completely eliminated should then be identified as "unavoidable". Finally, as part of the Implementability Element these unavoidable adverse impacts should be discussed in detail in the community to determine if any are "overriding" such that the alternative should be eliminated from consideration. Two examples of "overriding" adverse natural resource impacts identified recently in Metropolitan Washington were presented earlier in the chapter. In both cases, the alternative was eliminated during the public review process.

Summary tables for presentation to decision-makers and the public should be prepared for each of the activities in the Natural Resources Impact Element. These should include the parameters to be investigated, the natural resource setting with and without the alternatives, value of parameter changes, indicators of relative importance of changes, and adverse impacts which are mitigated, unavoidable, or overriding. In addition, the background data used to prepare these summary tables should also be made available for public review.

In summary, the natural resources budget for the purposes of water resources management planning is considered to consist of two parts, each related to the concept of "carrying capacity" as defined during the Year 2000 Policies Plan Reexamination. The first is the expected "effectiveness" of an alternative strategy in achieving the objectives of the FWPCA of 1972 by testing various allocations versus criteria for each pollutant specified in adopted state water quality standards. The Framework Model Receiving Water

Component physical simulation serves as the primary tool for this in the Water Quality Objectives Element, although modification of the term "effectiveness" as proposed in this study is desirable.

The second part of the Natural Resources budget consists of assessing the "impacts" of alternative strategies on the air, land, and water media, and on species and habitat by utilizing available environmental impact assessment methodologies within the framework specified in the Natural Resources Impact Element.

Community Response Budget

The "Community Response Budget" is perhaps the most elusive in terms of quantitative description, but remains the most visible to public officials. On the one hand, it includes the political response of the community to decisions made or proposed. Public hearings, the electorale process itself, citizen suits, letters to Congressmen, and public opinion sampling are means by which this political response is measured. Such points of view are ways of gauging the "implementability" of a proposed action. In addition, the community response budget includes the expected "human" impacts of a proposal. Such social and economic factors as the displacement or division of jobs or households, aesthetics, equity, and neighborhood identity are representative of individual and community concerns which must be addressed.

For example, proposals for new wastewater treatment plants, sanitary landfills, or water supply impoundments in the Metropolitan Washington region are almost always opposed by those persons in whose neighborhood such a facility would be located. As in the case of the Natural Resources Budget, such concerns can become "overriding adverse" factors which cause the elected official or local governing body to eliminate a particular site from consideration. In a very real sense, the proposed facility would have exceeded the community response budget perceived available by the elected officials at that time.

Thus, the term "budget" is used to suggest limits for community response as well as fiscal and natural resources. At any given time the available resources (whether monetary, natural, or human) that can be devoted to the solution of any problem are considered to be finite. It is therefore necessary for elected officials to weigh social, economic, and environmental factors and to make difficult trade-offs in allocating limited resources to solutions of problems. Since the limits in the natural resource and fiscal budgets cannot be set by science alone, in the words of one of MWCOG's consultants, "we must rely on the value trade-offs from community response as the primary guide to where the cumulative effect of incremental decisions is at last taking a toll."[97]

It is therefore extremely important that the water resources management planning processes such as Section 208 areawide waste treatment management planning, provide adequate opportunity for the expression of relevant points of view and consideration of social impacts if the planning process is to result in implementable programs. The remainder of this section will review the methodologies and techniques currently used or available for incorporation into the Framework Model for this purpose.

Social Impact Element

Existing Methodologies - Recent court cases concerning the definition of "human environment" as used in the National Environmental Policy Act have broadened its interpretation to include physical, cultural, economic, aesthetic and social factors which affect the quality of life.[98] Many of the recent environmental impact assessment methodologies presented earlier therefore incorporate consideration of social impact under the broad context of "environment". For example, in the Environmental Evaluation System (EES) developed by Dee, et.al., and discussed earlier, thirty-six of the seventy-eight environmental parameters deal with social impacts as defined by the three-budget MWCOG system. These are grouped into such components as cultures, composition, man-made objects, historical packages, mood/atmosphere, and life patterns. In the EES, however, these "aesthetics" and "human interest" categories only receive a relative weight of 358 out of the 1000 points for the natural resource and social impacts together.

Table 7 displays a checklist comparison for alternative waste treatment plant sites in Montgomery County, Maryland, of the impacts to man-related and natural systems. Each impact is ranked on a relative scale of 1 (most favorable) to 5 (least favorable). Man-related impacts include such factors as dislocation of families, compatibility with adjacent land use, disruption of historical sites, and perservation of visual neighborhood character. Community values were assessed principally through comments of local citizenry expressed at neighborhood meetings, from questionnaires which were submitted subsequent to the meetings, and from adopted master plan statements of community goals and objectives. Factual information was obtained through site visits and inspection of existing data.[66]

A study of alternative arrangements and scheduling of waste treatment facilities for serving the Maryland portion of the

Table 8
ENVIRONMENTAL COMPARISON OF ALTERNATE
AWT SITES IN MONTGOMERY CO., MD.

COMPARISON ITEMS	AWT SITE RANKINGS[1]						
	PEPCO	S-1	M-2	W-2	R-2	M-2 R-2	W-2 R-2
ENVIRONMENTAL IMPACTS - NATURE							
Soils/Geology-Suitability for AWT	2	2	2	5	2	2	4
Topography-Minimal Grading	4	2	3	5	1	3	5
Effects on Potomac River	1	2	3	5	5	4	5
Wildlife Habitat	2	4	1	5	3	4	5
Mature Forest, Other Unique Vegetation	2	4	1	5	3	4	5
ENVIRONMENTAL IMPACT - MAN							
Community Reaction	2	3	1	4	5	5	5
Preservation of Visual Neighborhood Character	2	3	3	1	4	5	5
Disruption of Historical Sites	4	5	1	1	1	1	1
Compatibility with Adjacent Use	1	2	2	3	4	5	5
Dislocation of Families	2	2	2	1	1	2	1
Adaptability to Traffic and Proximity to Freeway	5	2	2	3	1	4	4
Drainage Area above Reservoir	4	5	2	1	1	3	1
Construction Impact	2	2	3	4	3	5	5
Augmentation Potential for C&O Canal	1	2	3	4	4	3	4
Reservoir Recreational Value	4	2	3	1	1	1	1
Delivery System Impact	3	2	2	1	5	4	4
Railroad Access	1	5	5	5	5	5	5
RANKING OF COSTS[2]	1	2	1	3	3	4	5
1) 1 = Most Favorable; 5 = Least Favorable							
2) Ratio of present value of project costs (1973-2000) to lowest cost site	1.00	1.03	1.01	1.05	1.05	1.13	1.17

From Reference 66, Table 21-1.

Metropolitan Washington area arrived at a "fundamental conclusion" that no single regional program was more cost-effective than all other alternatives, and therefore that the selection had to be made on the basis of intangible, or non-quantifiable factors.[85] The factors selected in the study were flexibility, speed of implementation, potential for wastewater reclamation, and community impact. The alternatives were then rated as good, fair, or poor for each factor.

In addition, there are requirements in certain Federal acts which must be met as part of the social impact analysis. For example, regulations published under authority of Section 106 of the National Historic Preservation Act of 1966 require that any draft environmental statement must include evidence indicating that the most recent listing of the National Register of Historic Places has been consulted and, if a site will be affected, the actions will be undertaken to remove any adverse impacts that could result from implementation of the selected alternative.[99,100,101] This requirement takes on special significance in historically important regions such as the Nation's capital.

Another Federal act of significance is the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970.[102] This Act requires that, in order to obtain Federal funds for projects (such as treatment works) resulting in the displacement of any person, the State must assure the Federal government that: (a) fair and reasonable relocation payments and assistance as defined under the Act, shall be provided to owners and tenants displaced from their homes, businesses, or farms; (b) relocation assistance programs shall be provided; and (c) comparable, decent, safe, and sanitary housing will be available for displaced persons prior to displacement.[103] Thus, the social impact analysis in the Framework Model should identify the number and types of homes and business to be directly affected by a proposed alternative.

Finally, many "secondary" or induced environmental impacts may be social or economic, and therefore should be included in the social impact analysis. Changes to the region's employment or household patterns which will result from implementation or an alternative should be identified. Much of the information will be contained in the Community Development Component and can be summarized here.

As a minimum the social and economic impact analysis portion of the Framework Model, to be called the Social Impact Element, will have to contain a checklist of factors or parmeters for consideration. As with the natural resource impact analysis, some parameters will be directly measurable and other, such as neighborhood identity, will undoubtedly derive from an individual's point of view. The underlying basis for the social impact analysis, however, is that there is a Community Response Budget which may cause any social impact to become an "overriding factor" sufficient to eliminate an alternative. The potential displacement of 10 households may appear "insignificant" to the consultant performing the study, but may be or primary importance, for example, to the City Council of the District of Columbia who, with 616 households in D.C. displaced in FY 1973, and replacement housing not readily available, may reject a proposed alternative for one which causes no residential displacement.

Proposed Social Impact Element - In this element the social and economic changes associated with an alternative waste treatment management system are evaluated by the process illustrated in Figure 21. This approach will assist in satisfying federal and state Environmental Policy Act, fulfill the social and economic impact analysis requirements of the Section 208 areawide waste treatment management planning process, and comply with requirements of several associated Federal Acts.

In the Natural Resources Impact Element, five types of impact assessment methodologies were discussed. Of those, the "checklist" approach appears to be most satisfactory for discussion of social impacts, although descriptions of certain factors may be generalized (ad hoc). Neither the "matrix" nor "network" approaches appear conducive to social impact analysis, while the "overlay" technique might have limited application for identifying the neighborhood-related factors to be discussed shortly. It is expected that, as these assessment methodologies become more refined through greater use, they will be used in social impact analyses.

Therefore, the first activity in the Social Impact Elment

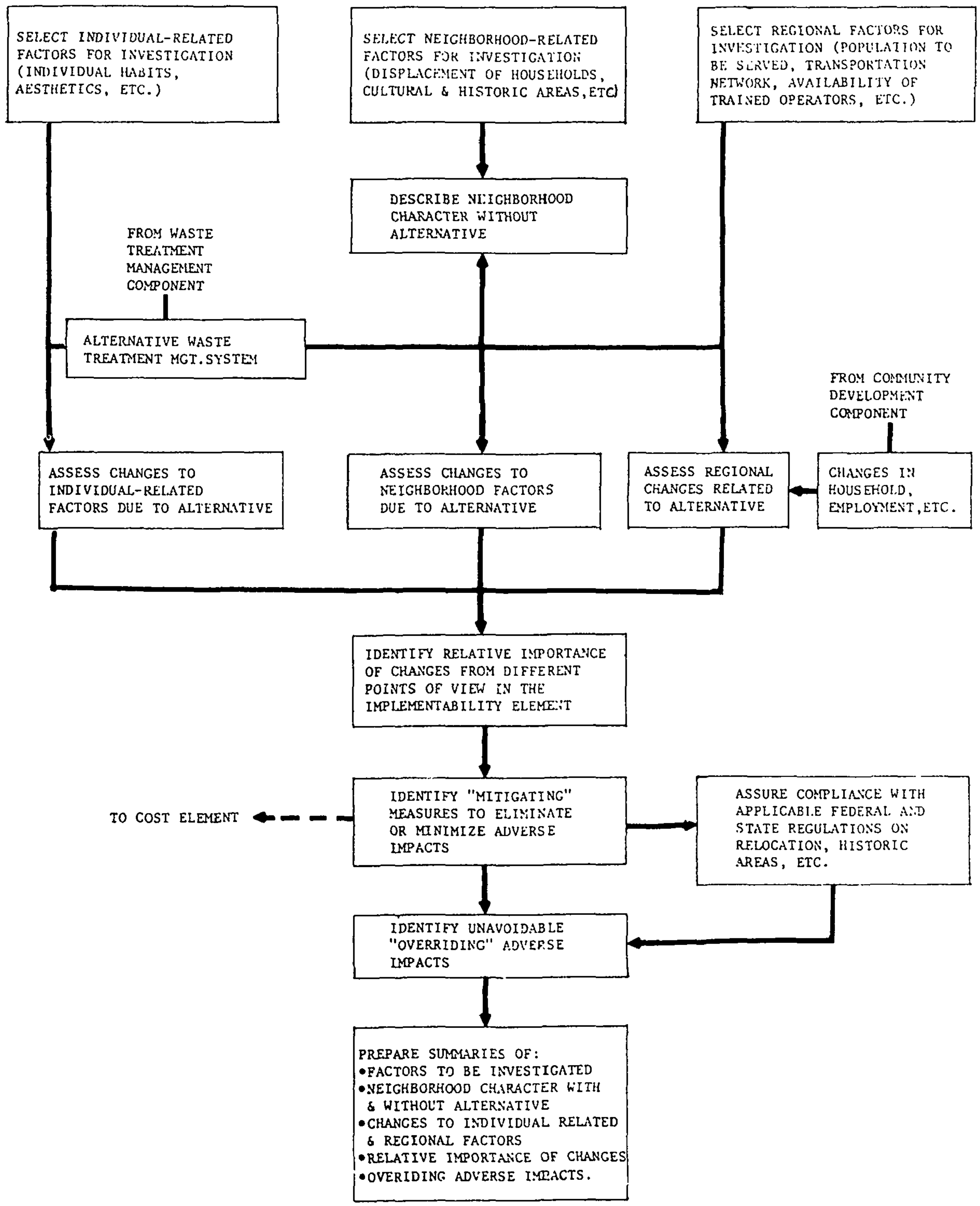


Figure 21 FLOW DIAGRAM OF SOCIAL IMPACT ELEMENT

is the selection of social factors to be investigated. It has been found through experience in metropolitan Washington that certain social issues commonly raised by citizens are associated with the specific neighborhood where an alternative is to be located, while others are linked to the pattern of regional growth which is expected to result. In the former case, these "primary" impacts might include the displacement of households and businesses, the disruption of historically or culturally significant areas, or other significant changes in neighborhood character. In the latter case, these "secondary" regional impacts include the potential growth in the service area of a facility, the effect on the regional transportation network or the availability regionwide of trained personnel to operate proposed facilities. In addition, with the broadening of the definition of waste treatment management alternatives to include public education, pricing and other nonstructural programs designed to change people's habits, a third category of social factors called "individual-related" must be added. Therefore, social factors are to be identified and grouped into the following three categories: (a) individual-related; (b) neighborhood-related; and (c) regional.

Next, for those alternatives such as treatment plants and conveyance facilities which require land, the characteristics of the neighborhoods under consideration as "sites" should be described without the proposed alternative (i.e., no action alternative) using the neighborhood-related factors previously selected. In most cases this can be accomplished by describing the existing situation, although proposed changes contained in master plans should also be noted. For example, a site which is currently farmland may be designated as part of an industrial park for 1978 in the local master plan, thus perhaps making it more suitable for use as a treatment plant site. Because of the nature of the individual-related and regional factors, a description of existing conditions would not be as meaningful.

The remaining series of steps are comparable to those to be performed in the Natural Resources Impact Element, so they are only highlighted here. The changes in each of the three factor categories due to the proposed alternative should first be assessed. In the case of the regional factors, much of the needed information on land use, household, and employment changes is contained in the Community Development

Component. Next, the relative importance of the changes should be assessed based on the points of view expressed during the review process. For those impacts which are assessed as adverse, "mitigating" measures should be identified to minimize or eliminate them.

As discussed earlier in the Community Response Budget, the user must ensure that these mitigating measures will permit the alternative to comply with the requirements of all applicable Federal, and State regulations, including the National Historic Preservation Act of 1966, the Uniform Relocation Act of 1970, NEPA, and any other legislation which might be or relevance. During the public review process any unavoidable "overriding" adverse impacts of an alternative should be identified. Finally, throughout the Social Impact Element wherever information or points-of-view are obtained, they should be summarized and made available.

Implementability Element

Existing Methodologies - The previous section leads directly to the second portion of the Community Response Budget - "implementability." Frequently in the past in metropolitan Washington the most significant action to result from a governing body's review of the results of an investigation and comparison of alternatives has been no action; i.e., the decision to obtain more information on one or more alternative before making a "firm" decision. Thus, in water supply-demand planning during the past few years, proposals for upstream reservoirs have been pitted against emergency use of the Potomac Estuary, resulting in the recent Congressional decision to restudy each alternative once again.[104] During this debate, local governments and agencies were quietly in the process of adopting water-saving plumbing code changes recommended by COG which, by 1992, are expected to have "saved" up to 25 million gallons per day in new-construction residential comsumption alone. Plumbing code changes were adopted while the other alternatives were stalled, because plumbing code changes were more "implementable".

Several factors made them implementable. First, local elected officials and citizen organizations agreed on the concept of eliminating the unnecessary waste of water. Second, the local government in its water supply utility had the power itself to take the desired legal action to change the ordinance. Third, there was no expenditure of local government capital funds required. Fourth, there were no identifiable significant adverse natural resource impacts. Fifth, there were no identifiable significant adverse social or economic impacts since manufacturers indicated the required fixture could be produced at costs comparable to those of normal fixtures provided the market was large enough. Finally, the decision would not influence the development patterns for future growth in the community. Although there were probably other reasons as well, it is clear that this alternative had great "implementability", the perceived advantages outweighed the disadvantages.

It is not proposed that "implementability" is an easily definable or quantifiable measure which a consultant can determine by conducting a study of it. Rather, it will evolve from the planning process itself by exposing elected and appointed officials to a wide range of viewpoints expressed through public hearings, personal discussions, citizen or developer lawsuits, questionnaires, and other mechanisms. In addition, there may be certain incentives or constraints to the implementation of a specific alternative which the elected official should be aware of. In deed, the Federal and State law and regulations cited throughout this report place meaningful boundaries on actions which local governments can or cannot take regarding water quality management, as well as providing such incentives as 75% federal funds for projects which conform with EPA regulations.

The Implementability Element of the Community Response Budget must therefore provide a means of obtaining and displaying these points of view and incentives/constraints to decisionmakers. Mechanisms available to regional planning agencies, such as the Office of Management and Budget Circular A-95 review and comment procedures for federally-funded projects[105] and those techniques identified in the U.S. EPA public participation guidelines[63] should be used to the maximum extent feasible.

Proposed Implementability Element - The basic objective of the Framework Model development has been to identify and link various techniques and methodologies for use in the water resources management planning process. Each component and element of the Framework Model has been designed to provide information needed by elected and appointed officials to make decisions. Perhaps most important of all is the need to provide decisionmakers with the varying and inevitably conflicting points of view of the community towards the alternatives under (or not under) consideration. The purpose of the Implementability Element is to assure that these points of view are solicited and obtained through an active public participation program such that a decision can be made and implemented.

The approach to be used to find an implementable alternative includes public participation in all portions of the planning process already discussed. However, certain additional steps are essential in every planning activity. These include:

a) Identify the public
b) Identify mechanisms to be used for public participation
c) Identify where to use these mechanisms in the planning process
d) Undertake public participation program
e) Summarize points of view
f) Identify incentives/constraints to implementation

In its Water Quality Training Institute workbook, the Conservation Foundation has identified the following four types of publics:

a) the general public often referred to as the man in the street
b) the organized public, such as civic associations and environmental groups
c) the representative public, including elected and appointed officials (and their staffs)
d) the economically concerned public, such as neighborhoods or developers, whose interests may be affected (adversely or favorably) by water quality decisions[106]

It is important that each of these "publics" have an opportunity to participate in the planning process, although certain mechanisms may be more appropriate for each group at certain times during the process than others. K. Warner has classified these mechanisms into three categories by primary emphasis, recognizing that many may be multi-purpose.

These three categories are:

1) Education/Information, such as newspaper articles, speeches, letters, brochures, and TV programs.
2) Review/Reaction, including public hearings, questionnaires, and access to material.
3) Interaction/Dialogue through advisory boards, workshops and informal contacts.[107]

Public participation minimum guidelines published by EPA under Section 101(e) of the Act specify certain mechanisms to be used at various points in the planning process with "interested" or affected persons or organizations.[63] In addition, such mechanisms as the Circular A-95 review and comment procedures published by the OMB provide an opportunity for affected local governments to review and comment on proposed Federally-funded projects and programs.[105] It is important that the public participation program be designed to provide for these mechanisms to be used at appropriate points in the planning process, i.e., before the "decisions" are made, so that the projected improvements in water quality can be identified and counted as advantages in the decision making process.

For example, there are numerous points during the procedures outlined in the Framework Model where public participation is essential. These include, but are not limited to:

a) Identification of inputs to Community Development Component
b) Selection of user-specified inputs to Water Demand and Sewage Generation Components
c) Identification of waste treatment management alternatives to be tested, including review of assumed removal efficiencies
d) Selection of alternative points of discharge, and options to be tested, in the Receiving Water Component
e) Review of all outputs from physical simulations
f) Identification of alternative financial arrangements to be investigated
g) Review of alternative user charges and customer charges from Financial Arrangements Element
h) Selection of "probabilities of occurrence" and various conditions to be simulated in the Water Quality Objectives Element
i) Review of "capability", expected "effectiveness",

and cost-effectiveness analyses

j) Selection of assessment methodology and parameters to be investigated in the Natural Resources Impact Element

k) Selection of factors to be investigated in the Social Impact Element

l) Expression of points of view on relative importance of changes to parameters and factors in the Natural Resources Impact and Social Impact Elements

m) Identification of adverse impacts which are "unavoidable" or "overriding"

n) *Improvements needed in Framework Model*

As these points of views are registered, it is desirable that a record be kept and that significant points raised be addressed. Although the guidelines by EPA require the preparation of a "Summary of Public Participation" for every grant application or plan, it is more important that there viewpoints be made known to elected and appointed officials during the areawide planning process.

Finally, it is likely that in any region there may be certain constraints to or incentives for implementation of alternatives under consideration which may be identifiable during the planning process. An example of a constraint may be a requirement by the state constitution or statutes that the sanitary commission but not the local government may construct and operate treatment works (as in Maryland portion of metropolitan Washington) or a state policy that interim treatment works cannot be built unless the permanent facility to replace it has received necessary state and local planning approvals (as in Virginia). The most readily identifiable incentive is the Federal Title II construction grant program under the Act which provides 75% federal funding of treatment works which conform with EPA regulations. Such regulations covering all parts of the Act are published regularly in the Federal Register, which is obtainable from the U.S. Government Printing Office. Legal and institutional changes are a recognized part of the waste treatment management planning process, however. Thus, changes which are deemed necessary as part of the selected management program should be offered.

The key concept of this element and the Community Resource

Budget is that there are limits for community response as well as fiscal and natural resources, and that these limits must be identified to the greatest extent possible as a part of the water resources management planning process. Although it is the most difficult to quantify, the Community Response Budget is the most visible to the elected and appointed decisionmaker.

CHAPTER IV

DEMONSTRATION OF THE FRAMEWORK MODEL

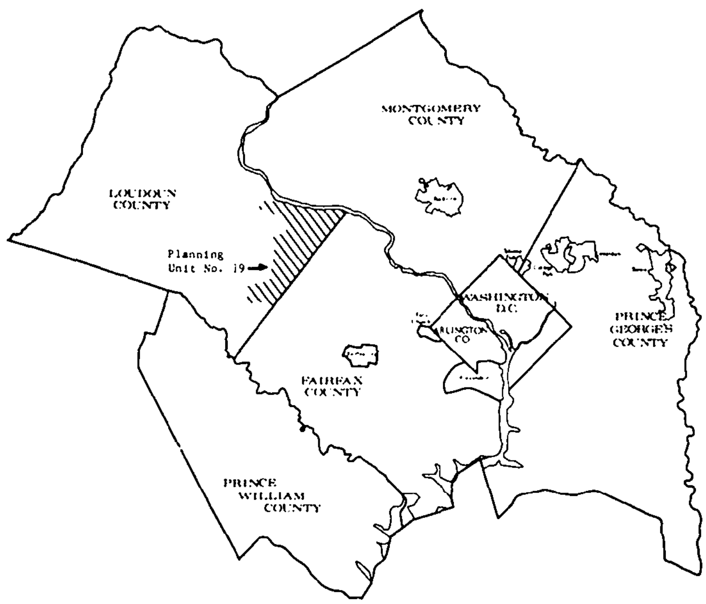
The Framework Water Resources Planning Model is a flexible and versatile tool for use in areawide water resources management planning. This chapter illustrates through a variety of examples the application of the Framework Model in metropolitan Washington. As an aid to understanding how the physical simulation components of the model fit together, the first part of this chapter presents the results from a typical model run for the year 1976. For ease of presentation, emphasis is placed on showing the model output starting with one of the fifty "planning units" identified in the study for metropolitan Washington.

Then, to demonstrate the use of the full Framework Model capabilities, six alternative areawide water resources management strategies which are in various stages of consideration in metropolitan Washington are simulated for the year 1992. Through use of the three-dimensional estuary profile plots, the water quality response of the upper Potomac Estuary for each alternative is displayed. From these plots produced by the Receiving Water Component, the "capability" and the expected "effectiveness" of the alternative strategies as defined in the Water Quality Objectives Element is compared. Next, using the procedures contained in the Cost Element, the present values by cost element of the alternative areawide water resources management strategies are determined.

Finally, the cost effectiveness of the alternative areawide water resources management strategies is compared.

TYPICAL COMPUTER RUN OF FRAMEWORK MODEL PHYSICAL SIMULATION COMPONENTS

This section presents the results of a typical computer run of the Framework Model physical simulation components. The forecast year selected for analysis is 1976. The "planning unit" chosen to begin illustration of the model results is No. 19. It is located along the eastern boundary of Loudoun County, Virginia, south of the Potomac River, and north of Route 50 as indicated in the figure below. The natural drainage in the area flows into Broad Run and then to the Potomac River above Great Falls. Dulles Airport and the developed portion of Loudoun County are located in the area, which obtains water from the Fairfax City water supply on Goose Creek through the Loudoun County Sanitatation Authority. The area is part of a drainage basin sewered by the Potomac Interceptor Sewer, which transmits flows to the regional wastewater treatment plant at Blue Plains in the District of Columbia. The Blue Plains treatment plant discharges into the Potomac Estuary.



The location of Planning Unit No. 19
in the Washington Metropolitan Area

Planning Unit No. 19 is made up to two "Policy Analysis Districts", No. 766 and 767, from the Community Development Component. The relationship of geographic units used in the Framework Model as initially applied in metropolitan Washington is illustrated in Figure 22.

Community Development Component

The EMPIRIC Activity Allocation Model serves as the basic computational tool in the Community Development Component of the Framework Model. The EMPIRIC Model distributes metropolitan "control" totals of future population, employment, and land use growth in eight-year intervals among a set of smaller subregions or districts, based upon exogenously specified metropolitan planning policies. The following is an example of a portion of EMPIRIC output for 1976 for the most recent EMPIRIC alternative for the two Policy Analysis Districts (#766 and #767) that form Planning Unit No. 19.

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS

SUMMARY OF FORECAST RESULTS AND INPUTS - ALTERNATIVE 6.2 MOD.
SEPTEMBER 1972

DISTRICT 766

SUMMARY OF FORECAST RESULTS

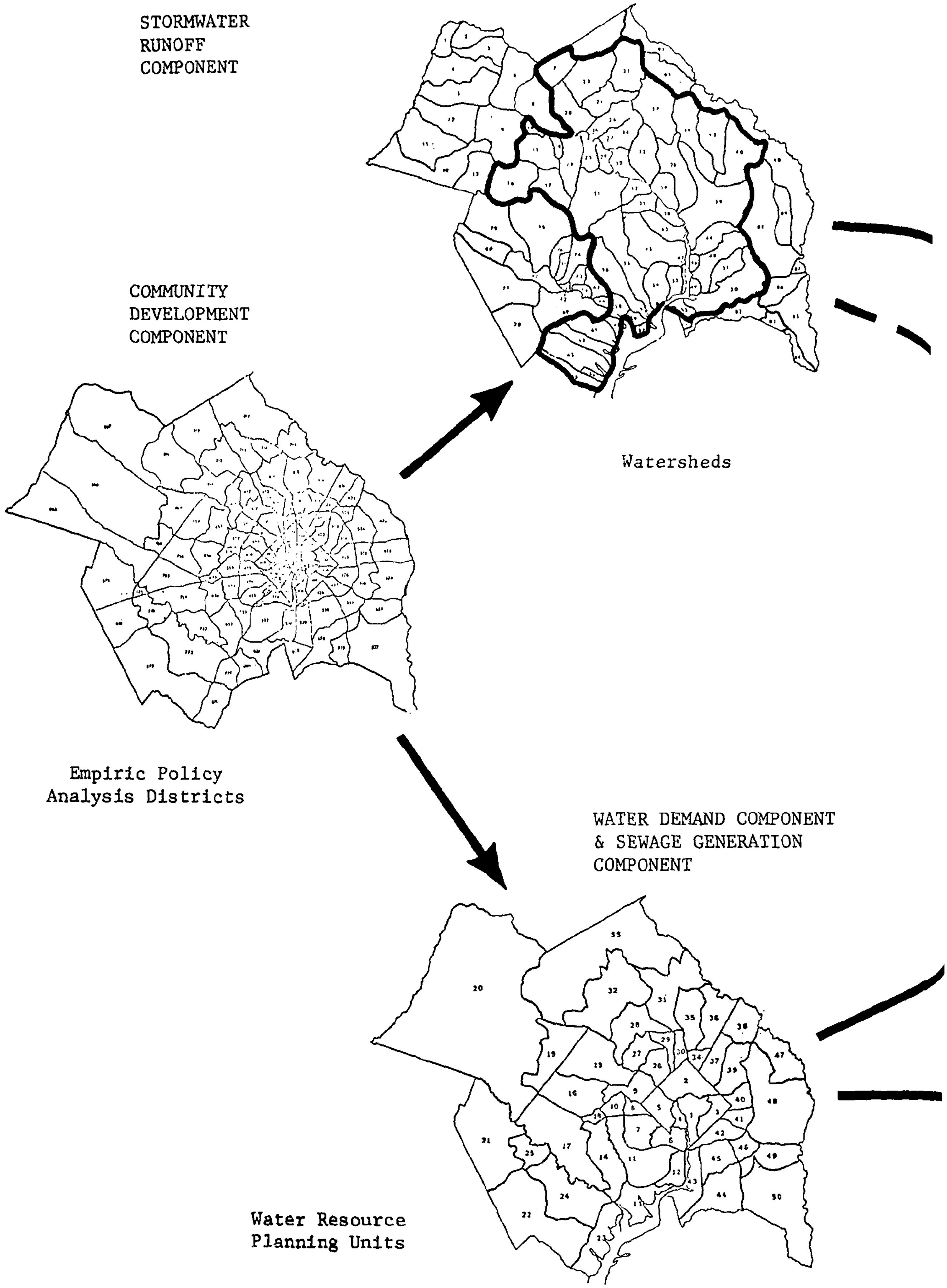
	1968	1976	1984	1992	CHANGE: 68-92
POPULATION	0.	0.	0.	0.	0.
HOUSEHOLDS	0.	0.	0.	0.	0.
EMPLOYMENT	2073.	2527.	5303.	6307.	4234.

DISTRICT 767

SUMMARY OF FORECAST RESULTS

	1968	1976	1984	1992	CHANGE: 68-92
POPULATION	6873.	41058.	59436.	72784.	65911.
HOUSEHOLDS	1843.	11206.	17575.	22977.	21134.
EMPLOYMENT	846.	2232.	8209.	12519.	11673.

For the entire metropolitan region in 1976, the EMPIRIC model estimates (or utilizes as a control total)[119] a total popula-


STORMWATER
RUNOFF
COMPONENT
Watersheds
COMMUNITY
DEVELOPMENT
COMPONENT
Empiric Policy
Analysis Districts
WATER DEMAND COMPONENT
& SEWAGE GENERATION
COMPONENT
Water Resource
Planning Units

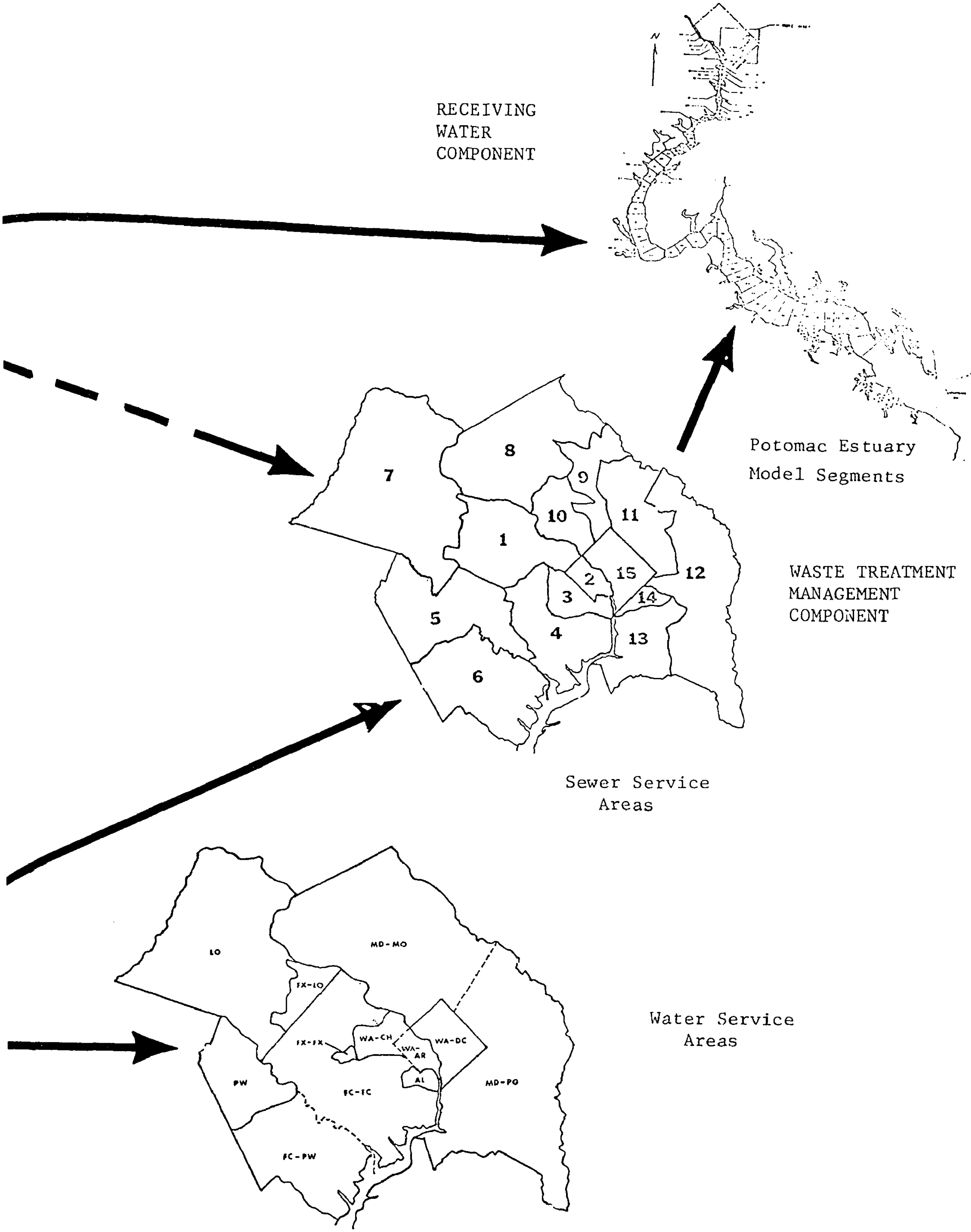


Figure 22 GEOGRAPHIC UNITS IN THE FRAMEWORK MODEL PHYSICAL SIMULATIONS

tion of 3,305,933, total households of 1,091,190, and total employment of 1,497,880. EMPIRIC forecasts are not official projections, and are used for study purposes only, as in this report.

Water Demand Component

The Interface program reformats selected EMPIRIC output into planning units. Then the "MAIN II System" is exercised to produce estimates of average daily, maximum day, and peak hour water demand by usage category for each of the 50 planning units shown in Figure 22 for each forecast year. For example, in 1976 single-family (metered) and multi-family (flat-rate) residential water demand in Planning Unit No. 19 is estimated as:

MUNICIPAL WATER REQUIREMENTS...PLANNING UNIT 19
ANALYZED BY MAIN SYSTEM

CURRENT RESIDENTIAL WATER REQUIREMENTS IN GALLONS PER DAY

ANNUAL AVERAGE	MAXIMUM DAILY	PEAK HOURLY
2564733.	4154761	12123045.

REQUIREMENTS BY TYPE - ANNUAL AVERAGE

	NO. OF UNITS	GALLONS PER DAY DOMESTIC	SPRINKLING	TOTAL
METERED AND SEWERED AREAS	7086.	1260628.	217927.	1478555.
FLAT RATE AND SEWERED AREAS	4120.	933086.	153092.	1086178.
TOTAL	11206.	2193713.	371019.	2564733.

SUMMER EVAPOTRANSPIRATION %INCHES < # 16.00
SUMMER PRECIPITATION %INCHES < # 6.75
MAX. DAY EVAPOTRANSPIRATION % INCHES< # 0.29

Commercial and industrial water demand in the planning unit is projected as:

MUNICIPAL WATER REQUIREMENTS FOR THE CITY OF PLANNING UNIT 19 FOR THE YEAR 1976
ANALYZED BY MAIN SYSTEM

TOTAL COMMERCIAL REQUIREMENTS IN GALLONS PER DAY

ANNUAL AVERAGE	MAXIMUM DAILY	PEAK HOURLY
510513.	708661.	1649186.

WATER REQUIREMENTS BY TYPE OF COMMERCIAL ESTABLISHMENT

TYPE	UNITS	NUMBER OF UNITS	ANNUAL AVERAGE (GALLONS	MAXIMUM DAILY PER	DAY) PEAK HOURLY
SCHOOL, ELEM.	STUDENT	5483.	29500.	53078.	269227.
SCHOOL, HIGH	STUDENT	2518.	16695.	49356.	304699.
MANU/TCU	EMPLOYEES	1823.	353786.	368026.	430239.
TRADE	EMPLOYEES	672.	48651.	130911.	339502.
FIRE/SERV.	EMPLOYEES	1149.	41519.	69432.	196424.
GOVERNMENT	EMPLOYEES	665.	18888.	35116.	106012.
AGRI/CONST.	EMPLOYEES	519.	1475.	2742.	3085.

Public and unaccounted-for water demand in the planning unit is projected as:

TOTAL PUBLIC-UNACCOUNTED REQUIREMENTS IN GALLONS PER DAY

ANNUAL AVERAGE	MAXIMUM DAILY	PEAK HOURLY
825261.	825261.	825261.

REQUIREMENTS BY TYPE OF PUBLIC-UNACCOUNTED USAGE IN GALLONS PER DAY

TYPE	ANNUAL AVERAGE	MAXIMUM DAILY	PEAK HOURLY
DISTRIB. LOSSES	611761.	611761.	611761.
FREE SERVICES	213500.	213500.	213500.

The average annual water demand estimates are then summarized by major water demand section as follows:

SUMMARY OF ESTIMATED AVERAGE DAILY MUNICIPAL WATER REQUIREMENTS
FOR METROPOLITAN WASHINGTON FOR THE YEAR 1976 AN16.
IN GALLONS PER DAY

PLANNING UNIT	RESIDENTIAL: SINGLE-FAMILY HOUSEHOLDS DOMESTIC	RESIDENTIAL: SINGLE-FAMILY HOUSEHOLDS SPRINKLING	RESIDENTIAL: APARTMENTS DOMESTIC	RESIDENTIAL: APARTMENTS SPRINKLING	COMMERCIAL & INDUSTRIAL	PUBLIC & UNACCOUNTED	TOTAL
..							
19	1260629	217929	933035	153092	510514	825261	3900511
..							

The output of the Water Demand Component can easily be aggregated into water service areas as illustrated in Figure 22 for water supply planning purposes. The total average daily water demand estimated for 1976 for the region is 455 million gallons per day,[120] which is approximately a 22 percent increase from 1968.

Sewage Generation Component

Estimates of domestic residential and commercial/industrial average daily water demands can be translated directly into uninfiltrated residential and commercial sewage flow by the Sewage Generation Component. Infiltration/inflow is then calculated exogenously based on the amount of developed land estimated by the Community Development Component. Estimated average daily flows for Planning Unit 19 are as follows:

SEWAGE GENERATION MODEL
CONTRIBUTION TO SEWAGE FLOW FROM MAIN II WATER ESTIMATES

PLANNING UNIT	DOMESTIC WATER USE (GAL/DAY)----- AVERAGE DAILY	COMMERCIAL/INDUSTRIAL WATER USE (GAL/DRY) AVERAGE DAILY	FROM INFILTRATION (MGD) AVERAGE DAILY
19	1205182.00	433860.000	0.6340

Both the uninfiltrated residential and commercial sewage flows are multiplied by user-specified pollutant concentrations to provide estimates of total sewage pollutant load by parameter as follows:

GENERATED SEWAGE

PLANNING UNIT	AVERAGE DAILY FLOWS AND LOADS---------			
	-----FLOW (MGD)	---LOADS (LBS/DAY)---------- BOD	NITROGEN	PHOSPHORUS
19	2.2730.	2195.	547.	130.

Stormwater Runoff Component

The Community Development Component, the source of population and growth forecasts used in projecting sanitary waste generation, is also used as input to the Stormwater Runoff Component. Figure 22 shows that the area chosen for this example overlaps five of the 92 major watersheds in the region which flow to the Potomac, Occoquan, and Patuxent Rivers. Watershed No. 17 is one of those covering the area used in the example.

From a data file, EMPIRIC outputs for each Policy Analysis District are assigned to watersheds in proportion to the fractions of area. This is done in the interface program "Prestorm" which adds assignment of population and employent to each watershed and accepts the input of the user's choice of storm to be simulated. For realistic simulation of storms actually experienced in the region, a "first decile" storm described by its changes in intensity and duration is superimposed. The dry period preceding a storm of this size is used to calculate the pollutant accumulation eligible for washoff, and the succeeding dry period is calculated to show the time possible flow retention stormwater treatment devices may be permitted to operate at an constant rate to treat the surge of stormwater.

The simulation of a storm is completed by the EPA Stormwater Management Model and the resultant runoff summarized by a program called "Split" which divides that portion of the runoff flow and load that will be discharged directly in the estuary, from that which will be simulated as treated as combined sewage in the Waste Treatment Management Component.

SPLIT FLOWS AND LOADS

WATERSHED NO.	TREATED FLOWS & LOADS				UNTREATED FLOWS & LOADS			
	RUNOFF (MG)	BOD (LBS)	NITROGEN (LBS)	PHOSPHORUS (LBS)	RUNOFF (MG)	BOD (LBS)	NITROGEN (LBS)	PHOSPHORUS (LBS)
17	** NONE TREATED **				30.35	230	**NOT INCLUDED IN THIS RUN**	

Comparison of the runoff projected for this area in 1976 shows that it will increase by 52 percent from the levels simulated for 1968. Had a more mature watershed, one with combined sewerage systems been chosen, the split printout would revel the stormwater loads contributed to the sewerage system. Watershed No. 36 is an example where this occurs:

SPLIT FLOWS AND LOADS

WATERSHED NO.	TREATED FLOWS & LOADS				UNTREATED FLOWS & LOADS			
	RUNOFF (MG)	BOD (LBS)	NITROGEN (LBS)	PHOSPHORUS (LBS)	RUNOFF (MG)	BOD (LBS)	NITROGEN (LBS)	PHOSPHORUS (LBS)
17	** NONE TREATED **				30.35	236	0.0	0.0
36	[illegible]	19332	0.0	0.0	682.22	21,328	0.0	0.0

The simulated stormwater flows that do not go through combined sewers can be "treated" in the Waste Treatment Management Component by removing a user-specified portion of the pollutant loads. The treated flows are then ready to join simulated flows of sewage when they are discharged into the estuary.

Waste Treatment Management Component

The Waste Treatment Management Component aggregates sewage flows and loads from the water resource planning units into user-specified sewage service areas such as those shown in Figure 22. (Planning Unit No. 19 is in Sewer Service Area No. 1 flowing to the Blue Plains Treatment Plant) and applies a user-specified removal efficiency to each pollutant to simulate the application of technology such as an advanced waste treatment. Flow to treatment plants due to stormwater runoff through combined sewer systems can also be simulated. In the following example the user-specified removal efficiencies for BOD_5, Total N, and Total P are 71.2 percent, 50 percent, and 50 percent, respectively.

SEWAGE TREATMENT TO ESTUARY 1976 LOCAL NO. 1

DESCRIPTION	AVERAGE FLOW(GPD)	AVERAGE LOADS (LBS/DAY) BOD	NITROGEN	PHOSPHORUS
SA VIRGINIA POTOMAC-DULLES INTERCEPTOR	18,655,300	6116	2290	541

Receiving Water Component

The effluent from the Waste Treatment Management Component and the additional stormwater flows and loads via the natural drainage system from the Stormwater Runoff Component are input via the Preestuary model to the Estuary Hydrodynamic Subprogram of the Receiving Water Component. This subprogram calculates the tidal stage versus time for each estuary segment and the flow versus time between adjacent segments:

```
METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS POTOMAC ESTUARY HYDRAULIC RUN
USING GREAT FALLS Q=[illegible] CFS, [illegible] Q=365 CFS, PINEY POINT TIDE OF 4-7&8-69
EXTRACT HYDRAULIC RUN [illegible] WITH 0.50 HOUR TIME STEP
THIS EXTRACT USED TO CHECKOUT [illegible]-BOD-DO-CHLOROPHYLL A MODEL 6-28-72
```

******* FROM HYDRAULICS PROGRAM ******* START CYCLE	STOP CYCLE	TIME INTERVAL	HYDRAULIC CYCLES PER QUALITY CYCLE	TIME INTERVAL IN QUALITY PROGRAM
1500	2000	90 SECONDS	20	0.50 HOURS

CHANNEL NUMBER	RET FLOW (CFS)	MIN (CFS)	MAX (CFS)	MIN (CFS)	MAX (CFS)	MIN (SQ. FT.)	MAX (SQ. FT.)	AVE (SQ. FT.)
1	7899.61	-8035.88	-7615.91	-2.227	-1.906	3553.5	4129.5	3885.4
2	7899.59	6199.83	8721.11	0.250	0.348	23943.0	26036.2	24969.3
3	7899.54	4694.50	9458.39	0.143	0.288	31347.8	33845.4	
4	7899.55	3271.37	10160.14	0.139	0.440	21334.7		
5	7899.52	1809.24	10896.05	0.068	0.444			
6	7899.46	-771.61	122226.08	-0.048				
7	7899.43	-3345.44	13624.51					
8	7899.34	-6898.50	15641.11					
9	7899.07	-22077.80						
10	7899.08	-24206.88						
11	7899.02							
12	7898.09							

NOTE: Not all of the Printout reproduced.

Output from the Hydrodynamic Subprogram is used directly by the Estuary Quality Subprogram which calculates the constituent levels for each segment of the estuary. The Estuary Quality Subprogram simulates constituent concentration for selected intervals of the twenty-four hour tidal cycle:

```
********************** QUALITY SUMMARY *******************

SUMMARY STARTS AT                       SUMMARY ENDS AT
CYCLE 575   (11 DAYS 23.5 HOURS)  CYCLE 600 (12 DAYS 12.0 HOURS)
```

CONSTITUENT NUMBER

1 NH3-MG/L DECAY = 0.23/DAY

2 BOD-5 MG/L DECAY = .17

3 DO MG/L R2 = 1

4 CHLOROPHYL

5 NO3 DECAY = .09

	** CONSTITUBNT NO 1 **			** CONSTITUENT NO 2 **			** CONSTITUENT NO 3 **			** CONSTITUENT NO 4 **			** CONSTITUENT NO 5 **		
SEGM	MIN.	MAX.	AVE.	MIN.	MAX.	AVE.	MIN.	MAX.	AVE.	MIN.	MAX	AVE.	MIN.	MAX.	AVE.
1	0.20	0.20	0.20	2.00	2.00	2.00	7.00	7.00	7.00	7.00	7.00	7.00	0.01	0.01	0.01
2	0.02	0.02	0.02	7.79	7.80	7.80	6.92	7.00	6.96	19.05	19.07	19.06	0.01	0.01	0.01
3	0.02	0.02	0.02	7.31	7.34	7.33	5.83	5.88	5.85	18.91	18.98	18.92	0.01	0.01	0.01
4	0.02	0.02	0.02	6.80	6.86	6.83	5.20	5.31	5.75	19.32	19.39	19.36			
5	0.02	0.02	0.02	8.61	9.40	8.92	5.34	5.48	5.41	13.80	15.48	14.83			
6	0.02	0.02	0.02	8.84	9.22	9.00	4.80	5.01	4.99	14.13	15.04	1463			
7	0.02	0.02	0.02	8.60	8.97	8.79	4.19	4.52	4.36						
8	0.02	0.02	0.02	8.26	8.49	8.38	3.90	4.55	4.21						
9	0.01	0.02	0.02	8.70	9.20	8.97									
10	0.01	0.05	0.02	8.64											
11	0.02	0.19	0.05	8.45											
12	0.01	0.43													

NOTE: Not all of the Printout reproduced.

To display the output data of the Receiving Water Component, three-dimensional estuary profiles showing constituent concentrations by estuary mile and time, and tables of dissolved oxygen response of the estuary are produced. The storm event is simulated to occur during one tidal day starting twelve and one-half hours after the start of the quality simulation. The condition of the estuary after 300 hours of the quality simulation is assumed to represent a steady state condition which occurs once the storm's effects have been dissipated in the estuary.

Figure 23 shows a generalized version of the three-dimensional estuary profiles produced by the Estuary Quality Subprogram of the Receiving Water Component. The large pollutant loads that are induced at hour 12.5 are dissipated by dilution, oxidation, ingestion and predation processes as they are moved downstream by water entering the estuary at statute mile zero. The characteristics of the estuary along the first fifty miles of its length are shown along the wall of the three dimensional box nearest the viewer. Three-dimensional estuary profiles are produced for the following constituents: biochemical oxygen demand (BOD), nitrate (NO_3), ammonia (NH_3),chlorophyll "a", and dissolved oxygen (DO). The relationship of these five constituents in the estuary quality model is shown in Figure 12.

In addition to the three-dimensional estuary profiles, the Receiving Water Component outputs a summary table of the dissolved oxygen response of the estuary as follows:

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS
FOR SELECTED AREAWIDE WATER RESOURCES MANAGEMENT STRATEGY

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH (KM.)	RIVER VOLUME (CU. KM.)	RIVER SURFACE (SQ. KM.)
	**** DURATION = 12. HOURS ****		
	28.355	0.115	26.657
1.0	33.337	0.153	34.346
2.0	33.337	0.153	34.346
3.0	35.494	0.153	34.820
4.0	42.261	0.219	46.209
5.0	59.690	0.504	105.583
6.0	80.571	0.887	
7.0	82.953	0.888	
8.0	82.953	0.888	
9.0	82.953	0.888	
10.0			
	**** DURATION = 24. HOURS ****		
	25.218	0.093	
1.0	28.356	0.115	
2.0	33.337		
3.0	35.494		
4.0	42.261		
5.0			
	**** DURATION = 48. HOURS		

NOTE: Not all of the Printout reproduced.

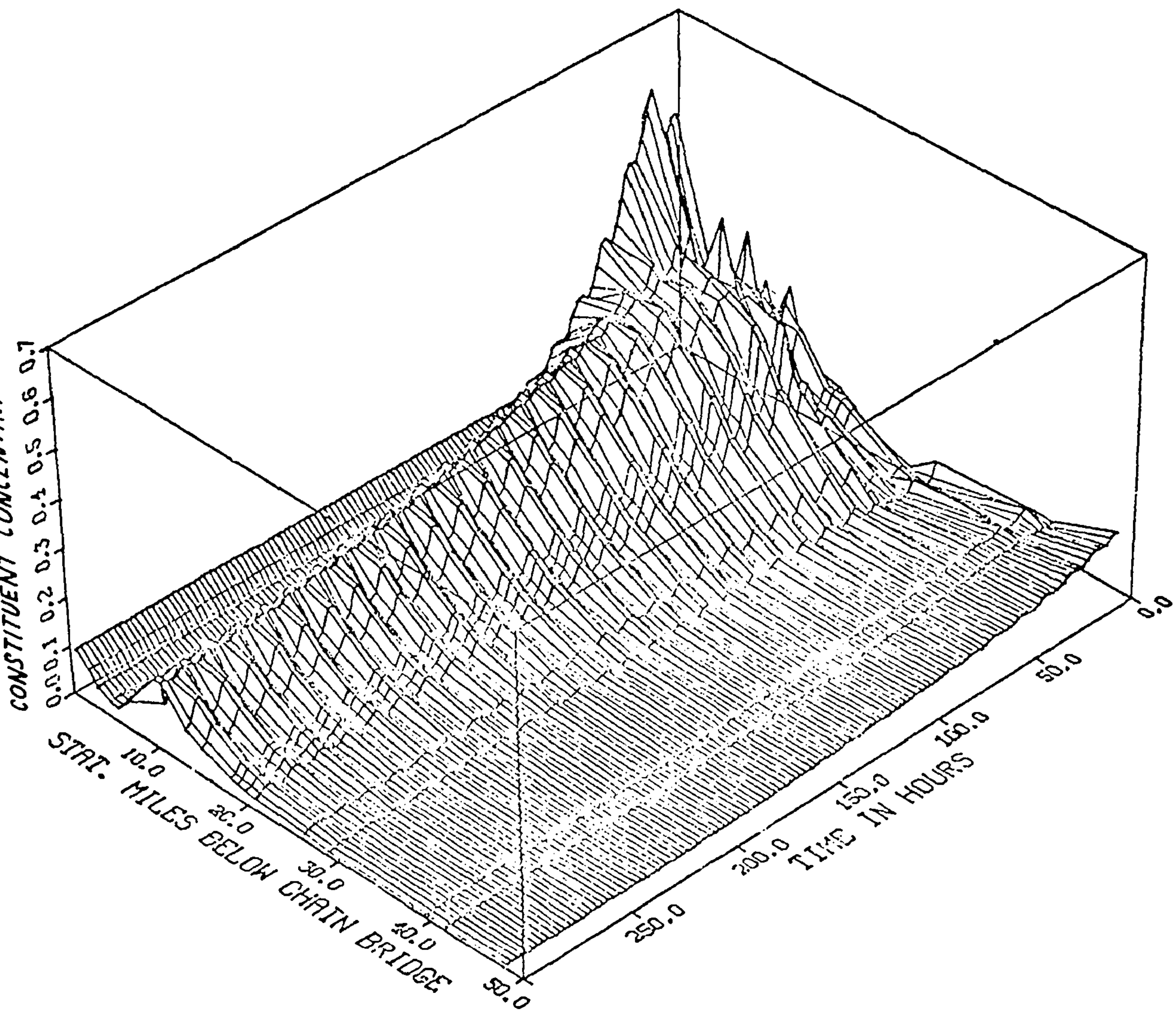


Figure 23 EXAMPLE OF THREE-DIMENSIONAL ESTUARY PROFILE FROM THE RECEIVING WATER COMPONENT

SIMULATION AND COMPARISON OF AREAWIDE WATER RESOURCES MANAGEMENT STRATEGIES FOR 1992

General Description of Areawide Strategies

To demonstrate the full Framework Model capabilities, six areawide water resources management strategies have been simulated for the metropolitan Washington region for the year 1992. These strategies were selected in Chapter II from the "Options For Action" in water resources identified during the MWCOG Year 2000 Policies Plan Reexamination. The six strategies were chosen to reveal the water quality impacts of applying different treatment efficiencies, and different public policies that influence the use of water resources. All strategies with the exception of strategy No. 5 are in various stages of consideration within the region.

The six strategies are summarized in Table 9 by displaying the conditions simulated in each. These strategies assumed that certain facilities or practices that would influence either wastewater, stormwater, or water supply would be applied in the region in 1992. It is important to note that strategies were chosen to illustrate the Framework Model's use and that assumptions made in forming each strategy can change to permit different assumptions to be tested.

Water Quality Effects of Each Areawide Strategy

In this section a detailed description of the conditions simulated and the resulting water quality effects of each alternative are presented. The three-dimensional estuary profiles of five constituents for each areawide strategy are displayed.

Strategy No. 1: Secondary Waste Treatment

This strategy assumed that all major wastewater treatment plants discharging directly or to tributaries of the Potomac would treat wastes to secondary treatment levels. (85% BOD removal efficiency; 13:3 mg/l. NH_3 and 1.0 mg/l DO effluent concentrations). The simulation of this treatment strategy was undertaken to provide a base from which to assess the gains to be expected from the application of more advanced

Table 9
CONDITIONS SIMULATED FOR AREAWIDE WATER RESOURCES MANAGEMENT STRATEGIES

Simulated Conditions / Areawide Strategies	Land Use	Water			Wastewater		Stormwater		Estuary
	Development Pattern (from Community Development Component)[119]*	Potomac River flow above water intakes	Water Demands (from Water Demand Component)[132]	Flow into Potomac Estuary	Sewage Flows (from Sewage Generation Component)[133]	Treatment level at municipal plants (from Waste Treatment Mgt. Component)[66]	Storm Event[51]	Stormwater Treatment level (from Waste Treatment Mgt. Component)	Simulation Length (of Receiving Water Component)
1. Secondary Waste Treatment	EMPIRIC Alternative 6.2 modified for 1992	1954 cubic feet per second (cfs)	1000 cfs (647 MGD)	954 cfs	769 cfs (496 MGD)	Secondary treatment=85% BOD removal; & effluent concentration DO: 1 mg/l NH_3:13.3 mg/l	First decile storm with volume=1.83" frequency ≥ 8.62 storms per year	None	3 times BOD half-life ≃ 12 days at 20°C
2. Advanced Waste Treatment	"	"	"	"	"	AWT effluent concentration = BOD:5 mg/l DO:5 mg/l NH_3:1 mg/l	"	None	"
3. Stormwater Treatment	"	"	"	"	"	"	"	50% BOD removal from 1st decile storm	"
4. Water Conservation	"	1902 cfs	948 cfs	"	715 cfs	"	"	None	"
5. Dry Waste Collection	"	1797 cfs	843 cfs	"	622 cfs	AWT for sewage flows before 1976. Non-water carried waste removal for construction after 1976	"	None	"
6. Indirect Estuary Re-use	"	551 cfs	860 cfs	-309 cfs (estuary withdrawal)	653 cfs	AWT	"	None	"

* Sources of data indicated by reference number.

forms of treatment or management practices. Combined sewer flows were assumed to be treated to secondary standards, although stormwater not flowing to combined systems was not assumed to be treated. The pattern of urban development was simulated for the year 1992 using Empiric Alternative 6.2 modified,[119] and this pattern influenced the amount of water demand (1000 cfs) waste generation, (including infiltration 769 cfs) and the quantities of runoff expected from storms.

A "first decile" storm (volume = 1.83 in, frequency 8.62 per year at 60% confidence level)[51] was assumed to occur during the period simulated.

An attempt was made to simulate river flow conditions. The seven-day ten-year low flow is that natural flow entering the upper Potomac Estuary from upstream which is expected to occur for a seven-day period once every ten years. The seven-day ten-year low flow is the standard used by the States of Maryland, Virginia, and the District of Columbia to determine the assimilative capacity for water quality aspects. The seven-day ten-year low flow into the region before water withdrawals is 954 cfs,[73] and this is less than the projected water demand in 1992 (1000 cfs). This fact caused the project team to choose between simulating a negative river flow (involving estuary withdrawal for water supply) or changing the assumed river flow or the assumed water supply system.

Because estuary withdrawal was an emergency strategy that would be simulated separately (Strategy No. 6), and additions to the water supply would mean a choice between several incomplete proposals to augment the metropolitan reservoir system, it was decided to simulate a greater Potomac River flow condition. It was decided that a total flow at the upper boundary of the metropolitan region of 1954 cfs would permit 1000 cfs of annual average day water supply to be withdrawn and still allow 954 cfs to enter the estuary. This flow for seven consecutive days has a recurrence interval of approximately 1.8 years.[73] Thus, the flow condition simulated is not an extreme case but one experienced generally every other year in the region. The resulting three-dimensional estuary profiles are therefore representative of normal rather than extreme hydrologic conditions of the river.

Figure 24 contains the three-dimensional estuary profiles of

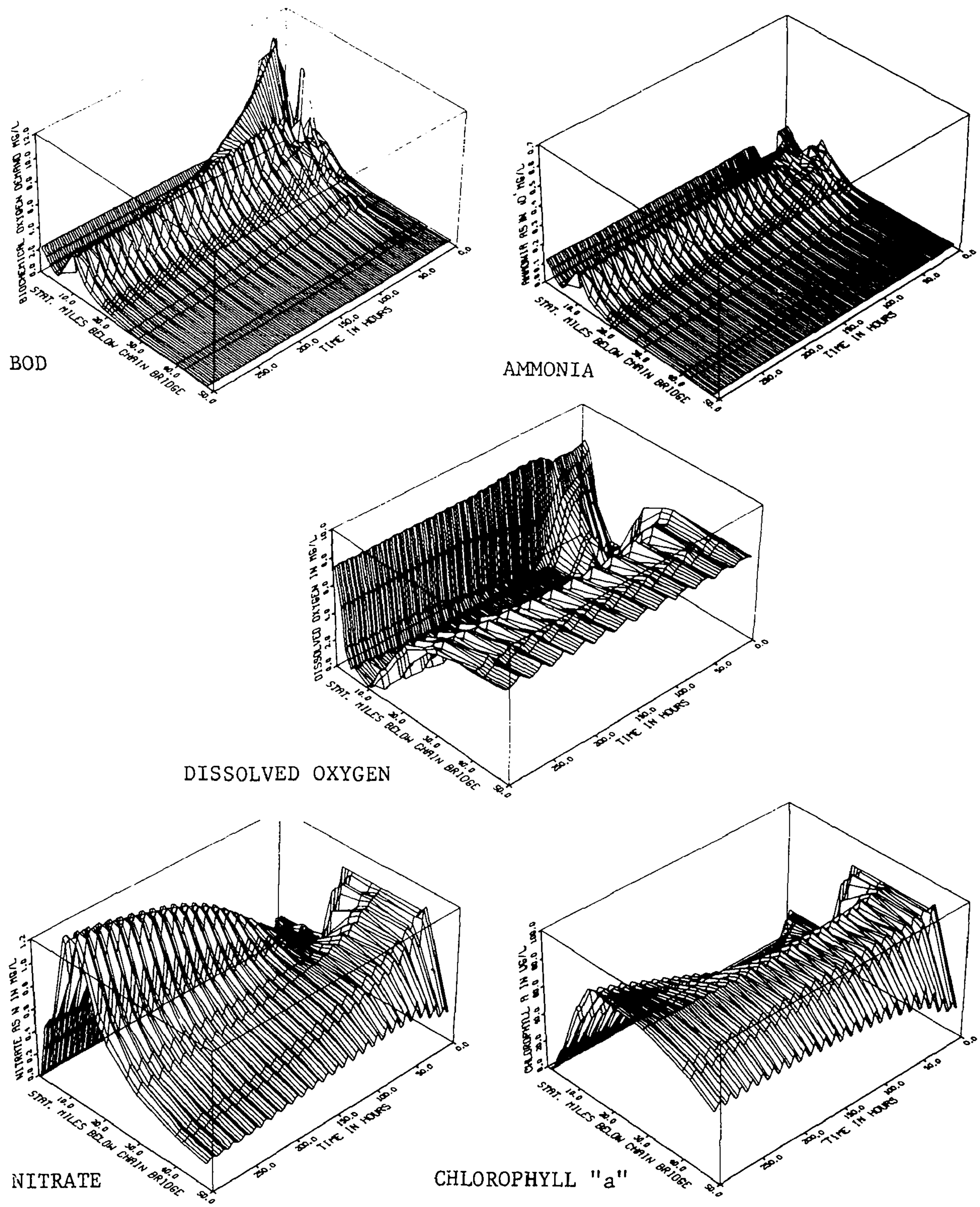


Figure 24 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 1
SECONDARY WASTE TREATMENT

the upper Potomac Estuary's response to the conditions simulated. The profiles show that significant BOD loads are washed into the estuary during a first decile storm over the fifty-three urban metropolitan area watersheds tributary to the Potomac when compared to treated wastewater BOD loads. During steady state, dry weather conditions, the major source of BOD and ammonia are the treatment plants in the upper estuary. Dissolved oxygen concentrations are shown to be depressed significantly below standards by both the storm and the dry weather waste discharges, and by the dry weather waste discharges alone.

Strategy No.2 Advanced Waste Treatment

This strategy assumed identical conditions of 1992 community development as the secondary treatment strategy, but wastes (including combined sewer flows) were assumed to be treated to advanced waste treatment (AWT) standards (5.0 mg/l DO, 5 mg/l BOD_5, and 1 mg/l NH_3 effluent concentrations). A first decile storm was also assumed. The three-dimensional estuary profiles in Figure 25 show that the effects of the untreated storm are nearly as great in Strategy No.2 as in Strategy No.1. However, the dry weather flow condition did not depress the dissolved oxygen levels to the same extent. Dissolved oxygen levels were still below standards in the neighborhood of the treatment plant outfalls in the upper Potomac estuary. Advanced Waste Treatment was assumed as the basis for the subsequent simulations of the water resource system in the region in Strategies No.3 through No.6.

Strategy No.3 Stormwater Treatment

The first two strategies simulated illustrated the important impact of untreated stormwater on the dissolved oxygen in the estuary. It was shown that the stormwaters were washed into the estuary where they remained until degraded. Because of relatively low estuary flows they were not washed downstream into the greater volumes of the expanding estuary where they would have been diluted. The third strategy simulated the treatment of both storm and sanitary wastewater in order to show that the treatment of storms could contribute significantly to improved water quality. Wastewater was assumed treated to the AWT standards simulated in Strategy No.2.

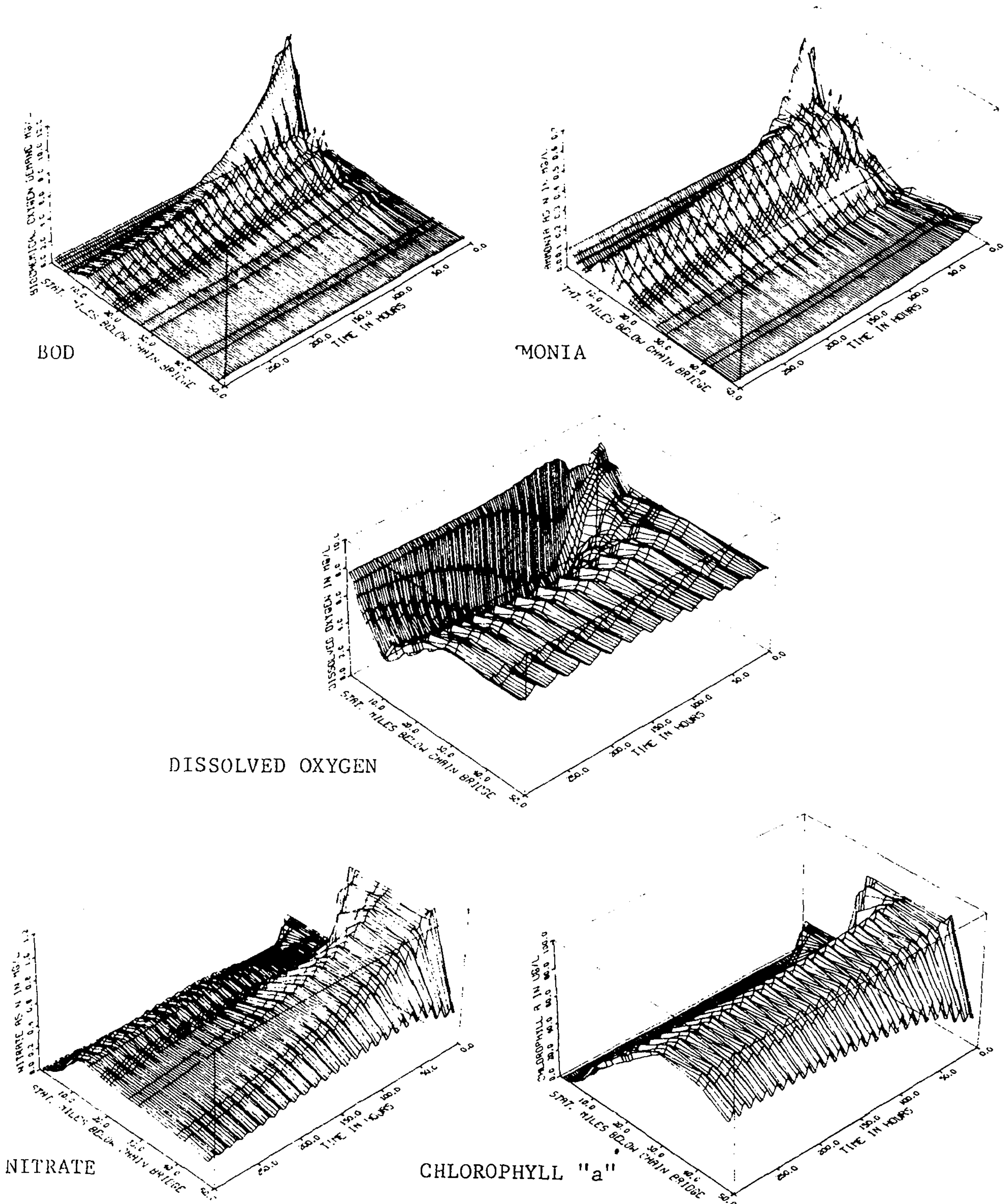


Figure 25 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 2
ADVANCED WASTE TREATEMENT

A stormwater treatment efficiency of 50 percent removal from a first decile storm for both BOD and NH_3 was simulated. It was computed assuming a greater degree of treatment on the watersheds projected to have the highest stormwater BOD concentration in 1992. It was found that treating the 19 watersheds with the highest stormwater BOD concentration at a 60% BOD removal efficiency would be equivalent to removing 50 percent of the BOD load from all 53 watersheds in the region directly tributary to the Potomac River. Because control measures for storm flows from these 19 watersheds would be constructed in built-up areas where large facilities would be difficult to locate, the removal of this pollution load was assumed to be accomplished with four hundred and forty 20 mgd stormwater treatment units comprised of a combination of bar racks, micro strainers, dissolved air flotation, and surface detention for 25% of first decile storm runoff. This assumption was made to facilitate cost estimates of stormwater treatment and did not alter simulated storm discharge points.

The results of this simulation are shown in Figure 26. The profiles reveal that the BOD loads to the estuary are greatly reduced during storms, but that water quality in the estuary fails to meet state-adopted water quality standards, although the model predicts the least violation when compared to the strategies simulated. The importance of this simulation is that it appears to point the way toward an important mechanism for improving water quality and an area in which model techniques should be refined to permit further analysis.

Strategy No.4 Water Conservation

The fourth strategy simulated the application of water conservation measures which have been proposed through the Council of Governments as a mechanism for reducing the ever-increasing demands imposed on the unregulated Potomac River. At the time of the simulation, code changes requiring installation of water saving devices in new construction were being adopted by local and state governments in the area. The plumbing code changes would reduce water used in toilets, showers and in faucets in residential and commercial establishments in new construction and in rehabilitation. These policies were modeled as being enforced after the year 1976, but only in new construction in the region since the future rate of renovation was not known. New residential, commercial

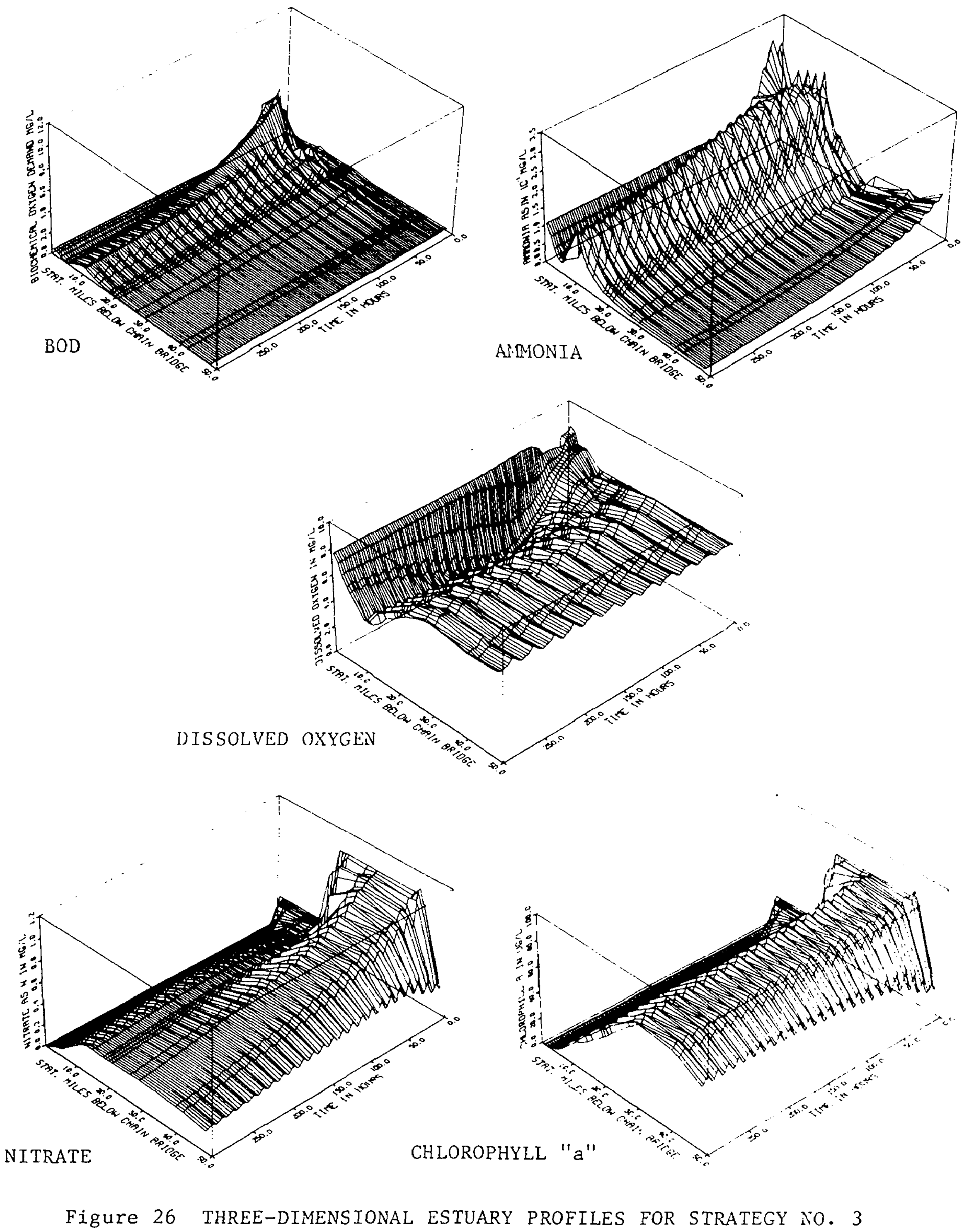


Figure 26 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 3
STORMWATER TREATMENT

and industrial construction was projected using the EMPIRIC model. Overall annual average day water demand in the year 1992 was projected to be 948 cfs, down from the 1000 cfs projected without water conservation measures. Water use in residential, commercial and industrial establishments was assumed to be reduced twenty percent, but major use categories such as public and unaccounted for demands and residential sprinkling were not considered to be reduced by these plumbing code changes.

Sewer infiltration/inflow was assumed to be reduced seven percent by implementation of stricter construction specifications and inspection programs. The combination of reduced water use and reduced sewer infiltration resulted in wastewater quantities of 715 cfs, down from 769 cfs in previous simulations. Advanced waste treatment was assumed for all wastewater flows and combined sewer flows. A first decile storm was also assumed, without stormwater treatment.

The reaction of the estuary to the discharges of reduced quantities of wastewater was not significantly different from its reaction to the second strategy simulated. This is shown in the estuary profiles in Figure 27. It should be remembered, however, that the Strategy No.4 is less expensive because it defers the staging of treatment capacity (both water and wastewater). The costs of the alternative strategies are discussed later in this chapter.

Strategy No.5 Dry Waste Collection

Wastewater treatment is simply a method of removing contaminants from water, and the question is often asked; why put wastes into water in the first place? Aside from the mechanical simplicity of the current water-carried system, it appears to have little logic because it involves mixing things together only to separate them again. To test the effects on the estuary of a hypothetical program of non-water carried waste disposal, a "dry" waste collection system was simulated for all new construction beyond 1976. All sewage flows generated before 1976 and combined sewer flows are assumed to be treated to Advanced Waste Treatment standards.

The system could involve direct collection by truck, incinerating toilets, or the universal use of functioning septic systems; the exact system was not specified. A parallel water-carried system for bathwater and other relatively clean

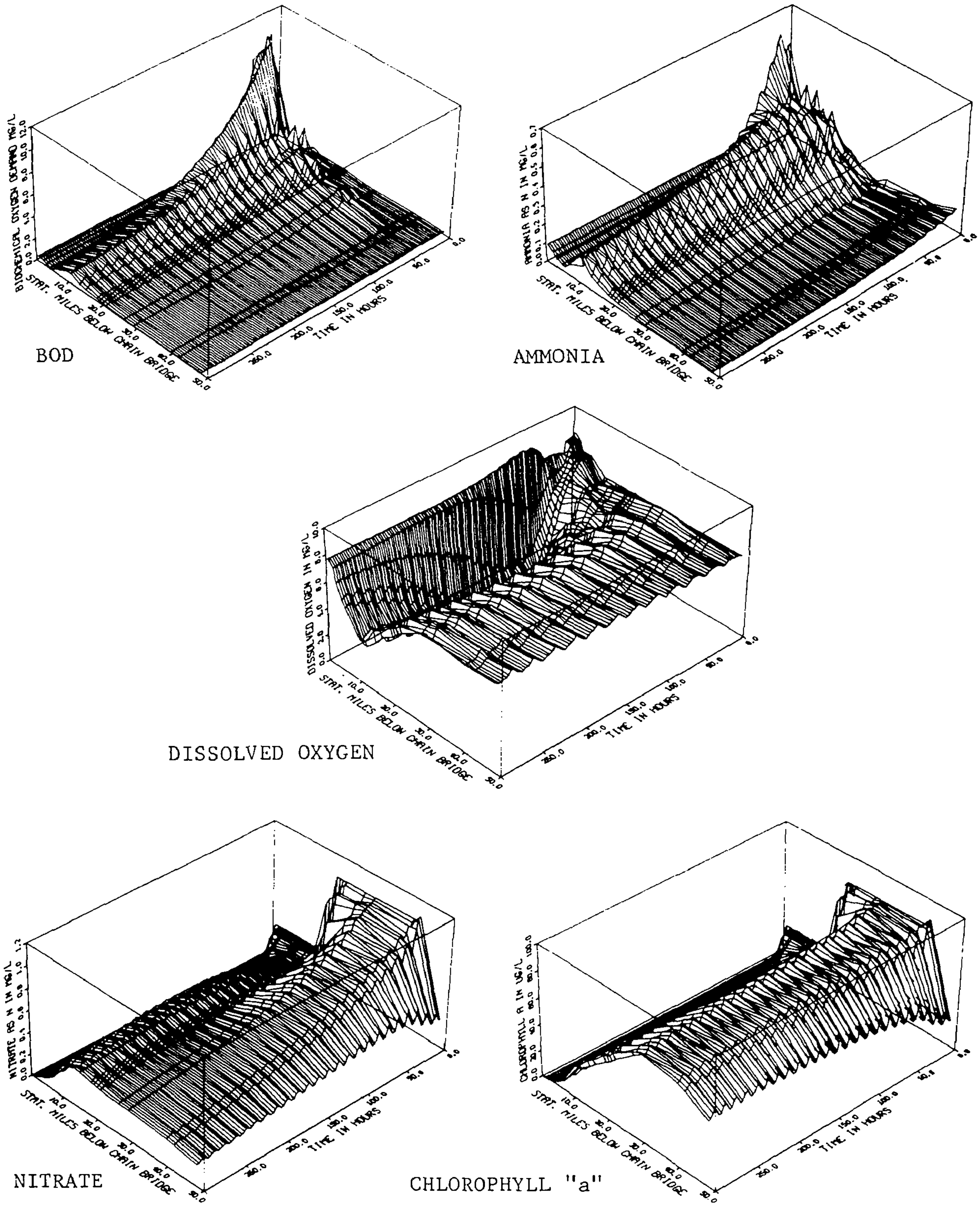


Figure 27 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 4
WATER CONSERVATION

water discharges from homes and commercial establishments was assumed. The system was assumed to be instituted in a manner similar to the water conservation measures simulated in Strategy No.4. New construction between the years 1976 and 1992 would contain "dry" systems. Water conservation through plumbing modifications would also be practices, although the benefits attributed to toilets using less water could not be credited to this strategy. As with all other alternatives, a first decile storm was assumed, in this case without storm-water treatment.

The results of the simulation contained in Figure 28 show almost no improvement in water quality as a result of this strategy when compared to the AWT Strategy (Strategy No.2). The removal efficiency of AWT resulting in the following effluent concentrations: 5 mg/l BOD_5, 1 mg/l NH_3, 5.0 mg/l dissolved oxygen, was simply too high to make changes in wastewater flows a sensitive variable. Use of "dry systems" for more than the '76-'92 growth portion of the region's population could be expected to show an improvement. If secondary treatment of remaining wastewater flows had been assumed, a greater degree of improvement would doubtless also have been observed. For the high levels of treatment used in both the AWT Strategy (Strategy No.2) and the Dry Waste Collection Strategy (Strategy No.5) the effect of the storm-introduced constituents appears to control the estuary dissolved oxygen levels.

Strategy No.6 Indirect Estuary Re-use

Proposals to use water from the upper portion of the Potomac Estuary as an emergency supply of water provided impetus for formulating this strategy. The prospect of emergency estuary reuse has been considered in previous studies from the water supply standpoint and by Congressional mandate must be further examined.[104]

The simulation of this strategy assumed that water needs would be reduced by plumbing code changes to effect water conservation as in Strategy No.4. It also assumed that the emergency water use restrictions included in the Water Shortage Emergency Plan adopted by the Council of Governments would be imposed to reduce residential domestic (inhouse) demand and sprinkling demand an additional 15 percent of the currently projected 1992 figure for Strategy No.1. An average annual day water demand of 860 cfs therefore was projected to be supplied through withdrawals from the free flowing portion of the river (551 cfs) and from the estuary, (309 cfs).

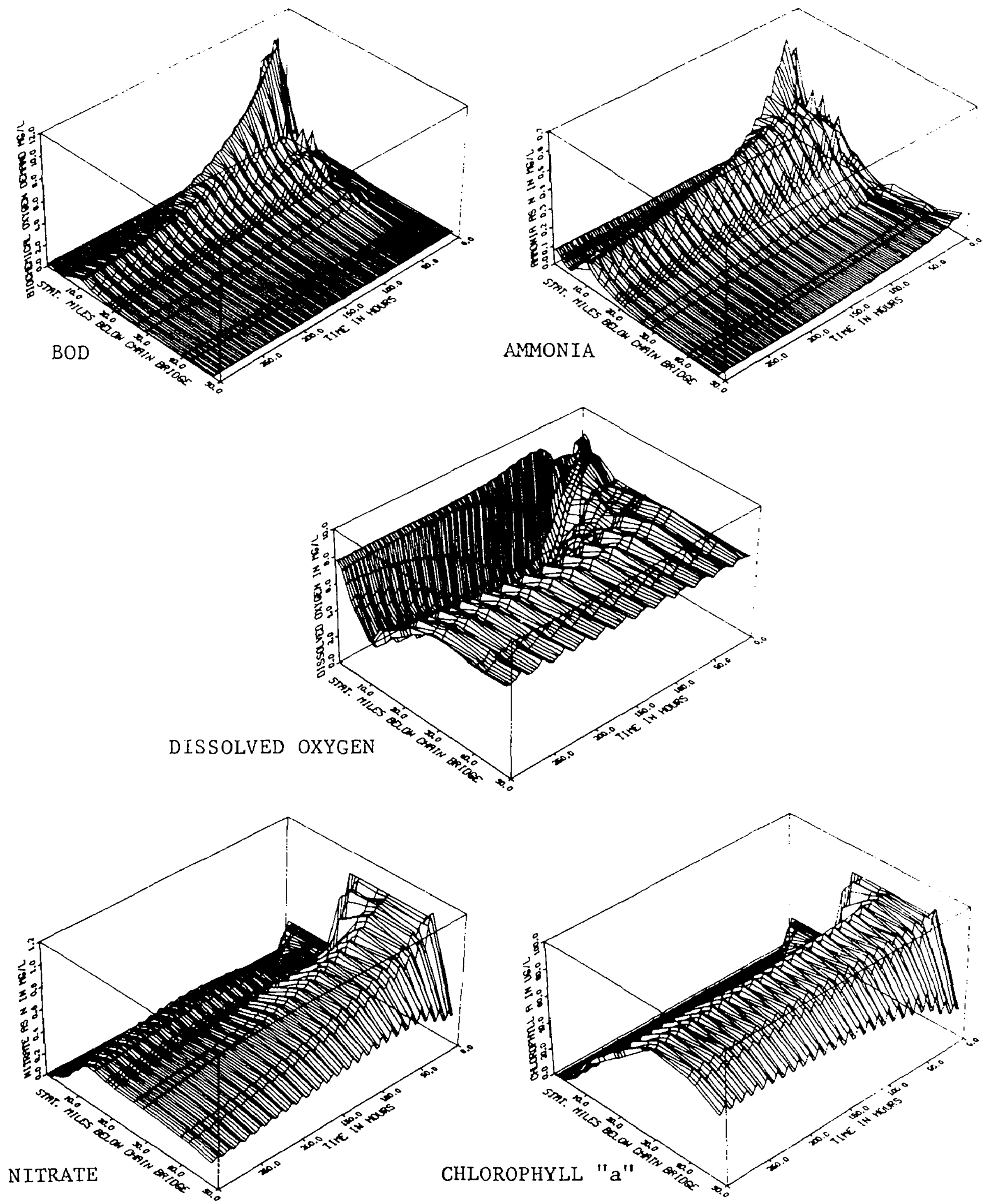


Figure 28 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 5
DRY WASTE COLLECTION

Under the conditions simulated, the conditions of low dissolved oxygen normally expected several miles below the head of the estuary are seen to move toward the intake in the estuary. Dissolved oxygen levels in the neighborhood of the treatment plants on the estuary actually appear to be improved as the result of the upstream movement of waters which have provided significant dilution to waste discharges. The results of the simulation of this strategy are shown in Figure 29.

Comparison of "Capability" of Areawide Strategies

In the discussion of the Water Quality Objectives Element in Chapter III, the "capability" of an areawide water resources management strategy is defined as the extent of a constituent concentration of less than or equal to a stated constituent concentration for greater than or equal to a stated duration. For the comparison of areawide strategies in this chapter, the constituent chosen for analysis is dissolved oxygen. One reason for this is that there are state-adopted standards for permissible minimum dissolved oxygen levels in the Potomac Estuary.

The extent measure selected for investigation is the length of estuary affected in kilometers because it represents a barrier to the movement of aquatic life and serves as a measure of the potential aesthetic effects from degraded water quality. A ninety-six hour duration was chosen so that the "capability" of each alternative could be compared if desired with 96 hour median tolerance limit data for both aquatic species and the associated species in their food chain. Such a comparison was not made as part of this study, however.

For each areawide strategy under investigation, the Receiving Water Component produced a computer-printed table of the extent of the Potomac Estuary affected (in area, volume, and length) by various levels of dissolved oxygen for various durations. For Strategies No.1 through No.6, these summary tables are presented in Appendix A as Tables No.A-1 through No.A-6, respectively. Using the information contained in the Appendix tables, Table 10 was prepared to present a comparison of the "capability" of the six areawide water resources management strategies. "Capability" is the length of the Potomac Estuary in kilometers at less than or equal to the stated dissolved oxygen levels for greater than or equal to

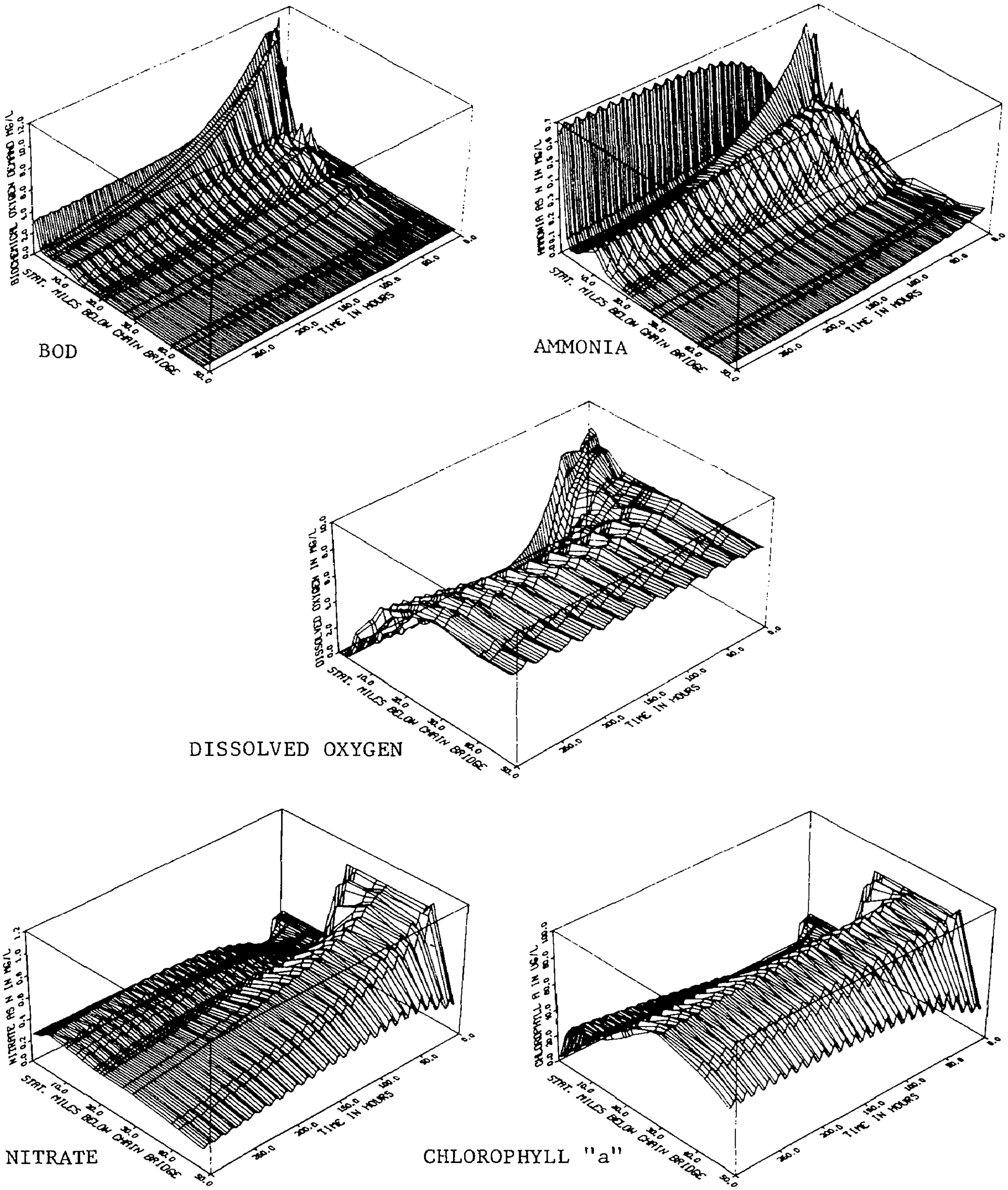


Figure 29 THREE-DIMENSIONAL ESTUARY PROFILES FOR STRATEGY NO. 6 INDIRECT ESTUARY RE-USE

Table 10
COMPARISON OF "CAPABILITY" OF AREAWIDE STRATEGIES

Areawide Strategy	"Capability" as Length of Potomac Estuary in Kilometers At ≤ stated dissolved oxygen levels for duration of ≥ 96 hours					Values taken from Table:
	Dissolved Oxygen Level, mg/l					
	1	2	3	4	5	
1. Secondary Waste Treatment	22.2	26.8	33.3	33.3	42.3	Table A-1 in Appendix A
2. Advanced Waste Treatment	6.3	13.3	16.8	22.2	28.4	Table A-2
3. Stormwater Treatment	0	0	8.3	13.3	22.2	Table A-3
4. Water Conservation	6.3	13.3	16.8	22.2	28.4	Table A-4
5. Dry Waste Collection	6.3	13.3	13.3	22.2	28.4	Table A-5
6. Indirect Estuary Reuse	12.3	12.3	19.3	26.7	29.8	Table A-6

Note that the lower the length of estuary affected, the better the capability of a strategy.

ninety-six hours. Note that for the strategy with the least number of kilometers of estuary affected for a stated dissolved oxygen level, the better is the "capability" of that strategy.

Thus, according to Table 10, for less than or equal to a concentration of four milligrams per liter dissolved oxygen, Strategy No.3, Stormwater Treatment, has significantly better "capability", although still violating the State-adopted standard that dissolved oxygen levels must never fall below four milligrams per liter.

Probability of Occurrence of Simulated Conditions

To perform a simulation using the Framework Model, assumptions must be made concerning such conditions as the expected Potomac River flow entering the region, the expected storm flow, the expected water demand withdrawals, the expected community development pattern, the reliability of treatment works to perform as simulated, and other conditions. It is important, as explained in the Water Quality Objectives Element, to consider the joint probability of occurrence of these simulated events for the period modeled.

For this comparison of areawide water resources management strategies, only the first two simulation conditions listed above, the Potomac River flow and ths storm flow, have been assigned probabilities of occurrence, primarily because these numbers were easily obtainable. These are shown as Event A and Event B in Table 11. All other simulation conditions have been grouped into Event C and assigned a constant probability of occurrence in the table. For simplicity this number was chosen as 1.0. In further applications of this methodology it is recommended that probabilities of occurrence be derived for other simulation conditions, such as the reliability of untested waste treatment works versus secondary treatment works, or the probability that the water demand withdrawal will be greater than or equal to the projected water demand.

In Table 11, Event A is defined as the Potomac River flow entering at the upper boundary of the metropolitan region being less than or equal to the simulated flow. This simulated flow equals the sum of the flow entering the estuary (954 cubic feet per second) plus the projected average daily water demand withdrawn upstream of the estuary (1000 cfs for

Table 11
COMPARISON OF "JOINT PROBABILITY OF OCCURRENCE" OF SIMULATED CONDITIONS

Areawide Strategy[3]	"Probability of Occurrence" for any seven consecutive days during a one year period[1] Event A Potomac River Flow[2] ≤ Simulated Flow	Event B Storm Flow ≥ First Decile Storm Flow	Event C Other Conditions = Simulated Conditions[4]	"Joint Probability of Occurrence" of Events A, B & C for any consecutive 7 days during a period of 1 year
1. Secondary Waste Treatment	0.55	0.15	1.0	0.083
2. Advanced Waste Treatment	0.55	0.15	1.0	0.083
3. Stormwater Treatment	0.55	0.15	1.0	0.083
4. Water Conservation	0.54	0.15	1.0	0.081
5. Dry Waste Collection	0.53	0.15	1.0	0.080

1) At 60 percent confidence

2) Before withdrawals for water supply

3) In this comparison and the comparison of effectiveness it is assumed that water withdrawals will not reduce the Potomac River inflow to the estuary to less than the provision of 954 cfs flow and quality conditions simulated. As Strategy No. 6 does not meet this condition it is not included for further comparison.

4) See text for discussion of other conditions

Strategies 1 through 3, less for Strategies 4 and 5).

This simulated flow of 1954 cfs for the first three strategies has a recurrence interval, for a seven-day consecutive period, of 1.8 years.[73] The probability of occurrence of the Potomac River flow being less than or equal to the simulated flow is simply the reciprocal of the recurrence interval, or 0.55. Because Strategy No.6, Indirect Estuary Reuse, does not assume 954 cfs enters the estuary, it is not included for further comparison.

The probability of occurrence of Event B, the storm flow being greater than or equal to the first decile storm, was determined from the results of the Rainfall Analysis Model of the Stormwater Runoff Component[2], and is equal to 0.15 for all strategies tested.

The product of each of these event probabilities, if one assumes the events are independent, is the joint probability of occurrence of all of these events during the same time period. A detailed investigation to verify that these events are independent was not part of the study. The resulting joint probability of occurrence of the factors considered for each strategy is shown in Table 11.

Comparison of "Effectiveness" of Areawide Strategies

The product of the 'joint probability of occurrence" and the "capability" is the expected "effectiveness" of an areawide water resources management strategy. Utilizing the values for capability contained in Table 10, and the joint probability of occurrence from Table 11, Table 12 presents the effectiveness of the five strategies. This table shows that effectiveness is the length of Potomac Estuary in kilometers at less than or equal to the stated dissolved oxygen levels for greater than or equal to 96 hours due to the joint occurrence of stated river flow, storm flow, and other conditions for seven consecutive days during a one-year period.

This table illustrates that even with Strategy No.3, Stormwater Treatment, more than one kilometer of the Potomac Estuary would be expected to experience dissolved oxygen levels at or below four milligrams per liter during the period modeled. The Advanced Waste Treatment (No.2), the Water Conservation (No.4), and the Dry Collection (No.5) Strategies

Table 12
COMPARISON OF "EFFECTIVENESS" OF AREAWIDE STRATEGIES

Areawide Strategy	"Capability" as length of Potomac Estuary in kilometers at ≤ stated dissolved oxygen levels for duration of ≥ 96 hours (from Table 10) Dissolved Oxygen Level, mg/1					"Joint Probability of Occurrence" of Events A, B & C for any consecutive 7 days during a period of 1 year (from Table 11)	"Effectiveness" as length of Potomac Estuary in kilometers at ≤ stated dissolved oxygen levels for ≥ 96 hours due to joint occurrence of stated river flow, storm flow and water withdrawals for 7 consecutive days during a 1 year period Dissolved Oxygen Level, mg/1				
	1	2	3	4	5		1	2	3	4	5
1. Secondary Waste Treatment	22.2	26.8	33.3	33.3	42.3	0.083	1.9	2.2	2.8	2.8	3.5
2. Advanced Waste Treatment	6.3	13.3	16.8	22.2	28.4	0.083	0.5	1.1	1.4	1.8	2.4
3. Stormwater Treatment	0	0	8.3	13.3	22.2	0.083	0	0	0.7	1.1	1.8
4. Water Conservation	6.3	13.3	16.8	22.2	28.4	0.081	0.5	1.1	1.1	1.8	2.3
5. Dry Waste Collection	6.3	13.3	13.3	22.2	28.4	0.080	0.5	1.1	1.4	1.8	2.3

See footnotes in Table 11. Note that the lower the length of estuary affected, the better the effectiveness of a strategy.

all have the same expected "effectiveness", but all are significantly better than Strategy No.1, Secondary Waste Treatment.

Table 12 therefore demonstrates that, although none of the strategies simulated can achieve the adopted water quality standard for dissolved oxygen, certain strategies are more effective than others for gaining incremental water quality improvements. The strategies differ not only in effectiveness, however, but also in cost.

Comparison of Cost of Areawide Strategies

The present value of each of the alternative strategies is summarized by cost element in Table 13. This table was developed using the methodology contained in the Cost Element described in Chapter III, and the assumptions detailed in Appendix E. The costs are expressed as the present value of capital, fixed operation and maintenance (O & M), variable O & M base element, and variable O & M growth element costs of each strategy for the planning period July 1, 1976 through June 30, 1992 in millions of January 1974 dollars.

The strategy with the lowest total present value is Strategy No.1, Secondary Treatment. By far the strategy with the highest total present value is Strategy No.3, Stormwater Treatment. By analyzing the total present value from Table 13 and the effectiveness from Table 12, the relative cost-effectiveness of the areawide strategies can be determined.

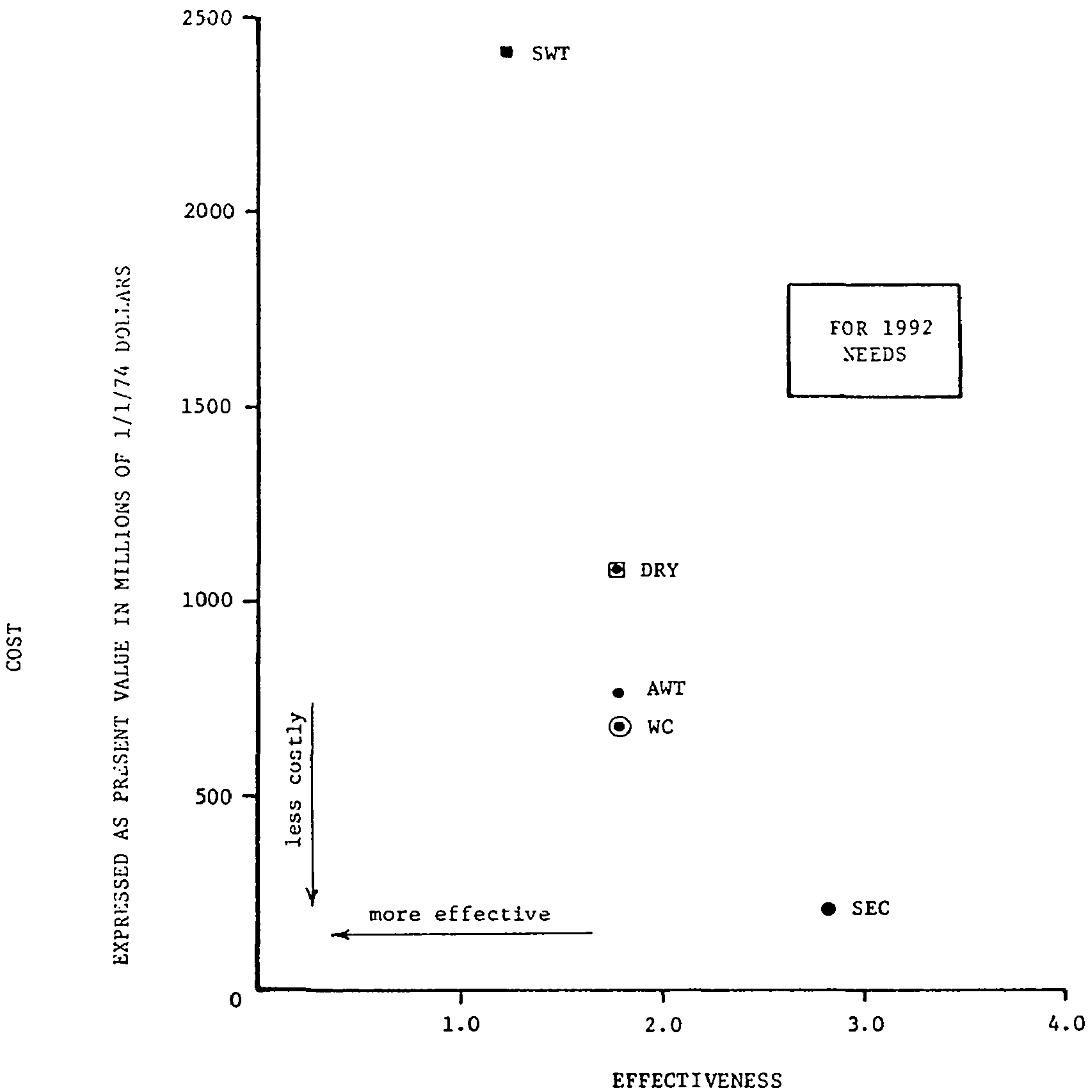
Comparison of Cost-Effectiveness of Areawide Strategies

The cost-effectiveness of each of the areawide water resources management strategies is shown in Figure 30. The chart shows that as less kilometers of the estuary are affected by depressed dissolved oxygen levels, the costs of the strategies employed to gain this improvement rise. Another conclusion that can be reached from an analysis of the chart is that the Water Conservation Strategy is more cost-effective than either the Advanced Waste Treatment or Dry Collection Strategies, even though all three have the same effectiveness. The chart also shows that the strategy which results in the greatest increment of effectiveness for the least increment of cost is the Water Conservation Strategy as well.

Table 13
MONETARY COST BY ELEMENT OF AREAWIDE STRATEGIES

Expressed as the present value of total monetary cost for planning period July 1, 1976 thru June 30, 1992 in millions of 1/1/74 dollars

Cost Element	AREAWIDE WATER RESOURCES MANAGEMENT STRATEGY				
	Strategy No.1 SEC	Strategy No.2 AWT	Strategy No.3 SWT	Strategy No.4 WC	Strategy No.5 DRY
Capital	133	426	1874	394	635
Fixed O & M	47	236	332	215	196
Variable O & M Base Element	16	75	75	75	75
Variable O & M Growth Element	2	11	138	5	145
Total Present Value of Strategy	198	748	2419	689	1051



EXPECTED EFFECTIVE LENGTH OF POTOMAC ESTUARY km/yr WITH DISSOLVED OXYGEN LEVEL ≤ 4.0mg/l FOR DURATION ≥ 96 hrs. DUE TO JOINT OCCURENCE OF STATED RIVER INFLOW, STORM FLOW, WATER WITHDRAWAL AND WASTEWATER DISCHARGE DURING A SEVEN DAY PERIOD.

Figure 30 COST EFFECTIVENESS OF AREAWIDE WATER RESOURCES MANAGEMENT STRATEGIES

REFERENCES

1. Promise, J. and M. Leiserson. Water Resource Management for Metrpolitan Washington: Analysis of the Joint Interactions of Water and Sewage Service, Public Policy, and Land Development Patterns in an Expanding Metropolitan Area. Metropolitan Washington Council of Governments, Washington, D.C. December, 1973. NTIS No. PB-232169/3WU.

2. Spooner, C.S., P.H. Graham, J. Promise, W. Febiger. Technical Summary of the Framework Water Resources Planning Model. Metropolitan Washington Council of Governments. May, 1974.

3. Washington Area Interstate Water Resources Program. The Basis for Planning an Action Program. Draft. Metropolitan Washington Council of Governments, Washington, D.C. November, 1972.

4. Washington Area Interstate Water Resources Program Policy Committee. A Report of Progress and Conclusions. Submitted to Governor Holton, Governor Mandel, and Mayor-Commissioner Washington. Washington, D.C. January, 1973.

5. U.S. Army Corps of Engineers, Northeastern Water Supply Study Group. Letter to Walter A. Scheiber, Executive Director, Metropolitan Washington Council of Governments, from Herbert Howard, Acting Chief, Planning Division. July 27, 1973.

6. Johns Hopkins University, Applied Physics Lab. Power Plant Site Evaluation Interim Report - Dickerson Site. Submitted to the Maryland Power Plant Siting Program. Silver Spring, Maryland. April 30, 1973.

7. 42 U.S.C. 4321-4347, Public Law 91-190, (January 1, 1970), The National Envirnomental Policy Act of 1969.

8. Wapora, Inc. Draft Environmental Impact Assessment for the Diversion Weir, Potomac River. Prepared for the Washington Suburban Sanitary Commission. Washington, D.C. 1973.

9. U.S. Army Corps of Engineers, Baltimore Engineer District. Draft Environmental Impact Statement for the Emergency Water Pumping Station. Prepared by Wapora, Inc. Baltimore, Maryland. August, 1973.

10. Metcalf & Eddy, Engineers, in association with Water Resources Engineers. Reconnaissance Study of Combined Sewer Overflows and Storm Water Discharges. Prepared for District of Columbia Department of Environmental Services. March, 1973.

11. U.S. Environmental Protection Agency, Region IV. Letter to P. Graham from H.S. True concerning North Fulton County, Atlanta, Ga. Environmental Impact Statement. October 30, 1973.

12. Graham, P.H., L.S. Costello, H.J. Mallon. "Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity." Journal Water Pollution Control Federation, 46: 717, 1974.

13. Berdine, S.P. and James S. Kutzman. Planning for Urban Water Pollution Control. Submitted for presentation at Confer-In 1973. U.S. Environmental Protection Agency, Atlanta, Georgia. October, 1973.

14. Metropolitan Washington Council of Governments. Re-examination of the Year 2000 Policies Plan Vol. I and II, Washington, D.C. January, 1974.

15. Peat, Marwick, Mitchell and Company. Background and Experience. Accompanied March 27, 1972, statement of work to the Metropolitan Washington Council of Governments in connection with OWRR project No. 14-31-0001-3400.

16. U.S. Environmental Protection Agency. "Areawide Waste Treatment Management Planning Agencies - 40 CFR35, Subpart F, Grants to Designated Areawide Waste Treatment Management Planning Agencies: Grant Applications; Grants; Plan Content and Approval." Interim regulations, Federal Register. 39(93):17202-17206, May 13, 1974.

17. 33 U.S.C. 1313, Public Law 92-500, October 18, 1972. The Federal Water Pollution Control Act Amendments of 1972.

18. U.S. Environmental Protection Agency, Guidance for Facilities Planning. Washington, D.C. January, 1974.

19. Council on Environmental Quality. "Preparation of Environmental Impact Statements: Guidelines - 40 CFR 1500." Final regulations. Federal Register. 38: 20550-20562, August 1, 1973.

20. Metropolitan Washington Council of Governments, Board of Directors. "Resolution Accepting Amendments to the Metropolitan Washington Council of Governments Model Plumbing Code, R50-73." Adopted June 13, 1973.

21. ________. Report on the Use of Regional Plumbing Codes to Effect Water Conservation. Washington,D.C. June,1973.

22. U.S. Environmental Protection Agency. "State and Local Assistance - 40 CFR 35, Subpart E, Appendix A, Cost-Effectiveness Analysis." Final regulations. Federal Register. 39(29): 5268-5270, February 11, 1974.

23. ________. "State and Local Assistance - 40 CFR 35, Subpart E, Appendix B1, User Charges and Industrial Recovery Cost." Final regulations. Federal Register, 39(29): 5270, February 11, 1974.

24. ________. "State and Local Assistance - 40 CFR 35, Subpart B, 35. 400," Interim regulations. Federal Resister. 38(125): 17217-17222, June 29, 1973.

25. Metropolitan Washington Council of Governments. "Recommendation No. 1 of the Potomac Enforcement Conference, April, 1969." In: Water and Sewerage Plan and Program 1971-72. Appendix F. Washington, D.C. 1971.

26. Hydroscience, Inc. A Water Resource Analysis of the Potomac Estuary - Phase I. Preliminary copy. Prepared for Maryland Environmental Service. Washington, D.C. April, 1973.

27. U.S. Environmental Protection Agency. "State and Local Assistance - 40 CFR 35, Subpart E, 35.900," Final Regulations. Federal Register. 39(29): 5252-5269, February 11, 1974.

28. Prince Georges County, Maryland. "Prince Georges County 1973-1982 Ten Year Water and Sewer Plan and 1973-1978 Six Year Capital Improvements Program of the Washington Suburban Sanitary Commission." July, 1972.

29. Montgomery County, Maryland. "Comprehensive Ten Year Water and Sewerage Plan, FYS '74-'83." August, 1973. As Amended by Council Resolutions No. 7-901 and 7-1539.

30. Prince Georges County Council Resolution CR.51. "Prohibiting the Operation of the Piscataway Incinerator Until 30 Days After Final Environmental Impact Statement Has Been Approved." Enacted May 28, 1974.

31. National Capital Regional Planning Council. A Policies Plan for the Year 2000. Washington, D.C., 1961.

32. Maryland National Capital Park and Planning Commission. On Wedges and Corridors: A General Plan for the Maryland-Washington Regional District. 1964.

33. National Capital Planning Commission. Proposed Comprehensive Plan for the National Capital, General Land Use Objectives 1970-1985. Amended January 31, 1974.

34. Northern Virginia Regional Planning Commission. Northern Virginia Regional Plan, Year 2000. 1965.

35. Gordon, M. Optimum Growth: Consequences for the Year 2000 in Metropolitan Washington. A report to the Metropolitan Washington Council of Governments. August, 1973.

36. U.S. Environmental Protection Agency. "The Quality of Life Concept, A Potential New Tool for Decision-Makers." Symposium Report. March, 1973.

37. Peat, Marwick, Mitchell & Co. EMPIRIC Activity Allocation Model, Application to the Washington Metropolitan Region. A report to the Metropolitan Washington Council of Governments, Washington, D.C. 1972.

38. Metropolitan Washington Council of Governments. Areawide Land Use Element - 1972. Washington, D.C. 1972.

39. Hittman Associates, Inc. Forecasting Municipal Water Requirements - Volume I - The Main II System. Columbia, Maryland. September, 1969.

40. __________. Forecasting Municipal Water Requirements - Volume II - The Main II System. Columbia, Maryland. September, 1969.

41. Linaweaver, F.P., et. al. A Study of Residential Water Use. The Johns Hopkins University. Baltimore, Maryland. Undated.

42. __________. Report I - Phase Two - Residential Water Use Research Project. The Johns Hopkins University. Baltimore, Maryland. 1964.

43. __________. Report II - Phase Two - Residential Water Use Research Project. The Johns Hopkins University. Baltimore, Maryland. 1965.

44. Howe, C., et. al. Future Water Demands. Resources for the Future, Washington, D.C. March, 1971.

45. Wolff, J.B., et. al. Report on the Commercial Water Use Research Project. The Johns Hopkins University. Baltimore, Maryland. 1966.

46. U.S. Department of Commerce, Bureau of the Census. 1968 County Business Patterns CBP-68-10. Washington, D.C. 1970.

47. Maryland Environmental Service. State of Maryland-Potomac Metropolitan Area Basin Water Quality Management Plan. Review Draft. Annapolis, Maryland. 1973.

48. Metcalf and Eddy, Inc., University of Florida, and Water Resources Engineers, Inc. "Stormwater Management Model." A report to the Environmental Protection Agency, Volumes I through IV, 11024DOCO 7/71. Washington, D.C. 1971.

49. Lager, J.A., R.P. Shubinski, L.W. Russell. "Development of a Simulation Model for Stormwater Management." Journal Water Pollution Control Federation. 40:2424, 1971.

50. U.S. Department of Commerce, Weather Bureau. Rainfall Frequency Atlas of the United States. Technical Paper No. 40. Washington, D.C. 1963.

51. Unpublished study by P. Graham and T. Gill, MWCOG, conducting an applied rainfall analysis for stormwater quality forecasts. 1973.

52. National Climatic Center "Hourly Precipitation Data (Card Deck 488) for Washington, D.C./National Airport Weather Bureau (#44-8906) 1/60-12-71, Tape 1/2 inch, 9-channel, card image format, blocked 10 cards/record, EPCDIC, add parity, 800 bpi." Environmental Data Service, National Oceanic and Atmosphereic Administration, U.S. Department of Commerce. Washington, D.C. 1973.

53. Feigner, K. and Howard S. Harris. Documentation Report, FWQA Dynamic Estuary Model. U.S. Department of the Interior, Federal Water Quality Administration. Washington, D.C. 1970.

54. Clark, L.J., and N.A. Jaworski. Nutrient Transport and Dissolved Oxygen Budget Studies in the Potomac Estuary. U.S. Environmental Protection Agency, Annapolis Field Office Region III. 1972.

55. Unpublished study by P. Graham, MWCOG, of Receiving Water Component equations and constants in Framework Model, 1974.

56. Jaworski, N.A. and L.J. Clark. Physical Data Potomac River Tidal System Including Mathematical Model Segmentation. Chesapeake Technical Support Laboratory, Middle Atlantic Region, Federal Water Quality Administration. Washington, D.C. 1970.

57. American Public Health Association, American Water Works Association, Water Pollution Control Federation. "Standard Methods for the Examination of Water and Wastewater." Thirteenth Ed. Washington, D.C. 1971.

58. Carter, S., M. Frost, C. Rubin, and L. Sumek. Environmental Management and Local Government, EPA - 600/5-73-016. Conducted by International City Management Association, Government Printing Office, Washington, D.C. February, 1974.

59. Trzyna, T.C. Environmental Impact Requirements in the States: NEPA's Offspring. EPA-600/5-74-006. Government Printing Office. Washington, D.C. April 1974.

60. Maryland Environmental Policy Act. Maryland Annotated Code, Article 41, Sections 447-453. Approved 1973.

61. Virginia Environmental Policy Act. Virginia Annotated Code, Chapter 384, Acts 1973. Approved March 15, 1973.

62. Warner, M.L. and E.H. Preston. A Review of Environmental Impact Assessment Methodologies. EPA - 600/5-74-002. Government Printing Office, Washington, D.C. April, 1974.

63. U.S. Environmental Protection Agency. "Public Participation in Water Pollution Control - 40 CFR 105." Minimum Guidelines. Federal Register. 38(163): 22756-22758, August 23, 1973.

64. __________. "State and Local Assistance-40 CFR 35, Subpart F, Grants to Designated Areawide Waste Treatment Management Planning Agencies." Interim regulations. Federal Register. 39(93): 17202-17206, May 13, 1974.

65. __________. Draft Guidelines for Areawide Waste Treatment Management. Washington, D.C. May 3, 1974.

66. Cornell, Howland, Hayes, & Merryfield, Clair A. Hill & Associates. Wastewater Treatment Study Montgomery County, Md. Vol. II. November, 1972.

67. Economic Development Bureau, Metropolitan Washington Board of Trade. Metropolitan Washington Municipal Budgets: How They Work. Washington, D.C. Fall, 1972.

68. Maryland Environmental Service, State of Maryland. Preliminary draft. Potomac-Metropolitan Area Basin Plan. Annapolis, Maryland. March, 1974.

69. 33 U.S.C. 466, et. seq. The Federal Water Pollution Control Act of 1965.

70. Izaak Walton League of America. A Citizens Guide to Clean Water. Washington, D.C. June, 1973.

71. Environmental Protection Agency. "Water Quality Management Basin Plans, Policies and Procedures - 40 CFR 130 and 131." Final regulations. Federal Register. 39(107): 19634-19644, June 3, 1974.

72. Environmental Protection Agency. "Areawide Waste Treatment Management Planning Areas and Responsible Planning Agencies - 40 CFR 126." Final regulations. Federal Register. 39(178): 25681-25683. September 14, 1973.

73. Jaworski, N.A., L.J. Clark, and L.P. Feigner. A Water Resource-Water Supply Study of the Potomac Estuary. Chesapeake Technical Support Laboratory, U.S. Environmental Protection Agency, Washington, D.C. April, 1971.

74. McHarg, Ian. Design With Nature. Garden City, New York: Natural History Press, 1969.

75. Metropolitan Washington Council of Governments. Natural Features of the Washington Metropolitan Area. Washington, D.C. January, 1968.

76. Kranskoff, Thomas M. and D.C. Bunde. "Evaluation of Environmental Impact Through a Computer Modelling Process." Environmental Impact Analysis: Philosophy and Methods, Ditton, R. and T. Goodale, (eds.). Madison, Wisconsin: University of Wisconsin Sea Grant Program. 1972.

77. Northern Virginia Planning District Commission. "Ecological Inventory of Broad Run Watershed - Environmental Data: Acquisition, Coding and Manipulation." Attached to May 10, 1974 letter from R. J. Basele, NVPDC.

78. Dee, Norbert, J. Baker, N. Drobny, K. Duke, I. Whitman and D. Fahringer. "An Environmental Evaluation System for Water Resources Planning." Water Resources Research. 9(3), June, 1973.

79. Conversation between J. Promise, MWCOG, and S. Joyner, U.S. Army Corps of Engineers NEWS Study, March, 1974.

80. Leopold, L.B., F.E. Clarke, B.B. Henshaw, and J.R. Balsley. A Procedure for Evaluating Environmental Impact. U.S. Geological Survey Circular 645. Washington, D.C. 1971.

81. Cornell, Howland, Hayes, & Merryfield, Clair A. Hill & Associates. Regional Water Reclamation Plan, Upper Occoquan Sewage Authority - Volume I Report. Project No. W6958.0 Reston, Virginia. January 28, 1971.

82. __________. Draft Study Area I Wastewater Treatment Study, Phase 2. For Northern Virginia Planning District Commission. April, 1974.

83. U.S. Environmental Protection Agency, Region III. Draft Environmental Impact Statement - Upgrading and Expansion of the WSSC Piscataway Wastewater Treatment Facility to 30 MGD AWT. Philadelphia, Pa. December, 1973.

84. __________. Draft Environmental Impact Statement, District of Columbia Water Pollution Control Plant (Expansion and Upgrading) Philadelphia, Pa. April, 1972.

85. Bechtel Incorporated. Executive Summary, Lower Potomac Basin Wastewater Facilities Study. For Maryland Environmental Service. October, 1972.

86. Northern Virginia Planning District Commission. Draft Phase I Water Quality Management Plan For Northern Virginia. Arlington, Virginia. October, 1973.

87. Department of the Army, Office of the Chief of Engineers. Supplement to Final Environmental Statement, Sixes Bridge Dam and Lake, Maryland and Pennsylvania, and Verona Dam and Lake, Virginia. 2 Volumes. Washington, D.C. May, 1973.

88. Howard, Needles, Tammen, and Bergendoff. I-66 Corridor Transportation Alternates Study, Draft Environmental/ Section 4(f) Statement. For Virginia Department of Highways. Virginia. November, 1973.

89. Warner, M.L. Environmental Impact Analysis: An Examination of Three Methodologies. PhD. Thesis. Department of Agricultural Economics, Wisconsin University. 1973.

90. Sorenson, J.C. and M.L. Moss. Procedures and Programs to Assist In the Environmental Impact Statement Process. California University, Berkeley, Institute of Urban and Regional Development. April, 1973.

91. Baltimore District, U.S. Army Corps of Engineers. Chesapeake Bay Existing Conditions Report - Summary. Baltimore, Md. December, 1973.

92. U.S. Environmental Protection Agency. "National Primary and Secondary Ambient Air Quality Standards, 42 CFR 410." Federal Register, 36(84): 8186-8187, April 30, 1971.

93. U.S. Environmental Protection Agency. "Preparation Adoption and Submittal of Implementation Plans, Maintenance of National Ambient Air Quality Standards, 40 CFR 51. Federal Register, 38(116); 15834-15837, June 18, 1973.

94. U.S. Environmental Protection Agency. "Preparation of Environmental Impact Statements - 40 CFR 6." Notice of Proposed Rulemaking. Federal Register. 39(138): 26254-26270, July 17, 1974.

95. "Fairfax County Water Authority Water System Budget for Fiscal Year Ending December 31, 1973, Details of Current Expenses, Exhibit 7". Annandale, Virginia. 1973.

96. "Washington Suburban Sanitary Commission Cost Studies, 1972 Actual-1973 Budget." Treasurer's Department, Controller's Division. Hyattsville, Md. 1973.

97. Development Sciences, Inc. Optimum Growth: Consequences for the Year 2000 in Metropolitan Washington. For the Metropolitan Washington Council of Governments. Washington, D.C. August, 1973.

98. High, M. Dean. "A Review of the Background, Preparation, and Use of Environmental Impact Statements." Journal of the Air Pollution Control Association. February, 1974.

99. 16 U.S.C. 470(f), The National Historic Preservation Act of 1966.

100. Advisory Council on Historic Preservation. "Procedures for Compliance with Section 106 of National Historic Preservation Act of 1966." Federal Register. 5430, March 15, 1972.

101. U.S. Environmental Protection Agency. "Preparation of Environmental Impact Statements - 40 CFR 6." Notice of Proposed Rulemaking. Federal Register. 39(138): 26254-26270, July 17, 1974.

102. The Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970. Public Law 91-646. (January 2, 1971), 91st Congress, S.L.

103. Metropolitan Washington Council of Governments. Relocation: A Place To Live. Washington, D.C. October, 1972.

104. Water Resources Development Act of 1974. Public Law 93-251. (March 7, 1974), 93rd Congress, H.R. 10203.

105. Office of Management and Budget. "Federal and Federally Assisted Programs and Projects - Evaluation, Review and Coordination." Revision to Circular A-95. Federal Register. 38(228): 32874-32881, November 29, 1973.

106. The Conservation Foundation. Water Quality Training Institute. Funded under training grant from Environmental Protection Agency, Office of Public Affairs. Washington, D.C. 1974.

107. Warner, Katherine P. Public Participation in Water Resources Planning. National Water Commission. Arlington, Virginia. July, 1971.

108. From unpublished survey of wastewater treatment plant performance records by W. Febiger, Metropolitan Washington Council of Governments. 1973.

109. From unpublished report by J. Promise, MWCOG, on use of MAIN II System in the Framework Model, Table 4-3. July, 1972.

110. From unpublished study by J. Promise, MWCOG, of 1968 water demand estimates for District of Columbia versus recorded D.C. water usage. January, 1973.

111. District of Columbia "Water Quality Criteria, Implementation and Enforcement Plan," Department of Public Health, January, 1969.

112. State of Maryland Water Resources Regulation 4.8, "General Water Quality Criteria and Specific Water Quality Standards," Department of Water Resources, April 1969.

113. Virginia State Water Control Board, "Commonwealth of Firginia Water Quality Standards," June 1970.

114. U.S. Department of Interior, Federal Water Pollution Control Administration. Potomac River Water Quality, Washington, D.C., Metropolitan Area. Technical Advisory and Investigations Branch, Division of Technical Services, Cincinnati, Ohio. 1969.

115. District of Columbia Department of Environmental Services, District of Columbia State Continuing Planning Process, February 15, 1973.

116. Virginia State Water Control Board, 1973-74 Continuing Water Quality Planning Process, December 1973 (Revised).

117. Maryland Environmental Service et al, State of Maryland Continuing Planning Process For Water Quality Management, February 15, 1973 and map attached to the "Letter of Transmittal" of classifications, December 27, 1973.

118. U.S. Environmental Protection Agency. Final Environmental Impact Statement - District of Columbia Water Pollution Control Plant (Expansion and Upgrading). Philadelphia, Pa. May, 1974.

119. Metropolitan Washington Council of Governments National Capital Region Transportation Planning Board. Zonal Land Use Allocations for Regional Travel Demand Forecasts, Alternative 6.2 as modified. September, 1973.

120. Computer printout of MUNWATRE subprogram of Water Demand Component for 1976 utilizing MAIN II run titled MAIN2. FIXSINP.LOCAL.PU50.Y76.NO1, May, 1973.

121. "Joint Workshop on the Physical Environment", Land Use Policy Committee and Health and Environmental Protection Policy Committee of MWCOG, Meeting notice and attached issue papers. June 18, 1973.

122. Bower, Blair T. and W.O. Spofford, Jr. "Environmental Quality Management", Natural Resources Journal, Volume 10, No.4, October, 1970. The University of New Mexico School of Law.

123. Colony, William M. "The Tahoe 'Land Capability' Approach to Resource Management: A Case History", 1972.

124. Report of the Short-Term Planning Committee - Recommendation No. 4, prepared in accordance with Recommendation No. 4 of the "Conference on Pollution of the Interstate Waters of the Potomac River and Its Tributaries". Washington, D.C. 1971.

125. United States Department of the Interior, Office of Water Resources Research. Research grant number 14-31-0001-3400, Analysis of the Joint Interaction of Water Supply, Public Policy, and Land Development Patterns in an Expanding Metropolitan Area. Awarded to the Metropolitan Washington Council of Governments. Washington, D.C. 1971.

126. Environmental Protection Agency, Water Quality Office, Office of Research and Development. Offer and Acceptance of a Federal Grant for Research and Development - Project Number 16110 FEY, Systems Analysis in Urban Water Quality Planning. Awarded to Metropolitan Washington Council of Governments. Washington, D.C. 1971.

127. U.S. Envirnomental Protection Agency, Implementation Research Division, Office of Research and Monitoring. Continuation of Grant Systems Analysis in Urban Water Quality Planning, Revised Project Number S-802149. Awarded to the Metropolitan Washington Council of Governments. Washington, D.C. May, 1973.

128. Unpublished study by J. Promise and M. Leiserson, MWCOG, of approaches to meeting the MAIN II Model requirements for specification of number of dwelling units within home value categories. Fall, 1971.

129. Unpublished study by J. Promise, MWCOG, calculating expected usage coefficients for the commercial/institutional categories of the MAIN II system based on an analysis of establishments in metropolitan Washington within specified SIC industries. March, 1972.

130. Metropolitan Washington Council of Governments. National Capital Region Air Transportation Plan and Program - Synopsis of the Study. Department of Transportation Planning. 1974.

131. Unpublished Interviews with Representatives of Water Resource Utilities in Metropolitan Washington concerning Indirect and Overhead Costs. P. Graham and W. Febiger, MWCOG. 1973.

132. Computer printout of MUNWATRE subprogram of Water Demand Component for 1992 utilizing MAIN II run titled MAIN2. FIXSINP, LOCAL, PU50, Y92, NO1, June 4, 1973. Values converted to cubic feet per second.

133. Computer printout of Sewage Generation Component for 1992 utilizing sewage run titled SEWG, TRTINP. LOCAL. PU50. Y92, NO1. Values converted to cubic feet per second.

134. Black and Veatch Consulting Engineers. Water Supply Study for Washington Metropolitan Area, Fairfax County Water Authority, Government of the District of Columbia, Washington Suburban Sanitary Commission. April, 1974.

135. Monti, R.P., and P.T. Silberman, "Wastewater System Alternatives: What They Are...And What They Cost." Water and Wastes Engineering. Vol. II, No. 3, March, April, May and June, 1974.

136. Heaney, J.P., W.C. Huber, et al. Urban Stormwater Management Modeling and Decision-Making. U.S. Environmental Protection Agency, Washington, D.C. Publication Number 670/2-75-022, May, 1975.

137. Greeley and Hansen, Engineers. Report on Additional Water Supply, Fairfax County Water Authority. June, 1971. 123 p.

138. Goeppner, J. and D.E. Hasselmann, "Digestion By-Product May Give Answer to Energy Problem." Water and Wastes Engineering. Vol. II, No. 4, April, 1974.

APPENDICES

APPENDIX A DISSOLVED OXYGEN SUMMARY TABLES FOR SIX AREAWIDE STRATEGIES

TABLE A-1

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 1: SECONDARY WASTE TREATMENT

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	28.356	0.115	26.657
2.0	33.337	0.153	34.346
3.0	33.337	0.153	34.346
4.0	35.494	0.158	34.820
5.0	42.261	0.219	46.209
6.0	59.690	0.504	105.588
7.0	80.571	0.887	186.306
8.0	82.953	0.888	186.306
9.0	82.953	0.888	186.306
10.0	82.953	0.888	186.306
	DURATION=24. HOURS		
1.0	25.218	0.093	21.920
2.0	28.356	0.115	26.657
3.0	33.337	0.153	34.346
4.0	35.494	0.158	34.820
5.0	42.261	0.219	46.209
	DURATION=48. HOURS		
1.0	25.218	0.093	21.920
2.0	28.356	0.115	26.657
3.0	33.337	0.153	34.346
4.0	33.337	0.153	34.346
5.0	42.261	0.219	46.209
	DURATION=96. HOURS		
1.0	22.176	0.076	18.793
2.0	26.811	0.104	23.922
3.0	33.337	0.153	34.346
4.0	33.337	0.153	34.346
5.0	42.261	0.219	46.209

TABLE A-2

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 2: ADVANCED WASTE TREATMENT

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	14.781	0.041	10.433
2.0	14.781	0.041	10.433
3.0	22.176	0.076	18.793
4.0	25.218	0.093	21.920
5.0	35.494	0.158	105.588
6.0	59.690	0.504	186.305
7.0	80.571	0.887	186.604
8.0	82.953	0.888	186.604
9.0	82.953	0.888	186.604
10.0	82.953	0.888	186.604
	DURATION=24. HOURS		
1.0	11.506	0.030	7.698
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	30.513	0.120	27.132
	DURATION=48. HOURS		
1.0	10.018	0.027	7.197
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657
	DURATION=96. HOURS		
1.0	6.284	0.015	4.070
2.0	13.293	0.037	9.932
3.0	16.817	0.052	13.565
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657

TABLE A-3

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 3: STORMWATER TREATMENT

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	0.0	0.0	0.0
2.0	4.522	0.011	3.291
3.0	13.293	0.037	9.932
4.0	14.781	0.041	10.433
5.0	25.218	0.093	21.920
6.0	49.334	0.362	77.460
7.0	82.059	0.891	186.806
8.0	82.953	0.888	186.806
9.0	82.953	0.888	186.806
10.0	82.953	0.888	186.806
	DURATION=24. HOURS		
1.0	0.0	0.0	0.0
2.0	4.522	0.011	3.291
3.0	13.293	0.037	9.932
4.0	14.781	0.041	10.433
5.0	22.176	0.076	18.793
	DURATION=48. HOURS		
1.0	0.0	0.0	0.0
2.0	4.522	0.011	3.291
3.0	10.018	0.027	7.197
4.0	13.293	0.037	9.932
5.0	22.176	0.076	18.793
	DURATION=96. HOURS		
1.0	0.0	0.0	0.0
2.0	0.0	0.0	0.0
3.0	8.256	0.023	6.418
4.0	13.293	0.037	9.932
5.0	22.176	0.076	18.793

TABLE A-4

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 4: WATER CONSERVATION

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	14.781	0.041	10.433
2.0	14.781	0.041	10.433
3.0	22.176	0.076	18.793
4.0	25.218	0.093	21.920
5.0	35.494	0.153	34.820
6.0	59.690	0.504	105.588
7.0	80.571	0.887	186.300
8.0	82.953	0.888	186.604
9.0	82.953	0.888	186.604
10.0	82.953	0.888	186.604
	DURATION=24. HOURS		
1.0	11.506	0.030	7.698
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	30.513	0.120	27.132
	DURATION=48. HOURS		
1.0	10.018	0.027	7.197
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657
	DURATION=96. HOURS		
1.0	6.284	0.015	4.070
2.0	13.293	0.037	9.932
3.0	16.817	0.052	13.565
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657

TABLE A-5

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 5: DRY WASTE COLLECTION

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	14.781	0.041	10.433
2.0	14.781	0.041	10.433
3.0	22.176	0.076	18.793
4.0	25.218	0.093	21.920
5.0	35.494	0.158	34.820
6.0	59.690	0.504	105.588
7.0	80.571	0.887	186.604
8.0	82.953	0.888	186.604
9.0	82.953	0.888	186.604
10.0	82.953	0.888	186.604
	DURATION=24. HOURS		
1.0	11.506	0.030	7.698
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	30.513	0.120	27.132
	DURATION=48. HOURS		
1.0	10.018	0.027	7.197
2.0	14.781	0.041	10.433
3.0	18.306	0.056	14.066
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657
	DURATION=96. HOURS		
1.0	6.284	0.015	4.070
2.0	13.293	0.037	9.932
3.0	13.293	0.037	9.932
4.0	22.176	0.076	18.793
5.0	28.356	0.115	26.657

TABLE A-6

DEFICIT PERIOD MEASURES AT VARIOUS MINIMUM DISSOLVED OXYGEN LEVELS

STRATEGY NO. 6: INDIRECT ESTUARY REUSE

MINIMUM DISSOLVED OXYGEN LEVEL (MG/L)	RIVER LENGTH KILOMETERS	RIVER VOLUME CUBIC KILOMETERS	RIVER SURFACE SQUARE KILOMETERS
	DURATION=12. HOURS		
1.0	12.311	0.025	5.345
2.0	19.320	0.047	11.207
3.0	19.320	0.047	11.207
4.0	26.715	0.081	19.567
5.0	32.895	0.121	27.431
6.0	62.072	0.505	105.888
7.0	82.953	0.888	186.604
8.0	82.953	0.888	186.604
9.0	82.953	0.888	186.604
10.0	82.953	0.888	186.604
	DURATION=24. HOURS		
1.0	12.311	0.025	5.345
2.0	16.045	0.036	8.472
3.0	19.320	0.047	11.207
4.0	26.715	0.081	19.567
5.0	31.349	0.110	24.696
	DURATION=48. HOURS		
1.0	12.311	0.025	5.345
2.0	16.045	0.036	8.472
3.0	19.320	0.047	11.207
4.0	26.715	0.081	19.567
5.0	31.349	0.110	24.696
	DURATION=96. HOURS		
1.0	12.311	0.025	5.345
2.0	12.311	0.025	5.345
3.0	19.320	0.047	11.207
4.0	26.715	0.081	19.567
5.0	29.756	0.099	22.694

APPENDIX B

COMPARISON OF COSTS OF ALTERNATE WATER RESOURCES MANAGEMENT STRATEGIES

EQUATIONS USED TO COMPARE COSTS

The cost of alternate water resources management strategies tested with the Framework Model were computed through the application of the four equations illustrated in Figure B-1. The four equations reduce costs for capital, and total operating and maintenance costs to present values used in comparing alternatives. The equations were each formulated to recognize that the period of construction may differ significantly among alternatives. They do this by discounting costs to be incurred once operations begin and once debt starts being retired across the period of construction.

Equation (1) in Figure B-1 reflects the assumption that the capital costs will be paid annually in even increments during the construction process and thus cannot be discounted entirely to the beginning of the construction process. The expressions

$$\frac{i(1+i)^k}{(1+i)^k-1} \quad \text{and} \quad \frac{(1+i)^n-1}{i(1+i)^n}$$

reflect the assumption that the useful life in capital facilities at the end of the planning period can, in effect, be salvaged at a value proportional to its unused life.

Equations (2) and (3) in Figure B-1 each deal with uniform series of costs estimated to be incurred for operations and maintenance. Equation (2) deals with fixed costs, while Equation (3) covers variable operating and maintenance costs.

While these are estimated separately, their present values are computed by multiplying by identical factors, the first to determine the present value of the series at the time construction ceases, and the second to discount that value further to reflect the delays in the need for the expenditure during construction.

Equation (4) reduces an increasing series of operations and maintenance costs to a present value at the time of initial operations. Then, using the single payment present value factor, it further discounts that cost to reflect the delay in the need for the expenditure during construction. Operation and maintenance costs which might be treated in this way

FIGURE B-1

ILLUSTRATION OF EQUATIONS USED TO COMPARE COSTS

Total Planning Period Capital Cost Discounted to 1/1/74 =

$$\sum_{0}^{m}\left\{\left[\begin{matrix}\text{Total Capital Cost}\\ \text{at ENR 2000}\end{matrix}\right]\left[\frac{1}{m+1}\right]\left[\frac{1}{(1+i)^m}\right]\right\}\left\{\left[\frac{i(1+i)^k}{(1+i)^k-1}\right]\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]\right\} \quad (1)$$

Total Planning Period Fixed O & M Cost Discounted to 1/1/74 =

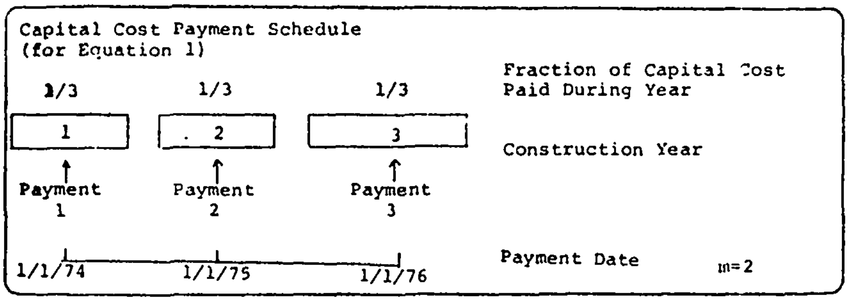
$$\left\{\begin{matrix}\text{Fixed Annual O \& M}\\ \text{Cost at End of}\\ \text{Planning Period}\end{matrix}\right\}\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]\left[\frac{1}{(1+i)^m}\right] \quad (2)$$

Total Planning Period Variable O & M Cost Base Component Discounted to 1/1/74 =

$$\left\{\begin{matrix}\text{Variable Annual O \& M}\\ \text{Cost-Base Component}\end{matrix}\right\}\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]\left[\frac{1}{(1+i)^m}\right] \quad (3)$$

Total Planning Period Variable O & M Cost Growth Component Discounted to 1/1/74 =

$$\left\{\begin{matrix}\text{Variable Annual O \& M}\\ \text{Cost-Growth Component}\end{matrix}\right\}\sum_{1}^{n}\left(\left[\frac{2n-1}{2n}\right]\left[\frac{1}{(1+i)^n}\right]\right)\left[\frac{1}{(1+i)^m}\right] \quad (4)$$



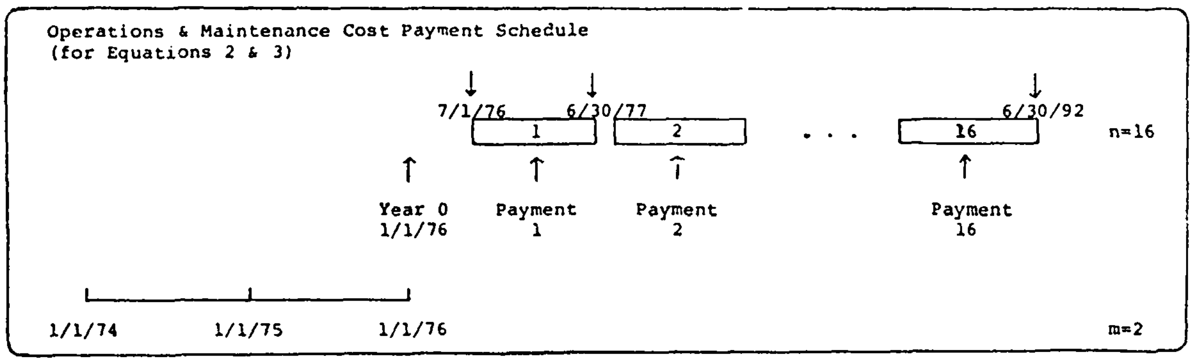
k= life of capital structure

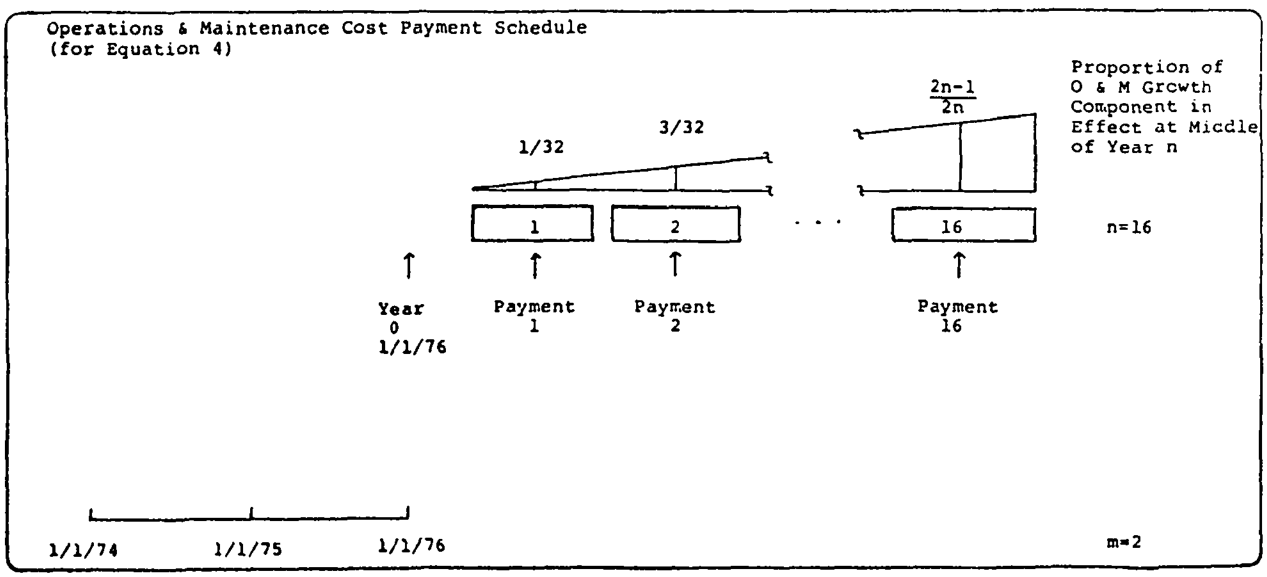
m= length of construction period

n= length of planning period

i= discount rate

ENR 2000= Engineering News Record Construction Cost Index on 1/1/74





include costs of chemicals and power which are proportional to the amount of designed capacity actually used.

The following section presents the methods used to determine the costs of the five alternative water resources management strategies in Chapter IV.

STRATEGY NO.1 SECONDARY WASTE TREATMENT

The cost of the secondary waste treatment strategy was calculated on the assumption that secondary treatment would consist of preliminary treatment by comminution and degritting, primary treatment by settling, secondary treatment by aeration and settling, and disinfection by chlorination. It also included the assumption, held constant except where specifically noted, that local impoundments would provide the sources of additional water supplies for the area. While this assumption is not valid from the standpoint of adopted plans, it allows the use of relatively recently prepared cost estimates of one alternative for the provision of additional water supplies.[134]

Secondary treatment costs were based on the addition to the existing treatment capacity of 215 mgd of eight secondary treatment plants of approximate size of 25 mgd to reach the average annual wastewater flow of 519 mgd by 1992. A thirty year life was assumed.

Capital costs for expansion during the planning period were based on Monte and Silberman.[135] Capital costs for upgrading existing facilities are computed at $.20/mgd of existing capacity based on budgeted secondary treatment costs reported by the Washington Suburban Sanitary Commission.[28,29]

Operation and maintenance costs were based on Monte and Silberman [135] and were applied only to the expansion of secondary treatment capacity required during the planning period.

STRATEGY NO.2 ADVANCED WASTE TREATMENT

The cost of the advanced waste treatment strategy was based on the following unit operations: preliminary treatment by communition and degritting, primary and phosphorus removed by chemical addition, aeration and settling, nitrification by aeration and settling, denitrification by mixing and methanol addition, filtration, carbon adsorbtion in columns, disinfection by chlorination, and final effluent aeration. Advanced waste treatment costs were based on the addition of

519 mgd of regional advanced waste treatment capacity as eight approximately 65 mgd capacity plants each with a sixteen year life. A thirty year life and a water supply alternative identical to Strategy No.1 were assumed.

Capital and operating and maintenance costs were based on Monte and Silberman.[135] Seventy percent of the values for operation and maintenance cost based on 1992 design capacity were assumed to be fixed[85] and therefore would be incurred in each year of the planning period. The remaining 30% were assumed to be variable and therefore incurred as a funciton of capacity used.

STRATEGY NO.3 STORMWATER TREATMENT

This strategy assumed water supply and advanced waste treatment identical to the second strategy and treatment of 50 percent of the regional stormwater load through the achievement of 60 percent BOD_5 removal from a limited number of urban watersheds.

The cost of the stormwater treatment strategy was based on Strategy No.2 plus the cost of the following devices: surface storage (reservoir, ponds, or tanks), bar racks, fine screens, and dissolved air flotation.

Stormwater treatment was based on 440 treatment units each designed for 5 million gallons of surface storage and for a treatment rate of 20 million gallons per day. The large number of these units was the result of the estimate of the small unit size seen needed for location without excessive disruption in areas urban in character.

The total planning period (16 years) capital cost of $1,448 million was divided into surface storage costing $880 million; dissolved air flotation costing $365 million; fine screens costing $151 million and bar racks costing $52 million. Surface storage of 25% of the runoff volume of a first decile storm from nineteen of the fifty-three watersheds estimated to have the highest annual BOD_5 concentration.

The surface storage life used in costing was 50 years with the life of the mechanical equipment set at 16 years, the planning period duration. The bar racks and fine screen cost equations are taken from the Stormwater Management Model. The dissolved air flotation cost equations were based on Heaney and Huber's refinements to this model.[136] Storage cost equations are based on Rohrer Associates data or $0.351 per gallon at an estimated ENR of 1400.[136]

Operations and maintenance cost for bar racks, fine screens and dissolved air flotation devices were based on fixed portion equal to two percent of initial capital cost and another fixed portion based on the treatment of the expected runoff in 1992 from the nineteen watersheds at a cost of $10 per million gallons at ENR of 1400. The present worth of the fixed operations and maintenance costs for the planning period for these facilities was calculated to be $20 million.

The operations and maintenance costs associated with surface storage were costed as sediment removal to the disposal site at $10 per ton and 80 percent removal of an estimated 1.6 million tons per year of sediment from the 342,580 acre area of the watersheds selected for stormwater treatment. The fixed operations and maintenance costs for the planning period for surface storage devices was calculated to be $107 million.

The total incremental present value of the stormwater treatment strategy over Strategy No.2, was $1,448 million in capital costs and $223 million in fixed operations and maintenance costs.

STRATEGY NO.4 WATER CONSERVATION

The cost of the water conservation strategy was based on Strategy No.2, Advanced Waste Treatment, with the addition of plumbing code changes in new and residential construction between 1976 and 1992 to reduce water use, and stricter sewer construction specifications and inspection programs to reduce sewer infiltration. These changes cause a reduction in annual water demand and wastewater flows of approximately 35 mgd. The incremental savings in dams, water purification facilities, and advanced wastewater treatment facilities are the basis for the cost savings of this alternative.

Of the total planning period capital cost savings, 75 percent was due to the smaller advanced waste treatment and secondary treatment facilites; 24 percent was due to a decreased requirement for water purification, including intake structures, and 1 percent was due to a reduced requirement for dams. Secondary and advanced waste treatment costs were based on Monte and Silberman[134], however, no costs for upgrading existing facilities as required in Strategy No.1 were included. Water purification costs are based on data from Greely and Hansen[137] and Washington Suburban Sanitary Commission[28] using a 30 year life. Dam costs are based data from Black & Veatch[134] using a 50 year life.

The total incremental present value savings during the entire planning period when compared to Strategy No.2, was $32 million for capital costs and $27 million for operations and maintenance costs.

STRATEGY NO.5 DRY WASTE COLLECTION

The cost of the dry collection strategy was based on water conservation and infiltration control measures as reported in Strategy No.4, dry collection facilities at each household, a household to digestion plant transportation system, a digestion plant, and final disposal by sanitary landfill.

The water conservation and infiltration control measures cause a 16 percent reduction in annual water demand totaling 102 mgd and a reduction in wastewater flows of 95 mgd. The cost savings due to the smaller facilities and lower operating costs were determined as in Strategy No.4, and amount to a total of $116 million for the planning period.

The capital costs of the dry collection facility having a 30 year life at each household are estimated based on $1000 per household for the 443,127 new households estimated for the 1976-1992 planning period for the watersheds directly tributary to the Potomac River. Capital costs for the commercial sector were calculated using the same 16 percent reduction as the residential sector multiplied by or the ratio of commercial water demand to residential water demand in Strategy No.2. The total present value planning period capital cost for the addition of dry collection capital equipment was calculated to be $273 million.

Household to digestion plant transportation costs are based on a $5/household/month estimated collection charge amounting to a total operation and maintenance cost of $90 million for the planning period. Addition of the commercial sector operations and maintenance cost in proportion to water demand of the residential and commercial sector as described earlier brought the total planning period household to digestion plant costs to $142 million.

Digestion plant costs for the planning period were based on total planning period costs equaling total planning period revenues from methane sales after Goeppner and Hasselmann.[138]

Transportation from the digestion plant to the final disposal was based on a population growth during the planning period in the metropolitan Washington area directly tributary to the Potomac River of 1,068,756 people, an average per capita per day total solids production of 0.55 lbs. and a hauling charge of $8 per ton. The total planning period transportation costs from digestion plant to landfill was calculated to be $4.0 million.

The total present value cost during the entire planning period of the dry collection strategy was $209 million in capital costs and $94 for operation and maintenance costs higher than the costs estimated for Strategy No.2.

APPENDIX C

OUTPUT AVAILABLE FROM COMMUNITY DEVELOPMENT COMPONENT (EMPIRIC)

ESTIMATES ARE GENERATED FOR EACH POLICY ANALYSIS DISTRICT AND EACH FORECAST YEAR FOR THE FOLLOWING:

HOUSEHOLDS AND EMPLOYMENTS BY:
- No. of Family Households in Low Income Quartile
- No. of Family Households in Low-Middle Income Quartile
- No. of Family Households in Upper-Middle Income Quartile
- No. of Family Households in Upper Income Quartile
- No. of Unrelated Inficidual Households
- Employment in Manufacturing, Transportation, Communication and Utilities
- Employment in Retail and Wholesale
- Employment in Financial, Insurance, Real Estate and Services
- Employment in Fovernment
- Employment in Agriculture and Construction

POPULATION Broken down by Age
- Under 5 years
- 5 - 14
- 15 - 19
- 20 - 29
- 30 - 49
- 50 - 64
- 65 and Over

HOUSEHOLDS Broken down by Size
- 1 Person
- 2 Persons
- 3 Persons
- 4 Persons
- 5 or more persons

HOUSEHOLDS Broken down by:
- Single-Family Households
- Multi-Family Households

LAND USE Broken down by Type
- Residential
- Inaustrial
- Commercial
- Intensive Institutional
- Extensive Institutional
- Parks and Open Space
- Vacant
- Residential (incl. streets)

EMPLOYMENT Broken down by Land Use
- EMP On Residential Land
- EMP on Commercial Land
- EMP on Institutional Land
- EMP on Agricultural & Vacant Land

APPENDIX D

PARAMETERS USED IN THE STORMWATER MANAGEMENT MODEL OF THE STORMWATER RUNOFF COMPONENT[55]

Watershed

- Acres
- Length to width ratio
- Imperviousness (%)
- Overland flow slope
- Impervious area coefficient of roughness
- Impervious area detention depth (in)
- Pervious area coefficient of roughness
- Pervious area detention depth (in)
- Pervious area maximum infiltration rate (in/hour)
- Pervious area minimum infiltration rate (in/hour)
- Pervious area decay rate of infiltration (sec -1)

Stream

- Length of main stream (ft)
- Width of main stream (ft)
- Slope of main stream (ft)
- Coefficient of roughness (Manning's n)

Land Use

- Residential (%)
- Commercial (%)
- Industrial (%)
- Undeveloped (%)
- Total (%)
- Specific Curb Length (ft/acre)

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/5-78-006a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE A Demonstration of Areawide Water Resources Planning		5. REPORT DATE June 1975 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) C.S. Spooner, J. Promise, P.H. Graham		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Metropolitan Washington Council of Governments 1225 Connecticut Avenue, N.W. Washington, D.C. 20036		10. PROGRAM ELEMENT NO. 1BA030 11. CONTRACT/GRANT NO. EPA 16110 FEY and S-802149
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Research & Development Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/16

15. SUPPLEMENTARY NOTES

16. ABSTRACT The MWCOG Framework Water Resources Planning Model developed and tested under this study is a comprehensive analytical tool for use in areawide water resources management planning. The physical simulation portion was formed by linking component computer models which test alternative future community development patterns by small area, estimate water demands by usage categories, calculate sewage flows based on water demands and add infiltration/inflow, simulate stormwater runoff, test application of alternative waste treatment management systems, and simulate the quality response of the region's major water body. The impact assessment portion of the Framework Model includes methodologies for assessing the fiscal, social, and environmental impacts of alternatives. The Framework Model has been tested for the Metropolitan Washington region by identifying the cost-effectiveness of six alternative areawide water resources management strategies, and is currently in use in many planning programs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water resources planning, Land use planning, Storm runoff, Water supply, Water quality, Systems analysis, Decision making, Computer simulation, Water pollution sources, Regional analysis, Data collection, Estuary, Social aspects, Environmental effects, Economic impacts Resource allocation	Metropolitan Washington, Areawide waste treatment management planning, Potomac Estuary model, Stormwater runoff model, Framework for assessing fiscal, social and environmental effects	06A, 06B, 03D, 05C, 05B, 05D, 05G, 06D, 07A

18. DISTRIBUTION STATEMENT Unlimited release	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 184
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978– 260-8880:33

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Research Information Center
Cincinnati, Ohio 45268

FOURTH-CLASS MAIL
Postage & Fees Paid
EPA
Permit No. G-35

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
AN EQUAL OPPORTUNITY EMPLOYER

If your address is incorrect, please change on the above label tear off; and return to the above address.
If you do not desire to continue receiving these technical reports, CHECK HERE ☐; tear off label, and return it to the above address.

EPA-600/5-78-006a