Examination of Water Production and Sewage Flow Forecasting at the Washington Suburban Sanitary Commission and Recommendations for Improvements

FINAL REPORT

by

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Acknowledgement

The help and advice of Mr. Nicholas J. Del Grosso, of the WSSC Water Resources Planning Section is much appreciated. His cooperation in the provision of data, information, and examples of forecasting methods at the WSSC was particularly helpful during the course of this study. Other WSSC staff who provided information on specific topics include Thomas E. Gingrich, John W. DiLoreto, Thomas M. Fischer, William Austin, and Marjorie L. Johnson.

In addition, Nazir Baig and Dominic J. Motta, among others, of the Montgomery and Prince George's County offices respectively, of the Maryland-National Capital Park and Planning Commission made documents available for reference and provided interpretation of population, housing and employment forecasts.

SUMMARY

Based on our examination of water production and sewage flow forecasting at the Washington Suburban Sanitary Commission, we offer a summary of our conclusions in the form of an evaluation of present methods and recommendations for improvement.

Evaluation:

1. In general, the methods used to forecast water production and sewage flow are consistent with the best contemporary practice in the water supply industry.

2. Data and information are organized and synthesized carefully in order to provide historical perspective and credible data bases. This is evidenced in the Distribution System Storage Study, The Development of Sewage Flow Factors and Their use in Forecasting Sewage Flow, and Residential Flow Factor Analysis.

3. In general, forecasting at WSSC involves the development of disaggregated demand factors (coefficients) on moderately large and relatively homogeneous customer groups. These factors are derived from recently initiated accounts in order to best reflect the type of customers who will be the constituents of future growth. Continuing use of the extensive computerized data processing facilities contributes to the good quality of forecasting methods.

4. The factors are applied to forecasts of future customer groups which are produced by an independent specialized cooperative process (the Cooperative Forecasting Program) designed to obtain the best results. This technique is superior to simply projecting past trends in water production and sewage flows.

5. Generally, although not always, forecasts are well documented with sources of data and explanations of methods.

6. In a comparison with the local electric utilities (which produce a commodity whose demand is driven by factors which are similar in many respects to those of water and sewer services) the forecasting practices at WSSC are similar in detail and extent.

Recommendations:

A number of inconsistencies and areas for improvement were detected during the course of the study. Their reconciliation and incorporation would enhance the forecasting process at WSSC.

1. Use of the Commission's Design Manual is rendered somewhat confusing and ambiguous due to the lack of documentation of the factors contained in the Appendices. There ought to be an accompanying explanation of how and when the factors were derived. Further, there should be differentiation between water production and sewage flow factors in order to take account of water main transmission losses, inflow/infiltration, and other distinguishing characteristics; and geographic disaggregation should be provided if appropriate.

2. The effects of changes in price and income should be incorporated into the forecasting process. Although the debate over the price elasticity of demand for water is far from finished, enough evidence is available to suggest that economics is a significant influence. Some degree of coordination with those involved in the preparation of the WSSC budget should be established.

3. A pattern of frequent re-evaluation of factors and their application should be adopted. In particular, Chapter IV of the Distribution System Storage Study, Project 6.02, should be updated and expanded for use in forecasting for planning purposes.

4. The value of increased disaggregation by property code, service type and location as available from billing records should be investigated. If significant differences exist among the many groups of customers, they should be further segregated for analysis and forecasting.

5. The currently available Round III Cooperative Forecasts of housing and employment should be used to update the analysis presented in the Water Production Report Through June, 1982. In the process of updating, this report might effectively be combined with Distribution System Storage Study, Project 6.02, in order to reduce duplication of effort and reference material.

6. The use of probability in the field of forecasting and control is now well established and should be incorporated into the forecasts produced by the Commission. Perhaps the simplest and most useful applications would be in presenting confidence limits on forecasts, and expressing results in the format of probabilities of exceedence.

7. A small, but significant recommendation, is to revise the results in the report Flow Projections for Workload Indices. The forecast should have as its base level the value of the normalized data regression line for FY'84, not the normalized value of flow for that year. Water use data for the analysis in this report have recently been changed to reflect water "consumption" only, excluding usage through submeters which is not returned to the sewers. These data are more representative figures for sewage flow calculations than total water "production". The derivation of work indices for water should be fully documented.

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Introduction

This report presents the results of an external examination of WSSC techniques used by staff of the WSSC in the development of forecasts of water production and sewage flow. The analysis focuses on the use of available data and information, and the degree to which that use is consistent with good and contemporary forecasting practice. The motivation for an external examination came from inconsistencies in the approach to forecasting methodology between WSSC staff and one or more of the Commissioners.

The organization of the report follows the format of addressing the nine inter-related tasks as set out in the proposal:

1. summarization and use of presently available data and information at WSSC, County Planning Boards of the Maryland-National Capital Park and Planning Commission, and Metropolitan Washington Council of Governments,

2. analysis of unit production and flow factors with respect to WSSC property codes, service types, and counties,

3. analysis of the effects of change in price and income levels,

4. investigation and incorporation of uncertainty due to weather into flow forecasting techniques,

5. incorporation of alternate future population, housing unit and employment scenarios into forecasts,

6. presentation of individual forecasts which are conditional upon discrete assumptions about the future,

7. presentation of example probabilistic forecasts in terms of probabilities of exceedence,

8. ex-post examination of previous plans and forecasts at the WSSC and planning agencies in order to determine historical accuracy, bias and variance,

9. outline future directions in data availability, analytical tools, forecasting techniques, and planning applications.

An Appendix, which contains a photocopy of an example of monthly climatological data, follows the main body of the report.

Forecasting Defined

Forecasting can be defined as both an objective and a subjective process: it is the subjective application of objective material. A forecast is a statement about the future which is conditioned on objective or factually derived relationships and influenced by various assumptions. It is subjective in that it is a statement about the future and therefore cannot be factual, but speculative.

Good and contemporary practice of forecasting involves the bringing together and analysis of all the pertinent information that time and effort will allow in the competition for limited resources, and having regard for the use to which the forecasts will be put and its relative costs and benefits. The information should be the most up-to-date that is available, but should be regarded in the context of previous information, and subject to change as new and revised information becomes available. The process of forecasting usually includes the establishment of a base level from which the forecast begins, and an examination of previous conditions in order to establish trends. Information which could influence the continuance of established trends is brought into the forecasting process so that final results are not a blind projection of the past.

Report of Work

All of the analyses, computations and results developed in this study make use of the latest available planning and forecast data which are relevant to the Washington Suburban Sanitary District (WSSD). The execution of the study is described in the fulfillment of nine interconnected tasks.

TASK 1

Evaluate the available data and information relative to forecasting the demand for water and sewer services in the WSSD.

The evaluation has concentrated on material which would be of most use in medium to long term forecasts for purposes of planning raw water and distribution facilities, sewage collection and treatment facilities, and budget considerations in the out years. The data and information is derived from reports and other documentary material, and from personal contact with persons involved with the collection of such data or the forecasting of future values. The material must necessarily cover past conditions of water production, sewer flow and explanatory variables, as well as forecasts of those explanatory variables and their functional relationships with respect to water and sewage.

The pursuit and analysis of information may sometimes be frustrating and tedious, and inevitably some overlap of information will be encountered in the descriptive and interpretive reference material. The organization and synthesis of data is certainly an important aspect of producing credible forecasts, and should be undertaken carefully.

There follows a summary of data and information available for forecasting the demand for water and sewer services in the WSSD. This information is organized by the providing agency.

WSSC

Documentary material including:

WSSC <u>Design Manual</u>

The Commission follows the practice of maintaining a <u>Design Manual</u>. Relevant information to forecasting for planning purposes is contained in several of the Appendices. Appendix D contains Flow Factors (coefficients) for numerous types of water using property, including types of housing, and educational institutions, retail and commercial properties. There is, however, no areal differentiation and no documentation refering to the method or date of derivation of these Factors. The lack of explanation fosters skepticism of their value as forecasting aids and contributes to the fact that they may not be regarded or used as well as they might be. Appendices E and F contain Dwelling and Acreage Factors respectively for the various land use zoning classifications, differentiated by County. Again, there is no supporting information as to date or method of derivation.

Special Studies:

ADC Trends

The Office of the Secretary of the Commission has conducted a series of studies which examine the consumption behavior of customers by Average Daily Consumption (ADC) group. The results of these studies are of use in understanding the relationship of water use to price, and in particular in seeing the effect of the Conservation Orientated Rate Structure which was introduced January 1, 1978. Although there is considerable unresolved debate as to the price elasticity of demand for water and sewer services, more of this kind of information on the effects of changes in rates, personal income and general rates of inflation should be incorporated in the forecasting process. No allowance for variations in weather seems to have been incorporated in this work.

Inter-office and inter-agency correspondence

A considerable body of data and information relative to forecasting exists in the files of the Water Resources Planning Section. Much of the best described and documented work is contained in the following reports:

1. Distribution System Storage Study
   Project 6.02
   Water System Planning Section, June, 1980.

2. The Development of Sewage Flow Factors and Their use in Forecasting Sewage Flow
   by Edward Graham
   Sewer System Planning Section, November, 1981

3. Residential Flow Factor Analysis
   Contract No. 83MM1093-A
   by Nick Del Grosso and Bruce Downes
   Planning and Engineering Division, November, 1984

These reports provide excellent background material and should be referred to in all forecasting exercises. It is recommended that the material in Chapter IV, on water demands, of the Distribution System Storage Study, Project 6.02, be updated and expanded for use in forecasting for planning purposes.

Flow Book

The Flow Book, being a compilation of computer generated data reports, is an important and consistent source of basic data necessary in the preparation of forecasts. Particularly useful reports in the Flow Book generally contain monthly data back through 1977 for average and rolling annual average sewage flows to each sewage treatment plant, monthly total precipitation at three area rain gauges, and monthly water produced at the Potomac and Patuxent treatment plants. These data (together with monthly temperatures available from the National Weather Service, Ref: NOAA and the Appendix) would be useful in expanding the Commission's efforts in normalizing water demand and sewer flows for varying weather conditions so as to more accurately understand the response to growth in housing and employment.

Plumbing Code

The regulations governing the installation and water using characteristics of new and replacement plumbing fixtures in the WSSD reflect the evolution of water conservation. The limitations on water use have successively decreased the permissible amount of flow through fixtures, and have progressively applied to more and more types of fixtures as summarized in Table 1. This information, together with some estimate of fixture usage, might provide a quantitative factor for incorporation into the forecasting process.

TABLE 1 Conservation Plumbing Code

Regulations Governing the Installation of Plumbing and Sewer Cleaning in the Washington Suburban Sanitary District

	Quantity (gal) or Flow (gpm)						
Issue Date	1961	1965	1972	1976	1980	1983	1984
Flushometer [gal]							
Toilet	>5		>3.5	<3.5			
Urinal				<3.0			
Toilet (tank) [gal]			<3.5				
Shower (stall) [gpm]			<3.5			<3.0	
Sink Faucets (h+c) [gpm]					<4.0		
Lavatories (h+c) [gpm]					<4.0		
(hot only) [gpm]						<0.25	

Historical Perspective

In the preparation of all forecasts, an examination should be made of the accuracy and assumptions employed in previous efforts. This would give an historical context and perspective that would aid in the accuracy, understanding and interpretation of the forecast. The reports mentioned above contain significant elements of historical documentation.

Personal Consultation:

The interpretation of documentary material, on whatever subject, is always enhanced by personal contact with staff involved in the production or use of that material. Among others, helpful resource people contacted for data and information in this study are listed below. It is important to realize that with employment turnover and organizational changes, individual personnel may come and go, but the institutional structure should be such that the data and information is maintained in a consistent and available manner.

Nicholas J. Del Grosso
of the Water Resources Planning Section is helpful in matters relating to sewage flows.

Thomas E. Gingrich
of the Water Resources Planning Section is helpful in matters relating to water production.

John W. DiLoreto
is helpful in matters relating to the plumbing code.

Thomas M. Fischer
of the Secretary's Office is helpful in matters relating to changes in consumption over time.

William Austin
is helpful in matters relating to water and sewer billing.

Marjorie L. Johnson
of the Public Affairs Office is helpful in matters relating to water conservation programs.

Montgomery County Planning Board of the Maryland-National Capital Park and Planning Commission

Documentary material including:

Comprehensive Planning Policies Report (annual)
This report contains a combined set of interrelated policies and data in one convenient reference volume. It also contains updated inventory data on development progress for County population and housing, and extracts of all previously adopted staging policies as contained in various master plans, sector plans and functional plans. The housing unit development status information is among the most important in this document. High, intermediate and low forecasts are compared with actual growth data. The latest population and employment forecasts are also given by Policy and Planning areas.

Long Range Forecast; People, Jobs and Housing

This publication, dated August 1979, presents a long range projection and analysis of population, households and employment growth to the year 2000 in Montgomery County and the Washington Region. It presents a more detailed Ten Year Forecast for Montgomery County. These forecasts are based on the Metropolitan Washington Council of Governments' (COG) Cooperative Forecasting Program. Round II and Round I Forecasts are compared; and high, low, and intermediate forecasts are given and defined. The high alternative is the greatest amount of growth which is foreseen to occur, whereas the low alternative is the minimum growth foreseen to occur. The intermediate forecast represents the County's attempt to forecast a most likely level of growth given the information available at the time the forecasts were developed. No probabilities of occurrence are associated with either of the extreme forecasts, but they are produced as an acknowledgement of the uncertainty inherent in forecasting and as a possible tool for use in risk assessment.

County Comprehensive Water and Sewer Plans

Under State law (Section 9-505, Health-Environmental Article), each county must adopt a plan that provides for the orderly expansion and extension of systems dealing with sewage, water supply, and solid waste disposal for at least a 10-year period. These plans are subject to review and approval by the State Department of Health and Mental Hygiene and are subject to periodic amendment or revision. The plans include:

1. present level of use and existing capacity for each sewage treatment drainage basin or service area,
2. population projections, anticipated treatment needs, and planned facilities,
3. water supply and waste disposal needs and planned facilities.

The population, housing and employment data and forecasts, as presented in these plans in recent years, have been drawn from the COG Cooperative Forecasting Program. They are based on county policy and planning areas, and extend by 5-year increments to the year 2000. In addition, current and future estimates of population (including ultimate capacity values) are given for major drainage basins in the county. This is of direct benefit in planning for sewer facilities. Recent plans have also tried to address the variability recognized in several of the influential factors affecting sewage flow. These include: growth rate forecasts, infiltration/inflow, water consumption, facility capacity rating, commitment policy and septic relief. Each factor and its possible effects are discussed. Household size (given in the 10-year plans) is an important factor used in converting from population estimates to numbers of housing units and then to water demand or sewer flow. Although much of the water and sewer data contained in the 10-year plans are doubtless supplied by WSSC, there is much to be gleaned in a qualitative sense for forecasting from the development and employment policies presented by the counties in those documents. An important function of the plans has been to attempt to define the "holding capacity" of the land; or in other words, its ultimate carrying capacity for development under present and future foreseen zoning limitations. This information is of great benefit to the WSSC for the planning of water and sewer facilities in that it helps define the present position in relation to the ultimate maximum potential demand for water and sewer services. Redevelopment, changes in the technology of water use and sewage generation, and other factors which continue to affect demand at full land use development must still be considered.

Personal Consultation

As stated in the Personal Consultation section under WSSC above, direct contact with relevant staff is helpful in complementing and interpreting published information. Those at Montgomery County included:

Nazir Baig

Environmental Planning Coordinator.

Robert Hnat

is helpful in matters concerning forecasts of dwelling units and holding capacity of the land in Montgomery County.

Prince George's County Planning Department, Maryland-National Capital Park and Planning Commission

Documentary material including:

<u>Growth Trends in Prince George's County and the Region: 1950-2000</u>

This report, published by the Research and Special Studies Division in November 1979, presents the growth and development trends expected to occur in Prince George's County from the mid-1970's to the year 2000. A good summary of growth from 1950 puts the future projections in perspective, and the County is viewed in the context of the entire Washington Metropolitan Area. The report focuses on the amount of growth that is likely to occur in population, households and employment. Projections are based on the then-current forecasts for the metropolitan area (Round II) and include descriptions of the basic process, methodology and assumptions. The report is concise, yet full of clearly stated detailed information and useful data, including: employment by industrial sector, average household size, dwelling unit completions, and a statement of assumptions used to produce low, intermediate and high future development scenarios. In addition, comparisons are made with previous forecasts of population and employment.

<u>Estimates and Forecasts of Dwelling Units, Population and Employment in Prince George's County</u>

This report, published in July 1981, presents useful information on the following subjects: assumptions used for dwelling unit and population forecasts 1980-2000; low, intermediate, and high alternative development scenarios; small area population forecast methodology; low, intermediate, and high alternative employment scenario assumptions; population/employment ratios; and employment forecasts by industrial sector. The degree of documentation of data and assumptions in this report contribute to making it a useful reference for water and sewer service demand forecasting.

<u>Forecasts of Growth in Prince George's County, Maryland: 1980-2010</u>

This document is sub-titled "Results of the Round III Cooperative Forecasting Program" and published in March 1984. It contains results of the most sophisticated analysis and assumptions to date, and is proportionately useful in preparing forecasts of future water and sewer use. Significant features include: geographic disaggregation by Policy Analysis Zone; 5-year interval forecasts to 2010; high, intermediate, and low development scenarios; household size projections; dwelling unit projections by single family and multi-family type; population projections by households and group quarters; and employment projections by industry group.

County Comprehensive Water and Sewer Plans
The Prince George's County 10-year Comprehensive Water and Sewer Plans provide substantially the same data and information with respect to development in this county as do the 10-year plans for Montgomery County, as previously described. This data includes estimates and forecasts of single and multifamily dwelling units, the COG intermediate population and employment values geographically disaggregated by sewer service areas.

Personal Consultation
Direct contact with the following personnel proved helpful with the interpretation of reference material:

Dominic J. Motta
of the Environmental Planning Division is knowledgable concerning 10-year Water and Sewer Plans.

Joseph Valenza
is helpful with the comparison of successive planning and forecasting efforts.

Metropolitan Washington Council of Governments

Documentary material including:

Cooperative Forecasting, Round III Technical Report - 1984
Data and information presented in this report form the basis of local and regional forecasts in the Washington Metropolitan Area. It contains forecasts of population, households and employment which are developed through a cooperative process involving the Council of Governments (COG) , its member jurisdictions, the states, and other planning agencies. This cooperative process is the best effort at producing local and regional forecasts which are coordinated in order to minimize local distortions. The report documents the forecasting process and

presents results for the period 1980-2010. In addition to local and regional forecasts, a geographic disaggregation is made on the basis of COG Analysis Districts. This is perhaps the most important and current document to be consulted when conducting forecasts for water and sewer services. As time passes, local jurisdictions may update their forecasts prior to the succeeding Round of Cooperative Forecasts.

Cooperative Forecasting, Round III Summary Report - 1984
This document presents the principal elements of the Round III Technical Report described above.

Personal Consultation

John McLean

confirmed that the Round III Technical Report contained a full comparison with previous Rounds.

Miscellaneous

Wolman reports
Early reports of consultants chaired by Abel Wolman on future sewerage requirements for the area present forecasts with factors of 100 gpcd, and 200 gal/acre/day infiltration; and commercial, industrial and institutional acreage with specified design gal/acre/day factors. Population projections, including ultimate capacity values, and forecasts of waste water flows are given for ten year intervals from 1960 to 2000.

Bi-County Water Supply Study
Considers existing demand for water and anticipated future demand. The report covers the subjects of future shortages, restrictions and structural solutions, although very little documentation of forecast assumptions is provided.

Other reports of studies involving demand forecasts for water and/or sewer services do exist. These include the Northeastern United States Water Supply Study and the Metropolitan Washington Area Water Supply Study, both by the U.S. Army Corps of Engineers.

Good forecasting practice involves the use of as much relevant data and information as time will permit, and subject to the intended application of the forecast. In partial fulfillment of this objective, demand forecasting techniques at the electric utilities in the Washington area were examined. The demands for gas and electric services have many similarities to those for water and sewer services. Therefore, an inquiry into the way in which that industry produces its forecasts of demand might uncover useful applications for water and sewage forecasting.

Baltimore Gas & Electric Company

Mr. Ernest Dawson, General Supervisor for Forecasting, provided the following information. Demand forecasting is performed on disaggregate customer groups: residential, commercial and industrial. The residential group is further disaggregated by similar types, and future estimates of housing starts and recent completions also factor into forecasts of demand. In addition, engineering models (those that rely on appliance censuses, usage and saturation rates) are applied to residential use forecasting. Commercial and industrial sector demand forecasts are functions of employment and industrial production. There is also some consideration of geographical distribution of demand, and the effects of price and income are analyzed. Sources of data for explanatory variables include: Chase Econometrics for industrial production indicies, employment, and personal income; the Regional Planning Council for demographic data; BG&E accounts for customer types and usage; and BG&E marketing surveys for residential appliance and industrial utilization information.

Potomac Electric Power Company

Mr. Edward Mayberry, Manager of the Forecasting Division, provided the following information. Electricity demand forecasting is carried out on several time scales; from hourly to long-term. Auto-regressive moving average (ARMA) models with transfer functions are developed and employed. Weather parameters drive demand: cooling degree days, humidity, etc. Other influential factors taken into account in modeling include: employment, price of product, price of household appliances. There is extensive customer disaggregation by major types of use (electric space heating, water heating, air conditioning) for all customers, and further commercial and industrial groups are based on size and pattern of demand. In addition, some geographic disaggregation is performed. Relatively sophisticated sensitivity analysis is performed with Monte Carlo simulation techniques in order to derive a probabilistic range of forecasts. Sources of data for explanatory variables include: Chase Econometrics for long-term macro economic forecasts; Bureau of Labor Statistics, Bureau of Census, Commerce Department (in general) for historic data. Based on these data Pepco has developed its own models for forecasting employment and demographic information.

WSSC planning staff develop disaggregated demand factors (coefficients) on moderately large and relatively homogeneous customer groups. The demand factors are derived from recent historical data and modified in order to take into account technological, socio-economic or other influences. Forecasts of customer groups are obtained from independent agencies whose responsibility it is to produce them. The demand factors are then applied to the future values of constituent groups in order to obtain aggregate forecasts. This format of producing forecasts is consistent with best practices of demand forecasting by water utilities, and closely approximates the level of detail pursued in the local electric utilities.

TASK 2

Analyze unit production and flow factors with respect to WSSC property codes, service types and counties.

WSSC Design Manual

The Commission follows the practice of maintaining a Design Manual which covers the minimum standard criteria to be followed by design engineers when preparing plans and/or specifications for the construction of water and sewerage systems in the WSSD. It contains equations for developing demands for water and sewer services. Appendix D contains Flow Factors (coefficients) for use with those equations when applied to numerous types of water uses, including types of housing, and educational, retail and commercial properties. The same factors are to be used for both water demand and sewage flow forecasts, with no apparent allowance or differentiation for water main transmission losses, inflow/infiltration or other characteristics which distinguish between water and sewage. The use of these Factors might be improved by geographic differentiation and documentation refering to the method and date of their derivation. Appendices E and F contain Dwelling and Acreage Factors respectively for the various land use zoning classifications differentiated by County only. Again, there is no supporting information as to date or method of derivation.

Billing System Information

WSSC maintains relatively detailed customer records which contain the twelve most recent transactions and identify each account by property type (18 codes), service type (8 codes), regional location (200 ft sheet number), and minibasin. More of this information could be used to develop locally disaggregate base factors for both water production and sewage flows.

Distribution System Storage Study (Project 6.02) June, 1980
Chapter IV of the report of this study contains an analysis of then-existing and projected water demands. The approach is thorough and the data and assumptions are well documented (i.e. future demands are based on Round II forecasts). The demands are disaggregated by distribution pressure zones or groups of zones. The results also include maximum day and peak hour factors and demands.

Water Production Report Through June, 1982
The purposes of this report include documenting historical water demand, presenting a procedure for determining water consumption for single family and multifamily residential and employment accounts, and developing data to be used for planning future improvements. Future demands are based on Round II results of the Cooperative Forecasting Program. The price of water and weather are acknowledged as influencing the demand for water, although their effects are not explicitly taken into account in the examination or forecasting of demand. Analysis by pressure zone and type of account should be especially useful to the Commission in forecasting. The procedure developed for determining unaccounted for water by pressure zone should also be helpful in determining the effects of leak detection and elimination on water production. Now that the Round III cooperative forecasts of housing and employment are available, the intentions of producing periodic updating of the analysis should be carried out.

Residential Flow Factor Analysis (Contract No. 83MM1093-A)
This report describes a well documented project to update the derivation of sewage flow factors. It is dated November 1984, and is the first major analysis of flow factors since the work of Klein, reported in 1979. Flow factors are developed for four residential property codes and two composites of single and multifamily dwellings for the WSSD. Factors are also derived for inflow and infiltration. In addition, a factor was assumed in order to cover all uncertainties, including meter misregistration. This study explicitly takes into account the effects of weather by normalizing annual sewage flow with respect to

rainfall. It is indicated that sewage flows in recent years are less responsive to rainfall, which is perhaps due to successful system-wide efforts to reduce inflow and infiltration.

In summary, there is sufficient data and methodological information available at WSSC for the production of forecasts which are disaggregated on the basis of property codes, service types, and pressure zones. And, with the implementation of the sewer system model, it should be possible and desirable to develop some form of flow factors on a sewage drainage area basis. The degree of disaggregation should be determined by a study of the difference in water use and sewage characteristics among the classified codes, types and zones.

TASK 3

Analyze (and use where appropriate) the effects of changes in price and income.

On closer inspection of the WSSC rate schedule for both water and sewer services, and the variety of service types; time would not allow the level of detail necessary to address this task as it was originally set out. For instance, during the first year of the period of analysis, flat rates were charged for water and sewer services. During the remaining six years, a sliding scale on one hundred rate steps was in effect. Such rate schedules are notorious for confounding the price of a commodity under investigation.

In this case, the analysis might proceed by determining the quantity of water consumed and of sewer services required during each month in each service type. In this way, a weighted average price per month may be determined and compared with personal income and quantity of water consumed (and sewage generated). For reference and possible future application, data on personal percapita income and retail price index are provided in Tables 2 and 3.

TABLE 2 1976-1983 Personal Percapita Income
Montgomery and Prince George's Counties

Year	Mont.	P.G.'s
1976	10128	7005
1977	11055	7749
1978	12304	8490
1979	13890	9361
1980	15641	10400
1981	16998	11172
1982	18375	12031
1983	19738	12939

TABLE 3 1976-1983 Washington Area Retail Price Index

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
76		178.4			182.2			185.5			188.1	
77	190.2		191.5		194.2		197.8		200.8		203.9	
78	208.7		212.6		216.0		220.4		222.9		225.4	
79	231.9		238.8		241.2		247.2		249.2		253.6	
80	257.2		262.3		264.7		271.4		271.8		275.5	
81	278.0		278.8		278.4		281.3		286.5		286.3	
82	289.0		289.0		292.6		296.8		300.9		302.7	
83	303.7		305.1		305.7		308.3		313.0		319.2	

The work of Thomas M. Fischer of the Secretary's Office indicates that consumption in both commercial and single family residential accounts has shifted toward lower usage successively between the winters of '76-'77 and '80-'81, and between '80-'81 and '81-'82. No account appears to have been taken of differences in weather patterns which may have affected consumption during these years.

Other reports by McGarry and Brusnighan, Arthur P. Brigham, and others tend to confirm the move toward lower consumption since the introduction of the Conservation Orientated Rate Structure in January 1978.

Thus, there has been some analysis of the effect of price and rate structure on production of water at WSSC, but it has been sporadic and inconsistent. There is, however, no straightforward methodological analysis applicable in a case with a rate structure as complex as this one. Any attempt at analysis should clearly state the assumptions which are made.

TASK 4

Investigate and incorporate uncertainty due to weather into water production and sewage flow forecasting techniques.

"As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality." Einstein

Having regard for Einstein's reflections on the applicability of uncertainty, it is still good practice to describe future expectations in terms of their likelihood of realization. The WSSC forecasting capability and practice for water and sewer services includes the use of exceedence probabilities of moisture deficit in short term revenue forecasting, and normalization with respect to rainfall in sewage flow forecasting. The moisture deficit information was developed by consultants in 1980 and has experienced some problems with credibility and implementation, although the concept of exceedence probabilities is gaining acceptance in some areas. The rainfall normalization analysis of sewage flows was carried out by Bruce T. Downes of the Planning and Engineering Division and described in reports dated November 1984. These are good examples of how, by removing some of the effects of weather, the underlying pattern of sewage flow is exposed for further analysis and forecasting.

Further investigation was carried out as part of the present work in order to confirm the relationships between weather and the demand for services. Water production, sewage flow, rainfall and temperature data were collated for analysis. Monthly data were examined for the years 1977-1984. Plots of water vs sewage, and water and sewage vs rainfall and temperature were prepared (Figures 1 - 5). This type of data presentation is often useful in developing lines of further investigation. Clear relationships are seen between water and sewage, rainfall and water, and rainfall and sewage.

FIGURE 1
1977-1984 Water Production and Sewage Flow

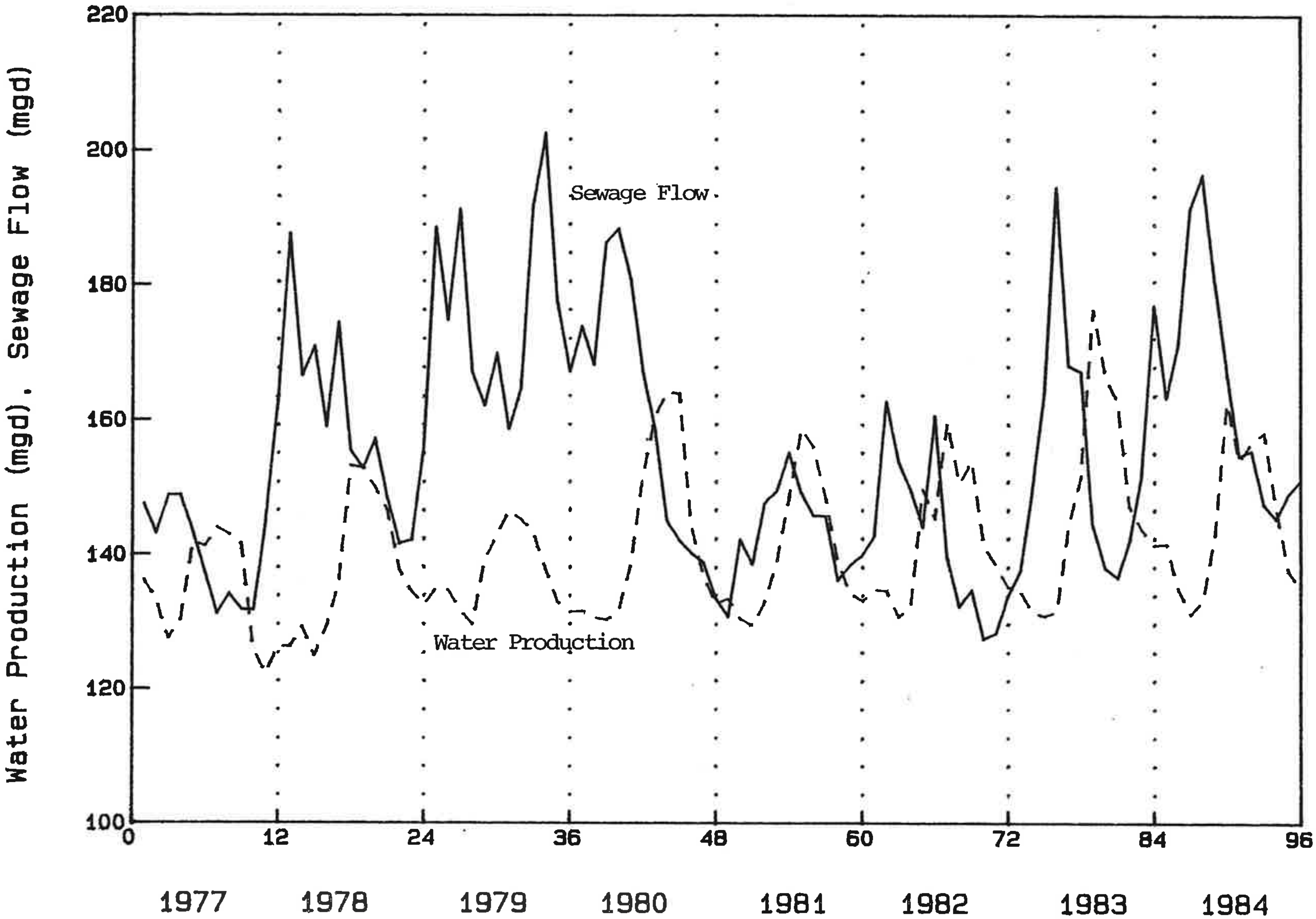


FIGURE 2
1977-1984 Water Production and Precipitation

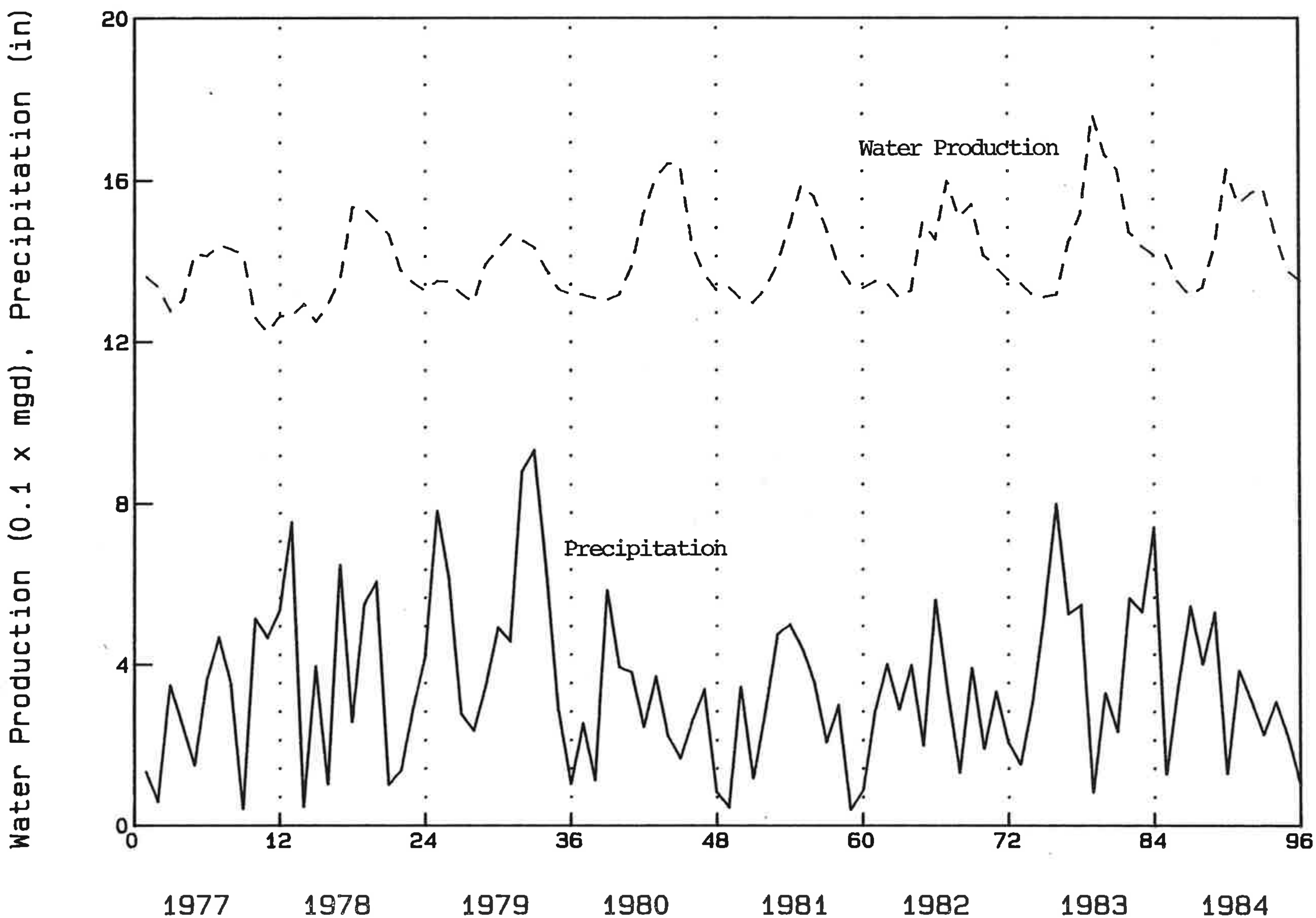


FIGURE 3
1977-1984 Water Production and Temperature

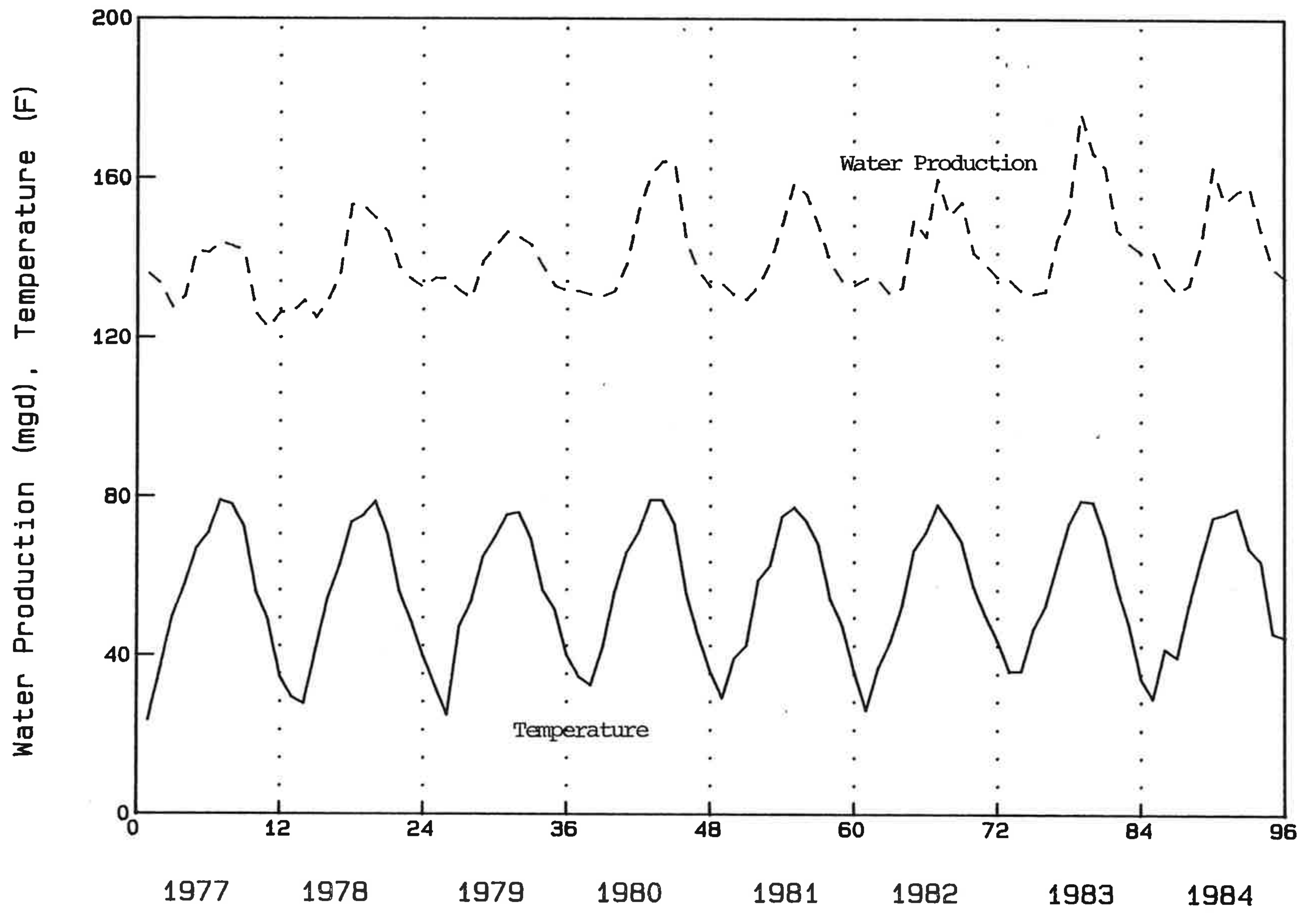


FIGURE 4
1977-1984 Sewage Flow and Precipitation

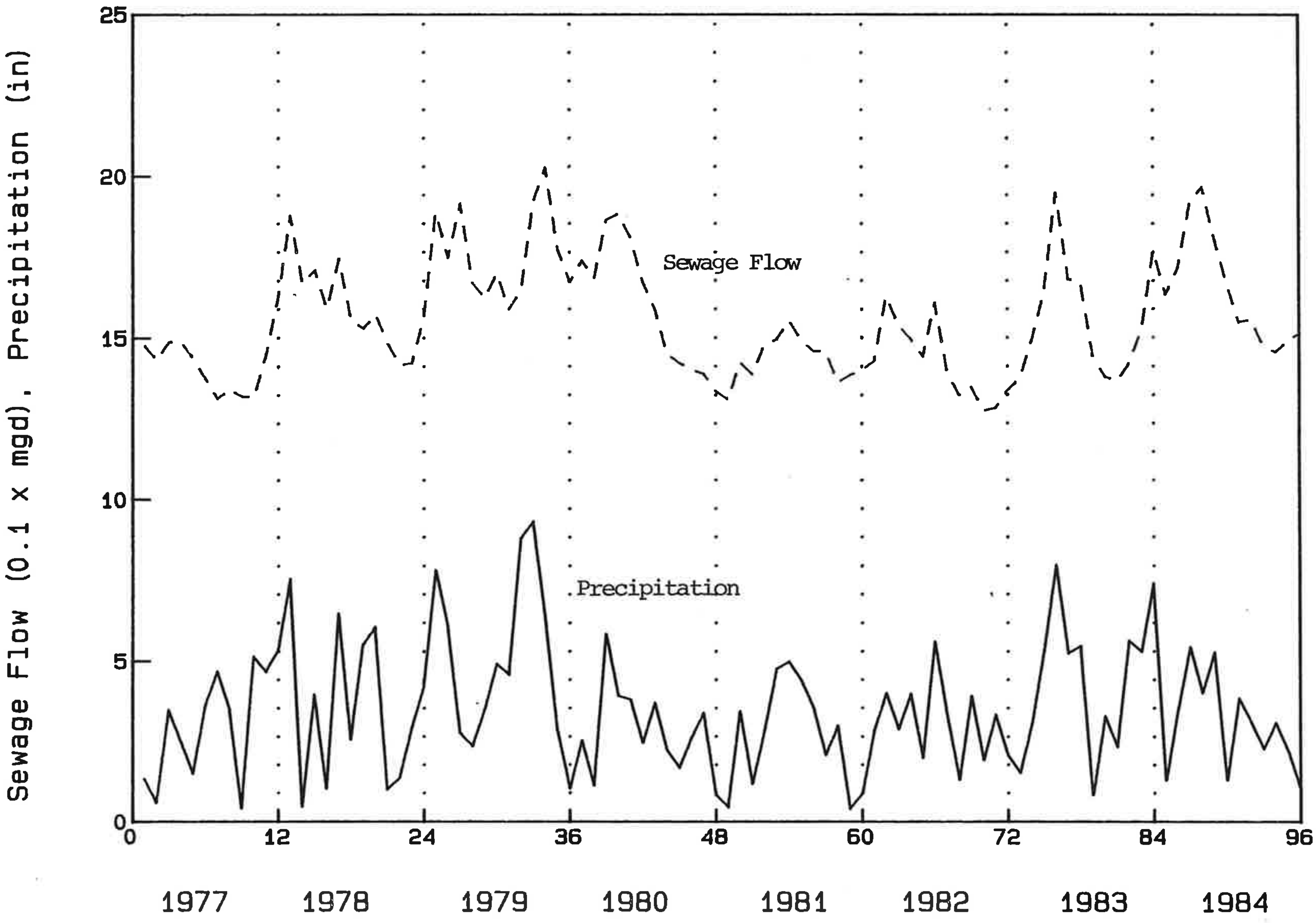
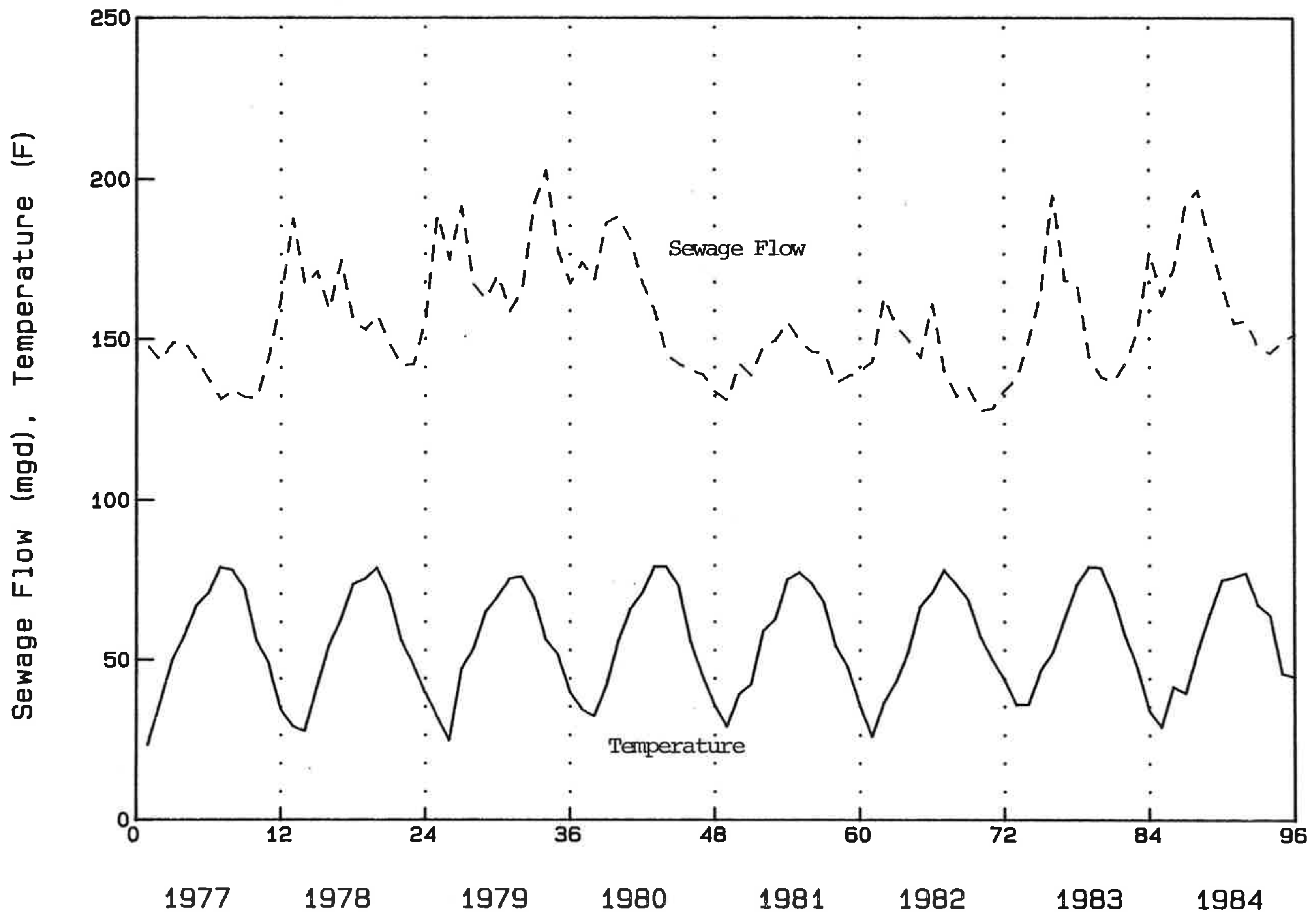


FIGURE 5
1977-1984 Sewage Flow and Temperature



Statistical correlations of monthly and annual data indicated that 1977 was an outlier, especially in water production data. It is always a matter of some judgement as to how long a period of historical record should be analyzed when deriving functional relationships to be used in forecasting. In general it should be as long as possible, provided that influential changes in the explanatory variables can be taken into account. In this case the rate structure underwent a significant change in January 1978 with appreciable antecedent publicity. Without further analysis, which is beyond the scope of this study, it is difficult to assess the effect of that change, and because it coincided with only the first year chosen for investigation, 1977 data might be dropped from further consideration.

The influence of both rainfall and temperature could be seen to vary through the year, i.e. heavy rainfall in early spring produces a greater response in sewage flow than a similar quantity of rain in late summer. It was hoped to capture some of the quantitative effects of this phenomenon by comparing cumulative monthly average temperature and rainfall with average annual water production and sewage flows. The results of this analysis were disappointingly inconclusive, and no significant statistical inferences could be drawn.

The motivation for performing statistical analysis of this nature is the resulting quantification of uncertainty in past experience. This knowledge of uncertainty can then be transferred (with some degree of confidence) to forecasts of future expectations.

There is still considerable room for improvement in removing the effects of weather in past water production and sewage flow data prior to forecasting. The combined effects of rainfall and temperature could be analyzed by joint functions such as moisture deficit, the annual cycle and variations in evapotranspiration, and drought indices. With these unpredictable influences removed and explained in probabilistic terms, the underlying trends due to changes in demography, housing and employment could be more easily determined and predicted. More complete forecasts could then be produced by imposing the probabilistic influence of weather.

An example calculation of such a forecast is presented in the description of Task 7.

TASK 5

Obtain and incorporate alternate development scenarios.

The most appropriate source of alternate scenarios is the Cooperative Forecasting Program of Metropolitan Washington Council of Governments. The most recent (Round III) cooperative forecast does present alternate scenarios of future conditions. The definitions of the alternatives incorporate explicit assumptions for the three scenarios. A summary is reproduced here for example purposes (Table 4).

Detailed documentation of alternate scenario assumptions is also provided in Estimates and Forecasts of Dwelling Units, Population and Employment in Prince George's County, July 1981. These assumptions are applicable to Round II Cooperative Forecasts and are reproduced here for historical comparison (Tables 5 and 6).

TASK 6

Present examples of forecasts which are conditioned on discrete assumptions about the future.

This concept follows directly from the previous subject. A forecast which would result from the use of alternate development scenarios would have several values of future conditions at each point in time. For example: low, intermediate and high; based on documented assumptions about the explanatory variables. The WSSC document Flow Projections for Workload Indices presents forecasts based on 5 discrete assumptions about future conditions:

1. a 15 year trend extrapolation,
2. a 10 year trend extrapolation,
3. a 5 year trend extrapolation,
4. Round III Cooperative Forecast results, and
5. Workload Indices for FY 86 budget preparation.

Another example might be to use the alternate development scenarios from the Round III Cooperative Forecast for each of the counties in order to produce alternate forecasts for water and sewer services. These would have to take into account the fact that WSSC does not serve all the outlying county areas which are subject to the Cooperative Forecasts. If the county scenarios are adopted, three scenarios would be applicable to forecasts for each county. Thus, potentially expanding the number of forecasts to 9 for the WSSD. Some judgement must be exercised when constructing scenarios in order to keep the numbers manageable. Perhaps in this case, forecasts for the WSSD could be based on scenarios limited to high/high, med/med, and low/low for the two counties, respectively.

TABLE 4

SUMMARY OF SCENARIOS

	LOW GROWTH SCENARIO		INTERMEDIATE GROWTH SCENARIO		HIGH GROWTH SCENARIO
1.	Continued decline in Federal employment until 1987, then stabilizing.	1.	Federal employment continues to decline until mid-1980s, then begins to grow again but at a lesser rate than in the past.	1.	Federal job growth assumption is the same as for the intermediate scenario.
2.	A slowdown in the rapid growth in services sector jobs, sluggish growth in others; decline in manufacturing after 1990.	2.	Steady growth of employment in services and retail trade sectors, as well as in other sectors; modest growth in manufacturing jobs.	2.	Strong growth in information-based employment causes structural shift to a more "high technology" region. Services, transportation/communications/utilities and manufacturing sectors all experience much higher rates of growth than under other scenarios.
3.	Overall lower pace of job growth, and therefore lower population increase.	3.	Overall moderate pace of job and population growth.	3.	Overall strong growth in jobs causes strong population increase.
4.	Low level of housing and commercial construction.	4.	Housing and commercial construction resume healthy pace.	4.	Construction of new housing and commercial buildings reaches highest levels.
5.	Less in-migration to region due to poor employment growth prospects.	5.	Continued in-migration to region due to growth in suburban employment centers.	5.	Such strong job growth that in-migration reaches highest historic levels, mostly to burgeoning suburban employment centers.
6.	A lessening of national economic recovery and return to cycles of recession and high inflation.	6.	National economic recovery continues with an abating of inflationary pressures.	6.	Strong national economy with high rates of real growth in all sectors.
7.	Unemployment rate higher than traditional regional levels, more akin to national rate.	7.	Unemployment rate lower than national rate and declines as more jobs are created in all sectors.	7.	Unemployment rate same as for intermediate scenario, indicating persistence of structural unemployment.
8.	Lower rate of multiple job holding, more self-employed people.	8.	More people working two jobs, fewer self-employed people due to healthy economy.	8.	Same assumptions for multiple job holding and self-employed (omitted) jobs as for intermediate scenario.

TABLE 5

DWELLING UNIT
SUMMARY METHODOLOGY

Period	LOW	INTERMEDIATE	HIGH
1976 to 1980	Single-Family • Same as intermediate. Multifamily • Same as intermediate.	Single-Family • Completions estimated from Building Permits equation (70-76) from 1977 and 1978. 1979 completions is average 1977 and 1978. Multifamily • Completions estimate from sewer authorizations to 1980 excluding any with legal or site plan problems.	Single-Family • Same as intermediate. Multifamily • Same as intermediate.
1980 to 1985	Single-Family • Completions are extrap-olocation of 1970-1976 rate of growth. Multifamily • Completions based on the 1977-1980 annual average of sewer authorizations excluding the ones with any problems associated.	Single-Family • Completions are the average of the extrapolation of short term and longer term trends. Multifamily • Average of the low and high rates.	Single-Family • Completions are extrap-olation of 1960-1977 rate of growth. Multifamily • Completions based on the 1977-1980 average sewer authorizations.
1985 to 1990	Single-Family • Completions are extrap-olation of 1970-1976 rate of growth. Multifamily • Completions based on these units being 40% of the housing stock.	Single-Family • Completions are the annual average rate of completions 1960-1977. Multifamily • Completions are based on the 1977-1980 average sewer authorizations.	Single-Family • Completions are extrap-olation of 1960-1977 rate of growth. Multifamily • Residentially determined assuming Prince George's maintains 21% of region's housing (less 5,000 units to smooth the curve).
1990 to 1995	Single-Family • Completions are extrap-olation of 1970-1976 rate of growth. Multifamily • Completions based on these units being 39% of the stock.	Single-Family • Completions are the annual average rate of completions 1960-1977. Multifamily • Completions are based on the 1977-1980 average sewer authorizations.	Single-Family • Completions are extrap-olation 1960-1977 rate of growth. Multifamily • Residentially determined assuming Prince George's maintains 21% of region's households.
1995 to 2000	Total Units • Completions based on Prince George's maintaining a constant share of a growing region.	Single-Family • Completions are the annual average rate of completions 1960-1977.	Single-Family • Completions are extrap-olation of 1960-1977 rate of growth.
1995 to 2000	Single-Family • The residual after sub-tracting multi-family units. Multifamily • Completions based on these units being 38% of the housing stock.	Multifamily • Completions are based on the 1977-1980 average sewer authorizations.	Multifamily • Residually determined assuming Prince George's maintains 21% of regionals households.

TABLE 6

SUMMARY METHODOLOGY OF EMPLOYMENT ALTERNATIVES BY YEAR

	Low	Intermediate	High
1980 and 1985		Maryland Department of State Planning Employment Projections	
1990	Share Analysis low at 15.7% of the region	Share analysis high at 15.7% of the region	Ratio of population/ employment improves to 2.47% or 0.70% of the region
1995	Share analysis low at 16.4% of the region	Ratio of population/ employment is 2.25% or 0.73% of the region	Share analysis high at 16.4% of the region
2000	Share analysis low at 16.9% of the region	Ratio of population/ employment is 2.13% or 0.74% of the region	Share analysis high at 16.9% of the region

SOURCE: Memorandum to Prince George's County Council, December 7, 1978, "Recommended Forecasts of Population, Households and Employment for Approval for Submission to COG and for Use in Prince George's County", Prince George's County Planning Department, Research and Special Studies Division.

TASK 7

Present example probabilistic forecast in terms of probabilities of exceedence.

Most water demand forecasts are deterministic in that they provide only one scenario. Typically, no attempt is made to assign any level of likelihood to these forecasts whereas water use does contain random components. The randomness (uncertainty) of water use can be quantified in the form of a classical probability distribution which is derived from historical data and applied to expected (base) future demand. Given this information, water system managers are better equipped to make decisions as to the level of risk with which to operate. The presentation of water use and sewage flow as stochastic phenomena impacts all other aspects of demand forecasting: price effects, conservation measures, revenue estimation, effects of weather, system planning, etc. In the following example the historic probability distribution is derived for sewage flow and a forecast is presented as being within confidence limits and as being below probabilities of exceedence. Either or both of these presentation formats may be applicable.

Base forecasts (sewage flow factors and water production factors times numbers of units) should have the same interpretation as the historic normalized data. After determining the probability density function from the historic data, it is applied at selected levels to the base forecast in order to produce forecasts which are explicitly probabilistic.

In this example, the work of Downes (1984) on sewage flow forecasts is extended as a probabilistic forecast. Nine years of data are used in the derivation of the probability distribution.

A regression of the Normalized Flows on 2-digit FY's (eg 77,78) produces the following information:

$$Req\_Normal = 12.7 + 1.74FY \quad (1)$$

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	12.73	24.50	0.52
FY	1.7367	0.3023	5.75

Standard Error = 2.342

R-SQUARED = 82.5 PERCENT
R-SQUARED = 80.0 PERCENT, ADJUSTED FOR DEGREES OF FREEDOM
Correlation Coefficient = 0.9083

Thus, now for each FY, there are values for actual flow, normalized flow, and a point on the regression line of normalized flows (Reg_Normal).

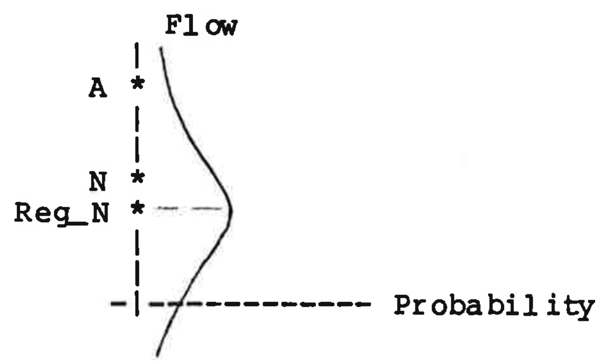
TABLE 7 1977-1985 Normalized Sewage Flow Data

FY	Sewage Flow	Water Consumed	Normalized Sewage	Regressed Norm. Sew.	NFFadj
77	147.20	137.5	148.2	146.7	0.9966
78	154.20	133.4	146.5	148.5	0.9630
79	162.62	138.9	149.4	150.2	0.9236
80	177.22	137.4	154.4	152.0	0.8577
81	143.44	142.9	153.6	153.7	1.0715
82	147.32	141.3	152.5	155.4	1.0548
83	148.01	142.1	153.6	157.2	1.0621
84	163.24	148.5	159.6	158.9	0.9734
85	151.75	146.2	162.8	160.7	1.0590

With this information, adjusted normalized flow factors (NFFadj) are calculated for each year by equation 2.

$$NFFadj = \frac{Reg\_Normal}{Actual\ Flow} \qquad (2)$$

In any particular year;



Reg_N is the estimate (regression value) of normalized flow, and the actual flow value is assumed normally distributed about that estimate of N in a random manner due to the effects of precipitation. Thus the quantification of the probability distribution of NFFadj is required in order to produce the transformation from Req_N to Actual Flow. Under the assumption of being normally distributed, the mean ($\overline{NFFadj}$) and standard deviation (sNFFadj) are required.

In this case:

$$\overline{NFFadj} = 0.99576$$
$$sNFFadj = 0.073735$$

The fundamental relationship (from Downes, 1984) is contained in equation 3.

$$\text{Actual Flow} = \frac{\text{Normalized Flow}}{\text{Normalized Flow Factor}} \qquad (3)$$

In order to introduce probability into the calculation of Actual Flows, equation 3 is modified to the form given in equation 4.

$$\text{Actual Flow}(p) = \frac{\text{Req\_Normal}}{\overline{NFFadj} \pm t(p)sNFFadj} \qquad (4)$$

Where, t(p) is a standard normal factor selected at a desired level of probability (p) from a table of standard normal distribution function values. Table 8 is reproduced here for reference.

The solution to equation 4 provides the range of values about the regression line of Normalized Flow within which the Actual Flow is expected to fall with the probability (p) associated with the selected t(p) value.

Referring to Table 8, and requiring an interval within which Actual Flows are 90% likely to fall, t(p) values of ± 1.645 are selected. Similarly, for an 80% probability (or confidence) interval, t(p) = ± 1.282. Upper and lower interval values for the 90% and 80% confidence levels are given in Table 9. In some forecast applications, the lower interval values may be of little significance, and only the upper limit is of importance to decision-making. The standard function Table 8 contains cumulative probability density function values; therefore, the Actual Flow values with a 5% probability of exceedence are given by the upper 90% interval values, see Figure 6, and those with a 10% probability of exceedence are given by the upper 80% interval values, and so on.

It should be noted that the interval values diverge, that is, the confidence bands are not parallel. This condition follows from Equation 4 for flow values at selected levels of confidence. An algebraic example illustrates this point:

$$Au = \frac{RN}{D-} \qquad Al = \frac{RN}{D+}$$

$$A'u = \frac{RN + c}{D-} \qquad A'l = \frac{RN + c}{D+}$$

where:

- Au,l = flow in an earlier year at upper and lower confidence levels
- A'u,l = flow in a later year at upper and lower confidence levels
- c = the increment by which RN increases between the earlier and the later year
- RN = regressed normalized flow
- D+,- = denominator with + or - applicable.

The confidence interval in the earlier year would be:

$$Au - Al = \frac{RN}{D-} - \frac{RN}{D+}$$

and the confidence interval in the later year would be:

$$A'u - A'l = \frac{RN + c}{D-} - \frac{RN + c}{D+}.$$

The confidence interval is diverging if:

$$[(A'u - A'l) - (Au - Al)] > 0$$

Test:

$$\frac{RN + c}{D-} - \frac{RN + c}{D+} - \left(\frac{RN}{D-} - \frac{RN}{D+}\right) > 0 \text{ ?}$$

$$\frac{RN + c}{D-} - \frac{RN + c}{D+} - \frac{RN}{D-} + \frac{RN}{D+} > 0 \text{ ?}$$

$$\frac{RN}{D-} + \frac{c}{D-} - \frac{RN}{D+} - \frac{c}{D+} - \frac{RN}{D-} + \frac{RN}{D+} > 0 \; ?$$

$$\frac{c}{D-} - \frac{c}{D+} > 0 \; ?$$

Yes, since the term with the smallest denominator (D-) is greater than the term with the larger denominator (D+). The condition may be explained further by the fact that the confidence level flow values (Equation 4) are derived by a ratio whose denominator is the sum or difference of two constants, while the numerator increases through time.

For clarity, Figure 6 shows the relation among cumulative probability, confidence interval, and probability of exceedence.

FIGURE 6 Relation among Cumulative Probability, Confidence Interval, and Probability of Exceedence

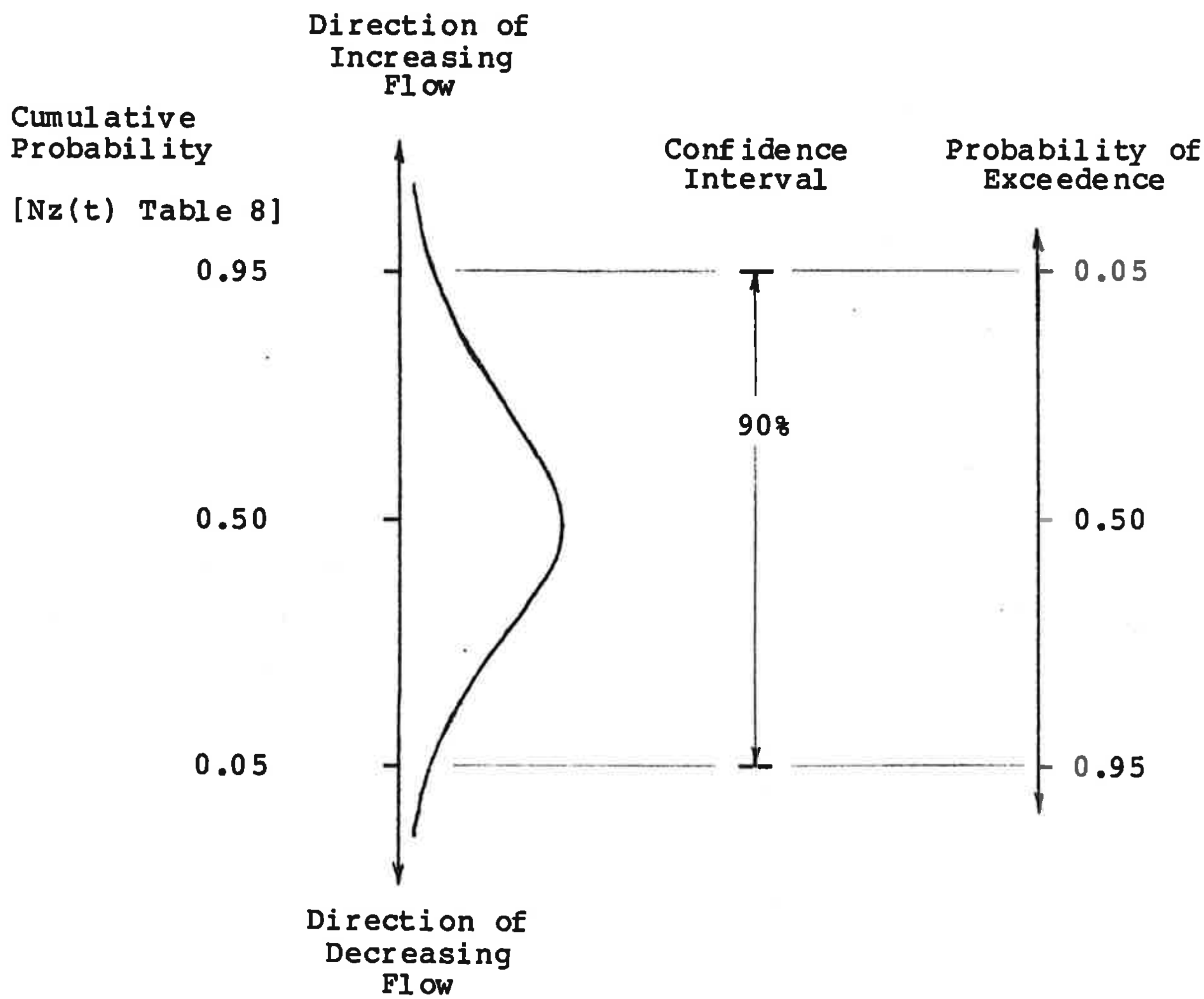


TABLE 8

Standard Normal Distribution Function

$$N_Z(t) = \int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz$$

t	0	1	2	3	4	5	6	7	8	9
−3.	.0013									
−2.9	.0019	.0018	.0017	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.0	.0227	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0300	.0294
−1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1921	.1894	.1867
−.7	.2420	.2389	.2358	.2326	.2297	.2266	.2236	.2206	.2177	.2148
−.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

Standard Normal Distribution Function (*continued*)

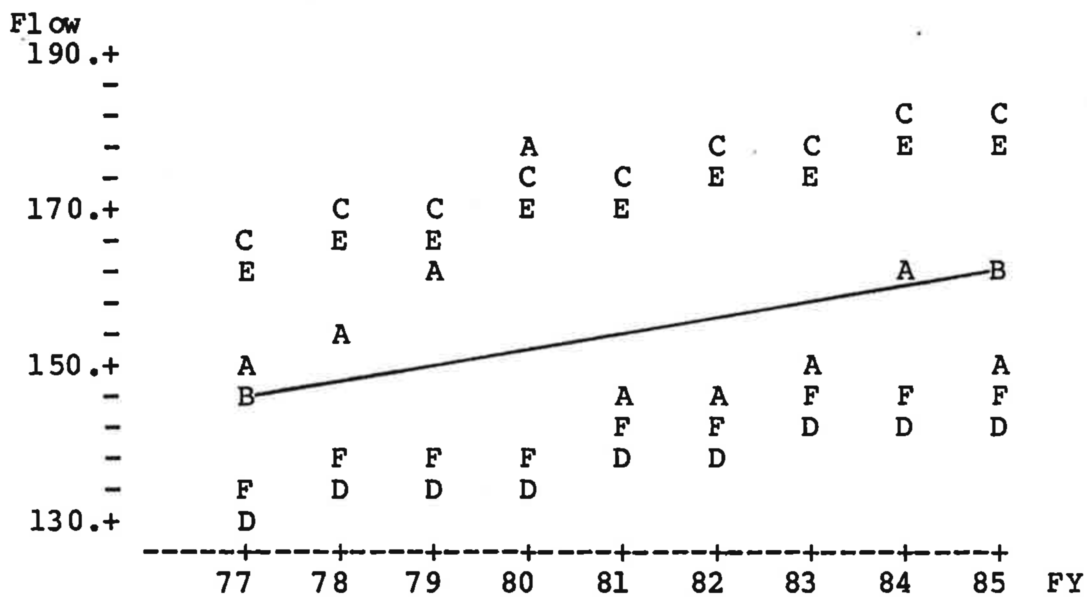
t	0	1	2	3	4	5	6	7	8	9
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8079	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9700	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9773	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.	.9987									

TABLE 9 Upper and Lower 90% and 80% Interval Values

FY	A.90up	A.90lo	A.80up	A.80lo	Regressed Norm. Flow
77	167.735	131.407	162.795	134.606	146.7
78	169.723	132.965	164.725	136.203	148.5
79	171.712	134.523	166.656	137.799	150.2
80	173.701	136.081	168.586	139.395	152.0
81	175.690	137.639	170.516	140.991	153.7
82	177.679	139.198	172.447	142.587	155.4
83	179.668	140.756	174.377	144.183	157.2
84	181.657	142.314	176.308	145.779	158.9
85	183.646	143.872	178.238	147.375	160.7

These examples are shown in Figure 7.

FIGURE 7 Upper and Lower 90% and 80% Interval Bands



Where: A = Actual Flow
B = Regressed Normalized Flow
C = Upper 90% Interval
D = Lower 90% Interval
E = Upper 80% Interval
F = Lower 80% Interval

In order to produce a probabilistic forecast, selected interval or exceedence probability values can be calculated from a base forecast in a similar manner. However, the base forecast must have approximately the same meaning as the historic Normalized Flows; that is, the base forecast must be essentially a forecast of the historic normalized flow regression. In this case, equation 5 would be the appropriate forecast formula.

$$\text{Actual Forecast Flow}(p) = \frac{\text{Base Flow Forecast}}{\overline{\overline{NFFadj}} \pm t(p)sNFFadj} \qquad (5)$$

The following illustrative example of a forecast, with a 10% probability of exceedence, shows the slope of the Base Forecast increased to 2.0 mgd/yr beyond the historic data period where the slope of the Normalized Flow regression line was 1.74 mgd/yr.

$$\text{Actual Forecast Flow}(10\%) = \frac{\text{Base Flow Forecast}}{\overline{\overline{NFFadj}} - 1.282sNFFadj} \qquad (6)$$

Where:

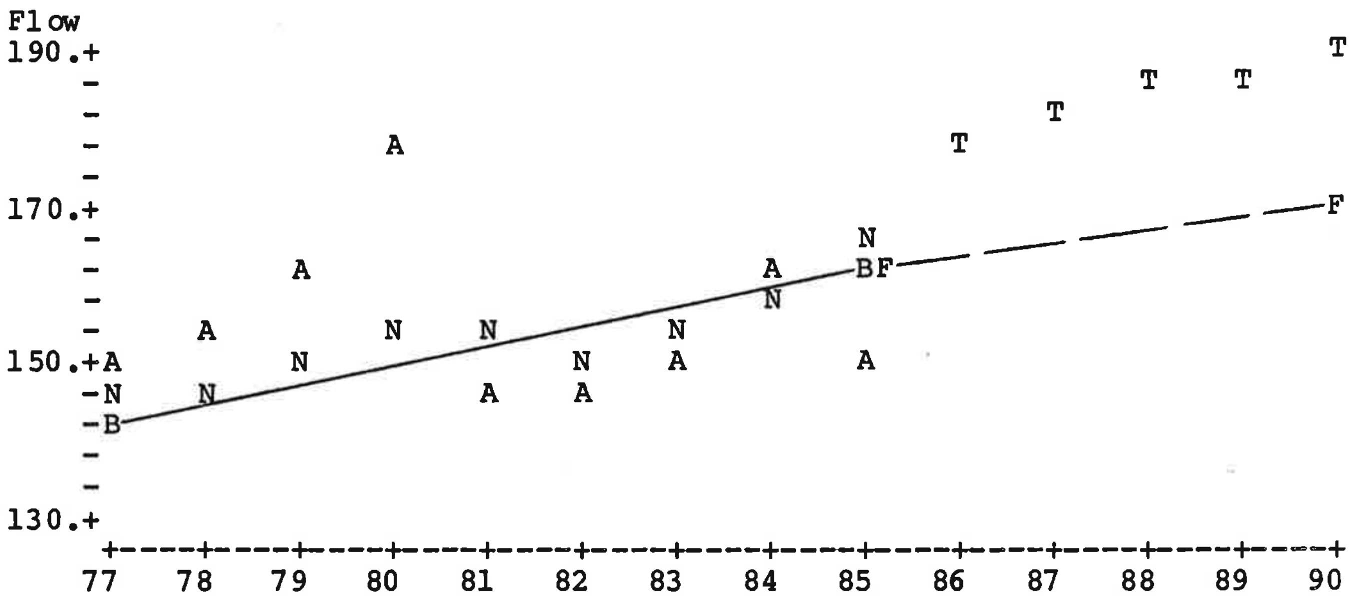
$$\text{Base Flow Forecast (slope)} = 2.0 \text{ mgd/yr} \qquad (7)$$

The relevant data and results for this example are given in Table 10 and shown in Figure 7.

TABLE 10 Example 10% Exceedence Forecast Data

FY	Base Flow Forecast	Forecast Flow with 10% Prob. of Exceedence
86	162.7	180.5
87	164.7	182.7
88	166.7	185.0
89	168.7	187.2
90	170.7	189.4

FIGURE 8 Example 10% Exceedence Forecast



Where: A = Actual Flow
B = Regressed Normalized Flow
C = Normalized Flow
F = Base (Normalized) Forecast
T = 10% Exceedence (Actual) Forecast

Further elements of uncertainty can be incorporated into analysis and forecasting. These include probabilistic assignments to the future levels of other explanatory variables. For instance, if distribution functions are assigned to alternate scenarios of future population, housing units and employment, these could be combined with each other and those of the Normalized Flow Factors. The resulting forecast could be presented in terms of joint probabilities of exceedence based upon all the chosen explanatory variables.

TASK 8

Ex-post examination of previous plans and forecasts for historical accuracy, bias and variance.

This Task, together with Task 1, most directly address the main issue of this study. A memo from Vice Chairman Jesse L. Maury to the other Commissioners and the General Manager dated October 17, 1984 discusses work load indices for FY '86 budget preparation. The primary subject of the memo concerns WSSC water production and sewage flow trends, and draws a comparison between Mr. Maury's extrapolation of short term historical trends and a forecast prepared by WSSC staff and reproduced in the report Flow Projections for Workload Indices by Mr. Bruce T. Downes dated November 7, 1984.

In the context of the results of this study, the forecasting methods employed by WSSC staff have greater merit.

The forecasts produced by WSSC staff are generally consistent with best contemporary practice; they are based upon unit use coefficients applied to disaggregated groups of customers (the forecasts of which have been estimated by independent agencies). The unit use coefficients (factors) are derived by WSSC staff in a very logical and conscientious manner. On the contrary, the straight line projections of past trends in raw data for total sewage flow and water production fall far short of good forecasts, given the fact that so much other relevant information is readily available.

In an attempt to reduce the computational burden, Mr. Maury (1984) constrained the intercept of his trend lines to the first data value in the time series of his analysis. This has the effect of skewing the slope (growth rate), which is the most important parameter value to be derived from the analysis. The same data produce the unconstrained slope values given in Table 11 for comparison.

Table 11 Analysis of Trend Slope Data

	Mr. Maury's Slope with Constrained Intercept	Slope with Unconstrained Intercept	Corr. Coef.
1975-1984 Water Production	0.60 mgd/yr	1.33 mgd/yr	0.87
1972-1984 Sewage Flows	0.14 mgd/yr	0.072 mgd/yr	0.03

Note: these analytical results are based on actual flows, not normalized flow.

Thus, the effect of constraining the intercept is to halve the growth rate for water production, and to double the growth rate for sewage flows. The savings in computational burden do not appear to be justified in the light of the relative magnitude of skew introduced into the results.

The following sewage flow and water production factors were used in the work described by Mr. Downes (1984):

	Sewage (gpd)	Water (gpd)
Single Family Dwelling Units	350	270
Multi-family Dwelling Units	330	253
Employment (Montgomery Co.)	49	60
(Prince George's Co.)	73	60

The source of information for numbers of dwelling units and employment figures is not made clear in the memo.

Sewage flows from 1972 to 1984, normalized for variations in annual rainfall, are represented by a regression line which shows an annual increase of 2.3 mgd. The forecasts just described used the normalized FY '84 flow as the base from which to start. A better base would have been the flow for FY '84 represented by the regression line; the implication being that it is the normalized flow which is being forecast, and that the regression line is its representation during the recent past. The 1984 base represented by the regression would be approximately 2.5 mgd lower than the normalized flow for FY '84, and thus each of the values in the forecast should be reduced by that amount.

The history of sewage flow factors used at WSSC is documented in the report <u>The Development of Sewage Flow Factors and Their Use in Forecasting Sewage Flow</u> by Edward Graham and dated November 1981. The description of WSSC sewage flow forecasts in that report is reproduced here for easy reference.

"Growth forecasts are provided by M-NCPPC, generally in 5-year increments, for population, dwelling units and employment. These can be prepared for appropriate sewer service areas. Accordingly, sewage flow forecasts can most easily be prepared using these data. The approach is quite straightforward:

1. Determine existing flow
2. Determine 'base' flow factors, based on water consumption, for employment and dwelling units,

3. Determine a composite flow factor to include an infiltration allowance,
4. Determine the flow increase from the growth projections and flow factors,
5. Prepare raw flow forecasts,
6. Adjust forecast as appropriate to reflect cost-effective I/I reduction."

This method has been expanded, and improved, to include normalization for annual rainfall in step 1. Present practice at WSSC also involves the use of only recently connected properties (assumed recently constructed) in order to determine "base" flow factors representative of the types of dwellings (plumbing systems and water using appliances) that will be contributing to future growth in sewage flow.

A recent analysis of residential sewage flow factors (Del Grosso and Downes, 1984) resulted in the recommendation that single family dwelling unit flow factors be reduced from 350 to 300 gpd and that those for multi-family units be reduced from 330 to 270 gpd.

One of the most significant changes in the way water and sewage flows are forecast is in the use of dwelling units as predictors instead of population. The analysis done on the subject at the time of the Bi-County Water Supply Study indicated that a better relationship existed between water use and dwellings than water use and population.

In general, water and sewage flow factors have been refined downward as analysis and data handling capabilities have improved. Concurrently, the high rates of growth experienced in earlier decades have not continued in the past few years and the ultimate carrying capacity of the land (development potential) has been increasingly taken into account as a limiting factor when long range forecasts are made.

Successive housing unit and employment forecasts produced by the counties and the Cooperative Forecasting Program have declined. All three future scenarios of the Round III dwelling unit forecast for Prince George's County lie below the intermediate scenario of Round II. All of the Round III employment scenarios lie below the lowest of Round II. The variance (spread) of employment scenarios is wider, whereas that of dwelling units is narrower in the more recent Round. Although the forecasts have not had long to run, it can be seen that the earlier ones were for future levels of development which would take longer to materialize than expected.

TASK 9

Outline future directions in data availability, analytical tools, forecasting techniques, and planning applications.

The detail and availability of data with respect to water production and sewer flows in the WSSD has improved dramatically in recent years. This is mostly due to the computerization of billing records and the generation of routine reports which classify the data in useful ways. It is expected that improvements will continue to be made in the way the data is stored, but the most important beneficial feature in the short term will be the increased access to this data directly by the different divisions of the Commission through the use of remote terminals and analytical tools such as the FOCUS software used for statistical analysis. The implementation of the Sewer System Computer Model should make spatial and temporal sewage flow data readily available on a very fine scale.

The cohort survival model made a great improvement in the field of population forecasting when it gained widespread acceptance. It was used in the Round II Cooperative Forecasts for Prince George's County, but because of the overwhelming influence of migration in recent years, it was not used in Round III. Other ways of using diverse data will be developed to forecast population where migration continues to dominate. Multiple regression analysis will gain in applications where the combined effects of multiple explanatory variables are desired to be segregated. The use of multiple regressions could also help in deriving factors for use in forecasting.

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Appendix

National Oceanic and Atmospheric Administration: example of Climatological Data

JANUARY 1981 VOLUME 85 NUMBER 1

Climatological Data

MARYLAND AND DELAWARE

TEMPERATURE AND PRECIPITATION EXTREMES

HIGHEST TEMPERATURE:	LA PLATA 1 W	MD.	62	DATE	26
LOWEST TEMPERATURE:	OAKLAND 1 SE	MD.	-14	DATE	09
GREATEST TOTAL PRECIPITATION:	MC HENRY 2 NW	MD.	1.78		
LEAST TOTAL PRECIPITATION:	HANCOCK FRUIT LAB	MD.	.20		
GREATEST 1 DAY PRECIPITATION:	WILMGTON PORTER RESVR	DEL.	.41	DATE	07
GREATEST TOTAL SNOWFALL:	OAKLAND 1 SE	MD.	28.5		
GREATEST DEPTH OF SNOW OR ICE:	FROSTBURG 2	MD.	13	DATE	18+

SUPPLEMENTAL DATA

	WIND (SPEED - M.P.H.)						RELATIVE HUMIDITY AVERAGES- PERCENT (STANDARD OF TIME EASTERN)				NUMBER OF DAYS WITH PRECIPITATION								
	RESULTANT DIRECTION	RESULTANT SPEED	AVERAGE	FASTEST MILE	DIRECTION OF FASTEST MILE	DATE OF FASTEST MILE	01	07	13	19	TRACE	.01-.09	.10-.49	.50-.99	1.00-1.99	2.00 AND OVER	TOTAL	PERCENT OF POSSIBLE SUNSHINE	AVERAGE (TENTHS) SKY COVER SUNRISE TO SUNSET
BALTIMORE WSO AP MD	29	6.1	9.2	33	NW	17	66	69	50	56	7	3	2	0	0	0	12	52	5.8
WILMINGTON WSO AP DEL	30	6.5	10.0	29++	32	17+	71	76	58	64	7	6	1	0	0	0	14	-	6.2

I CERTIFY THAT THIS IS AN OFFICIAL PUBLICATION OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION AND IS COMPILED FROM RECORDS ON FILE AT THE NATIONAL CLIMATIC CENTER, ASHEVILLE, NORTH CAROLINA 28801.

Daniel B. Mitchell
DIRECTOR
NATIONAL CLIMATIC CENTER

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA AND INFORMATION SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

DAILY PRECIPITATION

STATION	TOTAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
MARYLAND																																
SOUTHERN EASTERN SHORE 01																																
ASSATEAGUE STATE PARK	.46	.10	.03	.02				.08								.02						.20							.01			
CRISFIELD SOMERS COVE	.32							.10								.04						.18										
PRINCESS ANNE	.29							.15								.04						.10										
SALISBURY	.74	.07						.40								.12	.03					.12										
SALISBURY FAA AP	.49	T	T					.16								.26	T	T			.03	.04						T				
SNOW HILL 4 N	.39	.03	T					.12								.04		T				.19							.01			
CENTRAL EASTERN SHORE 02																																
CAMBRIDGE WTR TRMT PL	.45	.09						.21								.04	.01					.18										
DENTON 2 E	.60	.05						.27								.11		T				.17										
ROYAL OAK 2 SSW	.50	.15	T	T				.25								.03	.02	T				.12										
VIENNA	-	.03	.01					-	-	-	-	-	-	-	-	.35	.03					-										
LOWER SOUTHERN 03																																
LA PLATA 1 W	.49	.18	.01	T	T			.12								.07						.16										
MECHANICSVILLE 1 SE	.43	.19	T	T			T	.10								.05						.17										
OWINGS FERRY LANDING	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PATUXENT RIVER	.46	.10	T	T			T	.16			T	T		T		.06	T				T	.06						T				
SOLOMONS	-	-	-	-	-			.15									.02					.03										
UPPER SOUTHERN 04																																
ANNAPOLIS POLICE BRKS	.72	.20	.03					.21								.11						.17										
BALTIMORE WSO AP D	.69	.19	T	T			.01	.09		T	T					.07	T	T			T	.13										
BELTSVILLE	.46	-	.15					.09								.01	.03					.10										
COLLEGE PARK	.62	.13	.03	T	T			.23	T							.04	T	T				.19	T							o		
DALECARLIA RESVR D C	.47	.19						.02								.11						.15										
GLENN DALE BELL STA	.57	.21						.11								.09						.16										
LAUREL 3 W	.52	.10	.04					.20								.04	.01					.13										
NATIONAL ARBORETUM D C	.49	.30	T					.07	T							T	.08					.03	.01									
UPPER MARLBORO 3 WSW	.53	.12	.03					.15									.07					.16										
NORTHERN EASTERN SHORE 05																																
CENTREVILLE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	-	o
CHESTERTOWN	.56	.12	.02	T	T		.01	.20				T				.13	.03	T				.05								T		
MILLINGTON 2 WNW	.64	.12	T	T	T			.26								.14	.03	.02				.07								T	T	
NORTHERN CENTRAL 06																																
ABERDEEN PHILLIPS FLD	.39	-	.12			T		.18								.10	T					.07								T		
BALTIMORE WSO CI D	.41	.17						.09								.05						.10										
BENSON POLICE BARRACKS	.38	.15						.07								.09						.07										
BOTOS 2 NW	.21	.14														.03						.04										
BRIGHTON DAM	.30	.10	.04					.06								.04	.01					.13	T									
CATOCTIN MOUNTAIN PARK	.45	.16	.02		T		.07	.01			T					.06	.01					.11		.01						T		
CLARKSVILLE 3 NNE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CONOWINGO DAM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DAMASCUS 2 SW	.45	.13	T		T		.01	.03		T		T		T		.09	T		T			.17		T								
EMMITSBURG 2 SE	.65	.15	T		T		.05	.15								.10	T					.20		T			T			T		
FREDRICK POLICE BRKS	.41	.15					T	T								.10						.16										
FREDERICK 3 E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PARKTON 2 SW //	.94	.14	T	T	T		.07	.11								.06	.01	.03				.12								T		
POTOMAC FILTER PLANT	.35	.12						T								.06						.17										
ROCKVILLE 3 NE D	.30	.15	T					.07								B .00		T				T										
TOWSON	.60	.16						.10								.12		.01				.10					.03					
UNIONVILLE	.39	.15						T								.07						.17										
WESTMINSTER POLICE BRK D	.64 D	.25 D	.25	T	T		T	T								.10						.04										
WOODSTOCK	.41	.17	T				T	.08								.05						.11										
APPALACHIAN MOUNTAIN 07																																
CUMBERLAND 2	.35	.13	.02					T	T							.05	T					.12	.03		T							
EDGEMONT	.30	.10	.04	T				.05			T					.01	.02	T				.07	T		T			T				
FROSTBURG 2	1.12	.14	.10	.12	.04	.07	T	.03	.09	T	.02	.02	.02	T	T	.06	.01	.07	.06	T		.15	.02	T	.01					T	.02	T
HAGERSTOWN	.26	.19	T	T			T	T									T					.07			-		T					
HANCOCK FRUIT LAB	.20	.16														.03						.01					T					
ALLEGHENY PLATEAU 08																																
MC HENRY 2 NW	1.70	.19	.39	.12	.10	T		.18	.12	T	.11	.07	.06	T		.07	.03	.12	.07			.08		T	.07							
MERRILL	.79	.14	.20	.05	.03			.07	.03	T	.03		.03	T		.03	T	.04		T		T	.12		.02						T	
OAKLAND 1 SE	1.17	.22	.20	.05	T			.17		.03	.04	T	T	.02		.07	.05	.03				.10		.03	T					T		
SAVAGE RIVER DAM	.59	.12	.10		T	T		.03	.05	T	.02	T	T	T	T	.02	T	.03	T			.16	.04	T						T	T	

SEE REFERENCE NOTES FOLLOWING STATION INDEX

DAILY TEMPERATURES

STATION		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	AVERAGE
MARYLAND																																	
SOUTHERN EASTERN SHORE 01																																	
ASSATEAGUE STATE PARK	MAX	38	40	38	36	30	34	42	35	30	29	25	22	27	39	38	39	35	33	52	52	38	49	44	45	45	47	54	43	46	40	35	38.6
	MIN	24	31	19	13	11	18	29	14	13	13	10	7	5	5	23	32	22	15	20	28	28	23	32	31	29	31	37	32	27	21	19	21.4
CRISFIELD SOMERS COVE	MAX		39	37		34	37	38	34	28	28	25	23	23	37	36	33	31	35	45	48	46	40	41	41	43	48	52	49	44	40	32	37.5
	MIN		37	22		8	10	32	17	14	24	16	8	6	21	26	30	27	25	25	30	35	27	32	34	23	36	38	35	30	20	22	24.5
PRINCESS ANNE	MAX	33	40	37	37	28	41	41	36	31	31	25	22	25	42	38	35	34	33	52	55	49	45	42	43	47	54	60	54	46	38	35	39.6
	MIN	27	30	19	12	11	8	33	14	6	19	11	7	-1	15	24	31	22	12	17	24	33	23	31	33	19	31	39	34	25	21	19	20.9
SALISBURY	MAX	32	40	37	38	30	41	42	34	30	29	24	20	26	43	37	36	35	34	53	54	45	47	42	45	49	55	58	49	40	36	36	39.3
	MIN	25	32	19	12	11	13	32	14	9	18	11	6	5	14	25	30	21	14	21	26	32	26	30	34	21	35	42	35	30	20	17	21.9
SALISBURY FAA AP	MAX	33	39	38	29	29	41	42	25	29	28	24	17	25	41	37	35	29	32	53	53	38	46	40	44	47	55	59	47	44	32	34	37.6
	MIN	27	26	17	10	10	7	23	8	7	16	10	5	0	18	25	28	19	13	24	26	29	22	32	24	17	33	38	29	25	21	13	19.4
SNOW HILL 4 N	MAX	35	40	38	37	30	42	43	35	30	29	24	22	28	43	41	36	35	34	54	54	44	46	42	44	47	58	61	53	44	37	35	40.0
	MIN	26	30	18	13	10	8	32	14	7	19	6	2	-1	12	23	31	21	12	18	31	33	23	30	34	20	30	39	33	26	20	16	20.5
CENTRAL EASTERN SHORE 02																																	
CAMBRIDGE WTR TRMT PL	MAX	31	39	38	37	26	40	39	38	29	30	26	24	25	36	38	36	36	32	53	51	50	50	48	44	47	52	58	50	48	38	35	39.7
	MIN	25	27	25	15	13	13	31	16	11	21	10	9	3	17	21	30	23	15	22	31	33	25	31	35	22	22	37	36	30	23	23	22.4
DENTON 2 E	MAX	31	38	35	34	29	38	39	31	28	27	22	20	24	39	33	37	32	31	46	50	41	49	42	45	46	51	54	48	45	35	35	37.3
	MIN	23	28	17	12	10	9	31	11	2	16	9	2	-3	15	20	29	20	12	20	33	32	23	30	32	22	32	43	31	27	18	15	20.0
ROYAL OAK 2 SSW	MAX	31	39	36	36	27	37	37	32	29	27	23	21	23	36	33	37	34	35	53	51	41	47	42	44	45	52	54	47	42	35	30	37.4
	MIN	24	27	18	13	11	11	32	14	7	16	14	6	2	19	23	30	22	14	21	29	33	23	29	34	22	33	38	30	26	19	21	21.3
VIENNA	MAX	32	40	36	37	25		46	28	29	30	23	22	26	42	36	37	37	35	54	52	47	46	42	45	54	48	56	53	42	34	33	38.9
	MIN	24	24	20	12	10		27	13	6	12	10	5	2	16	27	26	21	14	21	29	33	25	31	34	24	31	40	31	29	20	19	21.2
LOWER SOUTHERN 03																																	
LA PLATA 1 W	MAX	33	40	38	33	26	38	38	29	31	27	26	20	24	37	35	40	33	38	59	52	43	48	43	45	51	62	56	51	44	34	30	39.1
	MIN	24	26	18	10	10	7	28	14	5	13	11	3	-2	17	25	28	20	8	17	29	34	24	30	31	19	32	42	31	22	20	16	19.7
MECHANICSVILLE 1 SE	MAX	32	34	35	34	26	40	41	29	30	27	25	18	25	35	34	39	35	34	54	52	47	42	41	42	46	57	59	50	44	33	34	37.9
	MIN	22	26	14	9	7	19	29	15	14	17	15	5	-1	20	23	28	19	6	17	27	31	24	31	30	20	31	42	31	22	18	14	20.2
OWINGS FERRY LANDING	MAX																																
	MIN																																
PATUXENT RIVER	MAX	32	41	38	28	27	44	40	26	30	28	25	19	26	37	35	41	30	37	58	53	37	48	43	47	45	61	58	47	46	34	34	38.5
	MIN	27	26	20	12	11	13	22	16	15	15	13	10	7	25	28	25	28	13	21	27	27	26	32	23	27	32	36	32	26	23	19	21.6
SOLOMONS	MAX						27	43	38	26	29			19	38		40			38	55	53	37	49			45	58	51	45	45		
	MIN						13	20	12	12			6	6	10		23			31	25	30	25	29			22	38	32	24	20		
UPPER SOUTHERN 04																																	
ANNAPOLIS POLICE BRKS	MAX	42	39	36	39	36	35	39	38	26	28	27	22	23	31	36	40	37	35	50	54	48	52	50	47	45	51	51	50	45	39	37	39.5
	MIN	24	28	18	12	9	9	29	23	8	23	11	6	3	20	21	30	21	12	27	38	31	26	33	35	22	33	41	33	34	21	16	22.5
BALTIMORE WSO AP	MAX	30	36	36	21	27	37	38	23	27	25	23	19	24	32	36	41	29	36	52	53	40	53	44	44	50	54	52	49	41	34	38	36.9
	MIN	24	19	14	8	7	8	17	7	4	15	8	1	0	19	28	22	17	11	24	37	27	25	36	27	22	28	38	30	27	19	14	18.8
BELTSVILLE	MAX			35	36	23	25	37	38	20			23	18	23	38	35	41	28	36		53	37	51	42	43	49	53	52	48	40	33	36.8
	MIN			12	9	5	5	9	10	0			-2	-5	0	19	27	21	8	18		32	24	27	34	20	23	36	26	29	16	14	16.0
COLLEGE PARK	MAX	32	36	37	37	21	27	37	41	24	28	26	25	20	23	33	36	42	29	40	51	53	40	51	43	44	50	57	52	51	40	33	37.4
	MIN	24	27	14	10	10	8	20	12	4	17	12	4	0	16	21	28	21	17	27	39	32	25	37	35	21	28	38	32	34	20	17	21.0
DALECARLIA RESVR D C	MAX	33	38	39	42	25	32	42	32	27	27	25	21	23	35	35	42	38	36	52	55	48	53	45	45	49	55	52	52	46	42	38	39.5
	MIN	24	24	14	9	7	9	28	11	5	9	9	7	1	22	20	19	15	9	22	32	33	35	34	33	21	20	35	30	29	20	17	19.5
GLENN DALE BELL STA	MAX	34	38	36	35	25	35	41	34	29	27	24	25	24	23	35	41	39	44	52	56	46	51	50	46	50	58	59	51	50	36	39	40.1
	MIN	22	27	21	10	8	4	31	11	0	10	11	0	-5	17	15	27	19	5	20	30	32	22	34	34	18	26	38	26	28	12	21	18.5
LAUREL 3 W	MAX	31	35	35	21	26	31	39	24	27	24	23	21	23	32	36	40	27	33	49	51	42	51	42	44	47	51	53	50	40	32	37	36.0
	MIN	20	18	17	5	12	15	6	11	15	9	8	7	10	19	23	18	13	13	27	35	27	33	33	29	27	30	36	33	23	18	14	19.5
NATIONAL ARBORETUM D C	MAX	36	35	37	37	17	25	38	40	24	29	27	25	23	23	34	36	40	32	37	53	55	40	54	45	44	49	60	52	50	40	33	37.7
	MIN	21	27	17	11	10	10	10	13	8	15	13	7	5	6	21	27	21	16	20	35	32	26	30	30	24	30	37	35	34	20	15	20.3
UPPER MARLBORO 3 WNW	MAX	33	34	38	38	16	26	38	40	25	32	27	25	20	24	34	36	42	29	37	53	54	36	50	43	45	50	61	51	50	41	34	37.5
	MIN	21	26	12	11	10	5	5	12	-2	11	12	-4	-7	-4	17	25	22	6	17	32	33	25	28	35	19	21	39	31	32	18	15	16.9
NORTHERN EASTERN SHORE 05																																	
CENTREVILLE	MAX																																
	MIN																																
CHESTERTOWN	MAX	32	36	35	26	29	37	39	23	27	26	23	14	24	33	32	37	28	32	48	50	38	45	42	43	45	51	49	48	40	32	35	35.5
	MIN	22	22	15	11	11	11	17	7	3	14	11	1	2	15	23	24	18	13	20	34	26	22	33	32	23	33	37	32	28	19	18	19.3
MILLINGTON 2 WNW	MAX	30	37	36	33	29	34	38	28	27	26	22	19	24	35	33	37	32	31	47	46	40	47	43	44	47	50	53	48	41	34	35	36.3
	MIN	22	26	11	-1	9	8	27	11	0	12	6	-1	-4	10	19	28	18	4	14	33	30	19	28	32	21	19	38	28	27	16	17	17.0

SEE REFERENCE NOTES FOLLOWING STATION INDEX