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ROUTINE STREAMS AND RIVERS WATER QUALITY TREND MONITORING REVIEW

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Water Resources Series
Technical Report No. 75
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by

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Under Contract to the Municipality of Metropolitan Seattle
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ABSTRACT

Four topics relevant to the Municipality of Metropolitan Seattle (Metro) routine stream quality monitoring network are addressed. These include: 1) A review of the literature on water quality trend assessment, and recommendation of a method to effect trend analysis, 2) A review of Metro's existing routine monitoring network with respect to number of stations, number of variables monitored, and sampling frequency, 3) An assessment of potential problems in assessing trends in water quality indices in time and space, and 4) a limited analysis of selected Metro stream and river quality data for trends.

The results of the investigations were: 1) Development of a computer program (TREND) to analyze water quality trends, drawing on previous work by the first author and recent developments by others, 2) A recommendation for reduction of Metro's routine monitoring network to 30 stations, retaining the existing monthly sampling frequency, and, with minor exception, retaining the existing suite of variables monitored. Cost savings would be used to implement a rotating intensive monitoring program with the aim of supporting predictive capability for sensitive basins, 3) Minimal problems were encountered in assessment of trends in Metro's water quality indices, however it is recommended that whenever trends in indices are assessed, the contributing variables be assessed as well. Further, as a general rule trend assessments should not be attempted when fewer than five years of data are available, 4) The demonstration trend analysis of five selected stream and river stations was inconclusive, due largely to the paucity of data available. Improved sampling protocol from 1979 on offers encouragement that more meaningful trend analysis will be possible within the next two years.

TABLE OF CONTENTS

TABLE OF CONTENTS, continued

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. INTRODUCTION

The Municipality of Metropolitan Seattle (Metro) is a metropolitan municipal corporation which is authorized to perform two functions: water pollution abatement and public transportation. Its jurisdiction encompasses all of King County, Washington and includes numerous municipalities ranging in population from several thousand to approximately one-half million. Representatives of many of these local jurisdictions sit on a council which has ultimate administrative authority.

Metro's first, and most widely visible, mission was the construction of four sewage treatment plants and over 100 miles of large trunklines and interceptors which replaced 28 older sewage facilities in the Seattle metropolitan area. This initial program completely eliminated the discharge of treated effluent into Lakes Washington and Sammamish. The facilities intercepted and treated all raw sewage formerly discharged into the two lakes, the Duwamish River, Elliott Bay and the adjoining Puget Sound waters (except combined sewer overflows). Much of Metro's resource base continues to be allocated to maintenance and expansion of this system, and many of Metro's current programs act in support of this responsibility to some extent.

An example of one such support program is Metro's receiving water monitoring associated with the four treatment plant discharges. Its purpose is to assess the effects of those discharges on freshwater, estuarine and marine waters. Metro regularly reports the results of this monitoring to a Water Quality Monitoring Review Board (WQMRB), whose members represent the State Departments of Ecology, Fisheries, and Game, as well as the Department of Civil Engineering, University of Washington. In response to changing Federal and State legislation, Metro's efforts in water pollution abatement have expanded beyond its wastewater treatment responsibilities to include regional water quality planning and management. In 1976 Metro was designated by the State of Washington Department of Ecology as the areawide water quality planning agency under Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (FWPCA). As such, Metro has assumed responsibility for monitoring the Lake Washington and Green River Basins of King County, and for developing plans to maintain or enhance the quality of these waters, consistent with the FWPCA. In effect, this expansion of Metro's pollution abatement responsibilities results in programs directed towards the abatement of non-point pollution in the Lake Washington and Green River basins. Under Metro's enabling legislation, the agency has authority to:

(1) prepare a comprehensive water pollution abatement plan including provisions for waterborne pollutant removal, water quality improvement, sewage disposal, and storm water drainage for the metropolitan area, and

(2) acquire, lease, construct and regulate the use of facilities for water pollution abatement including but not limited to, removal of waterborne pollutants, water quality improvement, sewage

disposal and storm water drainage within or without the metropolitan area (Metro, 1977).

Metro has no operational function for abating significant non-point pollution sources such as stormwater runoff and construction-related erosion and sedimentation; this remains with the local jurisdictions. This distinction is important, and has a direct effect on the objectives of Metro's streams and rivers sampling network, a review of which is the subject of this work.

As part of its 208 planning function, Metro has expanded its original water quality network to monitor periodically the quality of the rivers and streams within its jurisdiction. The original network was a core of several stations on the Green and Duwamish Rivers. As previously mentioned, these stations were established to evaluate the effects of the discharge from the secondary wastewater treatment plant at Renton Junction on the Green/Duwamish River (for those unfamiliar with local geography, the Green River becomes the Duwamish River below its confluence with the Black River, a now-minor tributary which prior to the construction of the locks connecting Lake Washington and Puget Sound was the outlet to Lake Washington). From this abatement-oriented network, numerous stations were added and others dropped to form, by 1980 a routine monitoring network of 80 stations. Of these, 11 were on the main stem of the Green/Duwamish, Cedar, and Sammamish Rivers, 3 on the tidally affected reach of the Duwamish River, 2 on the Lake Washington ship canal, and the balance of 64 on smaller streams. The network underwent further revisions in 1981. To be consistent with land use data employed later in this chapter, a baseline network of 64 stations is considered here in lieu of the 80 station 1980 network. The baseline network excludes the tidal reach of the Duwamish, the Lake Washington Ship Canal, and several small basins for which land use data are not available. The stations included in this network are listed in Appendix A (and shown in Figure 3, Chapter III). Of the 64 stations, 11 are on the main stem of the Green/Duwamish, Cedar, and Sammamish Rivers. Of the 53 stream stations, 12 are in the Green River drainage and the remaining 41 in the Lake Washington drainage. The preponderance of stations in the Lake Washington drainage, to some extent, reflects the natural configuration of the drainage network within King County, but more significantly it is a reflection of population density, and patterns of change in land use.

In this work, Metro's streams and rivers program is reviewed with respect to its stated goal, which is to track the quality of the streams and rivers within Metro's jurisdiction so that Metro is aware of all significant existing or developing problems within these waters. In addition to a review of the network, methodologies for assessing the existing data base are reviewed, with recommendation of a family of analytical tools for detecting trends in the data and provision of a computer program to effect trend detection in the manner recommended. Finally, technical complications in assessing trends in water quality indices are reviewed, and a demonstration application to five stations in Metro's existing network is performed.

A. Evolution of Streams and Rivers Network

As noted above, the existing streams and rivers network evolved from a series of stations on the Green/Duwamish river associated with the Renton Junction wastewater treatment plant. Data were collected at some of these stations as early as 1961, however sampling frequencies were somewhat sporadic and parametric coverage was sparse until the early 1970's. 1971 is the first year included in readily retrievable form on Metro's computerized data handling system. Periodic stream sampling was initiated as part of the RIBCO (Metro's River Basin Coordination Committee) study from July 1971 through December 1974. This study included 37 small streams in King and Snohomish County, many of which were in the Lake Washington drainage basin. Metro initiated its own program for monitoring small streams in 1975. Various station densities and sampling frequencies were employed; in the initial phase one third of the network was sampled each year during the period 1975-78. During 1979, the sampling frequency was increased, some stations were dropped, and the rotating strategy was discontinued. In January, 1981 the small streams program was merged with the RIVAL (River Basin Survey) program, an extension of the earlier Green/Duwamish network in operation for the period 1976-80, which included stations on the Sammamish and Cedar Rivers and Lake Washington Ship Canal as well as the Green/Duwamish.

The existing data base reflects the evolutionary nature of the network. Although the baseline network consists of only 64 stations Metro's streams and rivers historical data base includes 236 stations. A cursory review of the data allows some inference of perceived network objectives at the time the sampling was performed. The rivers component of the network contains many fewer stations than the streams component, and generally there have been fewer changes in station location. The streams network is characterized by extensive areal coverage, with relatively short record lengths. Many of the stations were sampled for a period of only one year during 1975-78 when the one in three year strategy was in effect. It is worth noting that essentially all stations included in the network were sampled on a periodic basis, i.e., at a one month time interval, rather than on a shorter term basis with increased areal coverage. This is so even for those stations sampled for only a single year. Although some intensive sampling has been conducted by Metro (the Juanita Creek study (Brenner, et al., 1978) is a notable example) intensive monitoring generally has not been employed either as an alternative or supplement to periodic sampling.

B. <u>Objectives of Existing Network</u>

As noted above, the stated goal of the streams and rivers monitoring program is to provide sufficient information to identify any significant existing or evolving water quality problems in Metro's service area. Within this general goal, the program has several specific objectives, which were identified through discussions with Metro personnel responsible for management of the program, and through review of Metro internal correspondence. These objectives include:

(1) To detect trends in water quality over time.

(2) To determine whether existing water quality conditions constitute problems or potential problems based on scientific criteria.

(3) To identify water quality conditions which the public may perceive as problems.

(4) To determine cause-effect relationships for water quality, especially in areas that may be affected by Metro facilities, such as treatment plants.

(5) To recommend mitigation and abatement measures, and to evaluate the effectiveness of such measures.

(6) To provide public awareness in the field in support of stated Metro policies, particularly in areas of high priority or sensitivity.

Although these stated objectives are comprehensive, they do not provide a full picture of the underlying basis for the network. One of the key motivations behind the monitoring program, and an area addressed extensively by other Metro programs, is the protection and enhancement of fisheries habitat. The many small streams in the Cedar and Green/Duwamish drainage basins historically have provided spawning and rearing areas for Coho, Chinook, and some Chum and Sockeye Salmon as well as various game fish such as steelhead and cutthroat trout. It is widely perceived in the water resources profession, and by the public as well, that urbanization has a degrading effect on native anadromous salmonid fisheries. With the notable exception of the Cedar River Sockeye run, there is a perception that some native fisheries populations in the Cedar and Green/Duwamish basins have showed a long term decline. In recent work for Metro, Harper-Owes (1981) found that the best parameter for predicting coho salmon abundance in small streams in King County was the ratio of the flood discharge of record to mean runoff, which in turn can be related to the fraction of impervious area within the basin. Although the results of the Harper-Owes work are sufficient to establish general empirical trends across many basins, cause-effect relationships in any particular basin cannot be established because of data limitations. Therefore, it is Metro's concern to document, on the basis of its monitoring network, stream quality conditions related to fisheries production, particularly for small streams.

Perhaps more importantly, Metro desires to bring public awareness to such stream resources on the basis of credible scientific data. The latter aspect of the network is especially important, since, unlike its wastewater management function, Metro currently acts, in most cases, in an advisory/coordination role on water quality issues, relying on local government authorities to implement appropriate non-point pollution abatement programs. Therefore, in addition to the specific objectives noted, a general objective of the network is to provide a credible basis for predicting water quality changes as well as for documenting those changes that have already occured. A key issue to be addressed in this work is the appropriateness of the existing program to accomplish this general objective.

C. Water Quality Monitoring - A Conceptual Perspective

The stated objectives of Metro's streams and rivers network are diverse, suggesting a range of potentially conflicting sampling strategies. For this reason, it may be useful to introduce a conceptual perspective to the classification of networks, to avoid confusion as to the type of information that can be provided by various design configurations.

Water quality monitoring programs can be classified into six general types, according to their objectives:

a) surveillance,

b) model parameterization,

c) cause-effect,

d) trend detection,

e) water quality control, and

f) baseline.

Surveillance networks are oriented toward either detecting the impact of a known pollution source, or of 'fingerprinting' unknown sources of undesirable water quality conditions, such as spills. Such networks usually must have relatively high sampling frequencies, possibly utilizing continuous monitoring, to obtain acceptable performance levels. Given the relatively minor importance of point source pollution (exclusive of wastewater treatment plants, considered to require type e monitoring) in the watersheds of interest, such networks will receive minimal emphasis here.

Networks designed to estimate parameters of an existing water quality model must provide data on time and space scales sufficient to allow identification of transfer rates and related model parameters. Insofar as such models generally are implemented at the stream basin level, and conditions nearly always vary within a basin, multiple stations per basin are implied. Further, time constants for most water quality interactions are on the order of hours or at most days, and the hydrologic response time for small watersheds is on the order of hours or minutes. Therefore, type b networks must have high spatial density and high sampling frequencies. However, a sampling program for model parameterization may need to be in operation only for a few days for a small number of storm events. A further distinguishing feature of such networks is their link to prediction* via the modeling process. The use of models, regardless of their level of sophistication, implies an input-output process, where the input is meteorological conditions and waste discharge flow rates, and the output is water quality.

Cause-effect networks operate on similar space-time scales to type b networks, however their purpose is limited to identification of the functions relating input and output. Although type b and c networks are similar, the absence of a conceptualization or model quantitatively relating input and output restricts the use of the data collected to assessment of present conditions. The information collected from a type c network may ultimately form the framework for synthesis of predictive relationships, however. Type d, or trend detection networks, are

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* A distinction between the often-confused terms forecasting and prediction should be made. Forecasting generally implies an estimate, in real time, of what will happen in the future. For example, weather conditions for a period of a few days in the future, flood peaks, spring snowmelt runoff, and perhaps water quality downstream of a measurement point for a few hours into the future, all can be forecasted. Prediction is a more general term, not necessarily implying time as the independent variable. As an example, a regression model might be used to predict water quality conditions given land use type, slope, etc. A common use of prediction in water quality management is evaluation of alternate scenarios for the future, for instance water quality conditions in a stream five years in the future might be predicted using a model driven by land use, alternate climatic scenarios, etc. Such predictions would not, in commonly accepted technical terminology, be considered a forecast.

directed toward retrospective analysis of time sequences of observations for evidence of changes in a statistical sense. Such networks have been analyzed by Lettenmaier (1975; 1977) and others; they usually represent resource allocations such that spatial density is sacrificed in favor of long sequences of observations at frequencies on the order of weekly or monthly. It is important to emphasize that trend assessment techniques, such as those reviewed in Chapter III, are entirely retrospective in nature and have little utility for predicting future conditions. Further, the type of data collected normally does not support predictive models, therefore any predictive capability based on the data collected from type d networks is limited to extrapolation a small number of time steps in the future using the persistence structure of the time series collected. Such extrapolation is usually of limited practical value. Therefore trend networks may be considered to be devoid of predictive potential from a practical standpoint.

Networks designed for water quality control (type e) represent an extension of type a networks where the measured water quality conditions in-stream are used in a control system to determine 'end of the pipe' effects on the receiving waters. Metro's two continuous monitoring stations in the vicinity of the Renton Junction wastewater treatment plant constitute such a network. Should the monitors detect unacceptable in-stream conditions, plant operations personnel are notified. Litwin and Joeres (1974) have proposed control methods to link data collected by type e networks to treatment plant operation.

Type f, or baseline networks are appropriate in cases where there are little or no pre-existing data. Although type f networks may have spatial coverage or time frequency of sampling categorically similar to either type b/c or type d networks, the level of sampling effort is generally much lower than that associated with the other networks and the data collected are appropriate only to establishing the level of the water quality constituents measured. Some of the stations sampled during the RIBCO study fall into this category.

The six network types can be represented with respect to their domains of influence in time as shown in Figure 1. A review of the stated objectives of Metro's rivers and streams network in this context immediately reveals a conflict with the existing network structure. Objective 1 (trend detection) clearly requires a type d network, while objective 4 (cause-effect) requires type c, or possibly type b. Objectives 2 and 3 (problem/potential problem, and perceived problem identification) are probably best served by a type c network, while objective 5 (control) requires type b and c. Objective 6 (public awaremess) does not clearly imply any particular network type; depending on specific circumstances either types b/c or type d might be preferable.

The important conclusion reached from comparison of Figure 1 with Metro's stated network objectives is that no single network will suffice. The existing network is largely oriented toward type d objectives, as are the analytical procedures discussed in this report, however it appears that some shift in sampling effort away from type d networks may be appropriate. The potential conflict represented by the

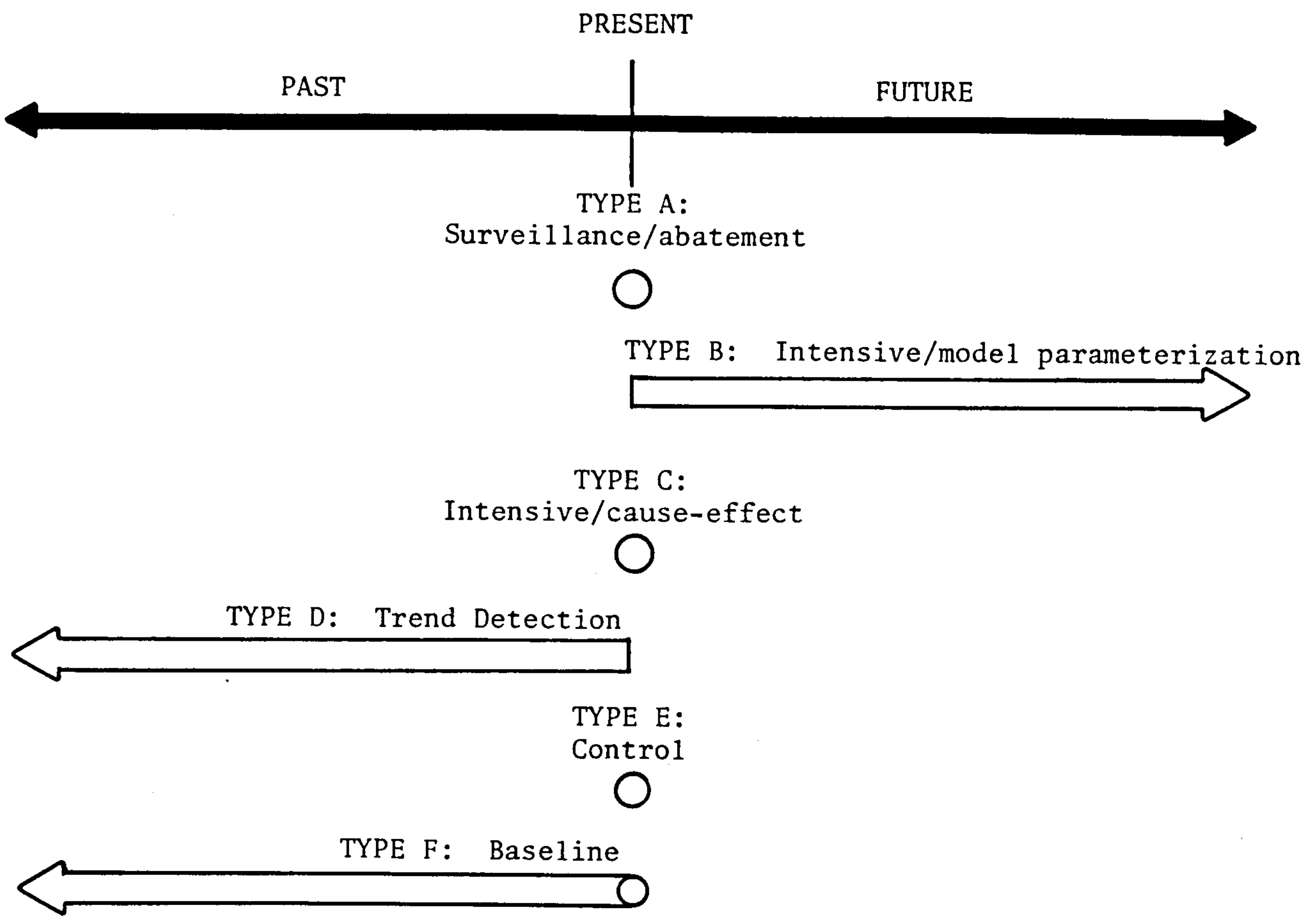

Figure 1: Time Domain Conceptualization of Water Quality Monitoring Networks.

diversity of stated objectives is important, especially as it relates to the space-time scale of monitoring networks. Chapter III suggests changes to the existing program to effect a data collection program more consistent with this range of objectives. For the present, an important point to emphasize is that trend networks (type d) are entirely retrospective, and the analysis of trends has no predictive or forecasting value per se. For predictive purposes, implementation of type b networks, and development of modeling expertise to utilize this type of data, is essential.

D. Objectives of This Study

The present study has four objectives, which are addressed in Chapters II, III, IV, and V, respectively. These are

1) to review water quality trend analysis approaches, to recommend operationally feasible trend assessment techniques, and to provide a computer program suitable for performing the recommended analytical procedures on Metro's streams and rivers data base,
2) to review Metro's existing streams and rivers network, and to recommend changes to make the network more compatible with the objectives reviewed above,
3) to review methodologies and problems associated with assessment of trends in water quality indices, and
4) to conduct a limited analysis of certain selected stations in the existing data base, making use of the techniqiues developed in Chapters III and IV.

This chapter concludes with a brief preview of the material included in each of the four subsequent chapters.

Chapter II includes a detailed review of the water quality trend analysis literature. The work of Lettenmaier (1977) is given special attention as an initial, integrated methodology for trend assessment. Important advances have since been made by Hirsch, et al. (1982). The distinguishing feature of Lettenmaier's and Hirsch's work is the use of nonparametric statistics. Hirsch proposes the use of seasonal tests, which obviate the necessity for pre-processing to remove seasonality. Another important advance of Hirsch's work is the development of techniques to remove the covarying effects of streamflow, which otherwise may confound water quality changes attributable to anthropogenic sources. The computer program developed by Lettenmaier (1977) has been revised and extended to include Hirsch's work, which was graciously released by the U.S. Geological Survey for incorporation in the TREND computer program described in Chapter III. A listing of the program and documentation is provided in Appendix B. The program as revised includes 20 analysis options; the sequencing of these options is at the user's discretion. Some of the options represent alternate approaches to a common analytical objective, so Chapters II and V provide some recommendations of the options the authors feel are most appropriate for Metro's data base.

Chapter III reviews Metro's existing network with respect to spatial coverage, frequency of sampling, and water quality constituents monitored. As noted in the preceding section, there is an apparent conflict between the configuration of the existing network and its stated objectives. In Chapter III, a methodology is developed to allow ranking of station importance by using a scoring system based on four criteria reflecting basin drainage area, projected land use change, and surrogates for swimmability and fishability. An algorithm is then developed to determine optimal n-station subsets of the baseline 64 station network, where n < 64. Justification is provided for reducing the existing type d network to approximately 30 key stations. The resources released by discontinuing the remainder of the present stations would be allocated to establishment of a type b monitoring program, where the same scoring system used for assessment of the existing type d network is recommended (but not actually implemented) to prioritize basins for the detailed, type b surveys. A related recommendation is that Metro augment its modeling capability to supplant some of its data collection activities, with predictive models to be supported by the type b surveys. The current, monthly sampling frequency at the type d stations is considered adequate, however it is recommended that the number of water quality constituents monitored at these stations be reduced somewhat, emphasizing a subset of the existing parameters monitored. It is also recommended that Metro act in cooperation with the State Department of Ecology to eliminate monitoring station duplication in the Cedar, Green/Duwamish, and Sammamish Rivers.

Chapter IV reviews statistical problems associated with assessment of trends in water quality indices. Water quality indices represent an attempt to express water quality conditions, measured by a vector of water quality constituents, as a single number. The attraction of indices is their ability to distill a large amount of information into a form which facilitates comparisons between basins, and in time. Metro currently makes use of two separate indices for swimmability and fishability (two key criteria in the FWPCA). These indices amount to non-linear transformations of the elements of the water quality constituent vector. Recent work in the water quality literature has pointed out complications that can result from attempts to assess changes in water quality indices, and has demonstrated that spurious trends may result when changes in the mean of a constituent are accompanied by changes in its higher order moments, such as variance. In Chapter IV, such problems are reviewed in the context of the indices used by Metro, and some limited analysis is conducted on selected stations. This review is important, since water quality indices are used as a public information tool, so the existence of spurious trends could have wide-reaching, and undesirable effects in terms of Metro's management goals.

Finally, Chapter V applies the trend assessment methodology to five selected stations for eleven water quality constituents, three of which make up Metro's swimmability index and the remaining eight the fishability index. The analysis of these records is carried out in a stepwise fashion, mimicking the actual output of the computer program. The use of as many program options as possible is emphasized, particularly where more than one approach is possible. Sample graphical and tabular output is included in these tutorial applications to assist the reader in using the program.

CHAPTER II. APPROACHES TO WATER QUALITY TREND ASSESSMENT

Concerns over changes in water quality are a relatively recent issue. Although statistical tests for change have a long history, little attention was given to water quality trends, and the statistical characteristics of water quality data, until the early 1970's. Even then, limitations on sample sizes served to limit trend assessment procedures to ad hoc methods (e.g., Enviro Control, 1972). As data collection programs, such as Metro's, have been established and refined, sufficient data have been accumulated to allow application of more refined statistical techniques, tailored to the problems of water quality data. In this chapter we review several approaches that have appeared in the refereed and 'gray' literature, recommend a family of statistical tests, and describe a computer program developed to perform the recommended analytical procedures.

A. Literature Review

The concerns of the last two decades over environmental degradation, and resulting expenditures of large sums of public and private monies on cleanup efforts have provided the motivation for attempts to assess trends in water quality. This interest was directed both toward long term (i.e., on the order of decades) changes associated with growth of industrial activities, urbanization, and other long term effects (Wolman, 1971) as well as the shorter term (i.e., on the order of a year or two) effects of cleanup efforts, such as construction of improved wastewater treatment plants. As noted above, early attempts at trend analysis were largely frustrated by the lack of adequate data bases. A noteworthy exception was the long-term water chemistry data collected by the U.S. Geological Survey for large rivers. The work of Steele, et al. (1974), who used harmonic analysis to estimate changes in annual chemical quality using this data base, was one of the first attempts at statistical analysis of water quality trends.

Lettenmaier (1975), by investigating daily water quality observations, concluded that lag-one Markov models (which assume that the present and previous observations of a process are linearly related with additive noise) are generally applicable to water quality time series for many variables. By examining statistical power under different sampling plans, enough justification was provided for the Washington State Department of Ecology (DOE) to switch from the former "one-in-three" sampling plan where, for reasons of economics, a region was intensely sampled only one year in three, resulting in two-year data gaps for each region, to a uniform time interval sampling plan. Lettenmaier (1977) also developed a computer program (which with modifications, is termed TREND herein) for editing, displaying, and analyzing water quality data. This program handles (1) removal of outliers, (2) data transformations to generate a symmetric distribution, and (3) removal of seasonal effects. The program has also been designed to handle incomplete data records (as most water quality records have at least occasional missing observations). Two nonparametric statistical tests were included: a Mann-Whitney step procedure to test the first part of a deseasonalized time series against the second part, and a Spearman's rho procedure to test for the presence of a gradual trend in the series rather than a definite break or step. Descriptions of both of these tests are included in standard texts on nonparametric statistics, e.g., Conover (1971). The presence of correlations among measurements over time was accounted for in Lettenmaier's work by producing a new set of critical test statistic values that are a function of the value of the persistence in the time series of observations. Aside from the tables of adjusted critical values, illustrative examples are also present. The report by Yake (1979) on water quality trend analysis in the Spokane River Basin is a useful application of the TREND program.

Hirsch, et al. (1982) have recently extended Lettenmaier's approach, producing some techniques for analyzing monthly water quality data (the techniques are easily generalized for seasons of any length, and we have done this in the revised version of TREND described in Section C of this chapter). Hirsch's seasonal Kendall test for trend considers data within each month (season) thus implicitly deseasonalizing in this manner before combining results from several months into a final test statistic. If a trend is established, the seasonal Kendall slope estimator (a median regression technique) measures the magnitude of the trend in (flow-adjusted) concentrations over time. The procedure is non-parametric (i.e., makes no assumptions about the specific probability distribution of the data) and is therefore robust against various departures from the assumption of a normal distribution of random errors. The desirability of adjusting concentrations for streamflow variation is also discussed and the techniques recommended are one of the most useful aspects of the Hirsch work. Harned, et al. (1981) have also addressed the problem of streamflow adjustment, proposing three methods including the one used by Hirsch, to reduce the effects of discharge on concentration values. Their methods appear to yield similar results.

A recent report by Harper-Owes (1981) for Metro addressed the problem of assessing water quality impacts by looking for predictive relationships among indicators of land use and various water quality/quantity parameters. Since all of the proposed (linear) relationships were applicable at a given time, only, the results are not reflective of long term trends. This work does, however, illustrate the difficulty in removing the effects of natural variability in identifying cause and effect relationships for water quality. Thus the need for assessment of long term behavior of water quality parameters is further underscored.

Water Quality Indices and Long Term Trend Assessment

Because of the multivariate nature of water quality, several techniques for constructing water quality indices have been proposed. Most indices take the form of a single number which is a function of values of the water quality variables which make it up. One index of particular interest was developed by Dunnette (1979) for the Oregon Department of Environmental Quality; it is a linear combination of transformed water quality variables. Swartz, et al. (1980) have employed Dunnette's method in developing both a fishability and a swimmability index for King County streams and rivers. Nonlinear parameter transform curves have been used to transform the individual constituents into values compatible with the index scale.

Landwehr (1974; 1979) has analyzed the nature of water quality indices (including those like Dunnette's) by reviewing some of their mathematical and statistical properties, and has arrived at some important conclusions. For instance, the parameter transform functions can influence the behavior of an index in unexpected ways. In both the fishability and swimmability indices devised by Swartz, et al. (1980), some of the parameter transform curves are monotonically increasing, some are monotonically decreasing, and some have slope directions which depend on the values of the constituent (e.g., temperature, pH). Also, the Swartz-Dunnette index uses a weighted linear combination of the constituents and hence is of the form $\bar{y} = \sum_{i=1}^{n} w_i y_i$ rather than a form like a geometric mean, $\tilde{y} = \prod_{i=1}^{n} y_i^{w_i}$ (where the y 's are the transformed constituents and the w_i 's are the weights). Landwehr (1979) has demonstrated that in many areas, a geometric mean construction like $\tilde{y}$ exhibits more stable (less natural variability) behavior than an additive mean like $\bar{y}$. For example, $\bar{y}$ is more sensitive to varying coefficients of variation (changing standard deviation with respect to a fixed mean) and less sensitive to changing means with fixed standard deviation, a kind of "backwards" property and not a desirable one. So, if the average conditions stay the same but underlying water quality becomes more variable, the index will tend to rise. If the parameter transform curve is decreasing so that a reduction in the mean of one of the index constituents is interpreted as an improvement in water quality, then it is possible for the index value to actually indicate a change in the opposite direction. Furthermore, as the standard deviation increases relative to the mean, quite different conditions can yield similar index ratings (Landwehr's cautions and general results are discussed in more detail in Chapter III, where distributional properties of the Swartz-Dunnette fishability and swimmability indices have been investigated.)

Stream Order and Location of Sampling Stations

Sharp (1970, 1971) introduced the concept of stream order as a measure of entropy (uncertainty) of a sample source. Stream order is simply a method of assigning a numerical value to the elements of a branching network. For example, the smallest distinguishable stream channel is, by definition, first order. Two first order streams combine to make a second order stream. A very large stream, e.g., the Columbia River, is typically of order about eight. Sharp proposed a binary search algorithm as a way to ensure that the expected number of tests or samples needed to find a single contamination source in a sequential search of a drainage basin would be kept to a minimum. Liebetrau (1979) extended this work by confirming that the best way to divide a region for water quality investigations is via the stream order method, and that for sampling purposes regarding spatial placement of stations, the set of all segments of the drainage network serves as the population. It was also found that Sharp's binary algorithm was unsuitable for synoptic surveys and long-term trend assessment. For these kinds of networks, a sequential student's t-test was proposed to detect changes in water quality variables. Of course, this kind of test depends on the normal distribution of the underlying data. Further, missing values are not allowed, and the magnitude of the suspected changes must be specified at the start. For other reasons, the sequential t-test would not be easily adaptable to Metro's water quality data. However, the ideas regarding the stream order design are applicable to the problem of station placement, and are used, at least subjectively, in Chapter III.

U.S. General Accounting Office (GAO) Report

The recent GAO Report, "Better Monitoring Techniques are Needed to Assess the Quality of Rivers and Streams" is deserving of special attention. Basically, the report recommends the elimination of periodic (or routine, in Metro's nomenclature) networks for trend assessment in favor of more intensive synoptic surveys (type b in the terminology of Chapter I). Many of the problems that the report points out are associated with a nation-wide, scattered data base supplied from many sources. The nature of interaction between federal and state agencies and inconsistencies in field and laboratory work from many studies contribute to the difficulties. Fortunately, by paying proper attention to considerations such as quality assurance/quality control in field procedures, laboratory analyses, and data recording, Metro should be able to avoid many of the problems that have plagued larger scale, nationwide water monitoring programs. However, issues such as adjusting concentration measures for in-stream flow variation and location of sampling stations are present even in smaller, local studies and will be addressed in Section C of this chapter.

B. Recommended Trend Assessment Technique

The trend assessment technique or techniques used must recognize the nature of the data being analyzed. As noted in the previous section, it generally has only been within the last ten years that statistically rigorous methods have been brought to bear on the problem of water quality trend detection. In part, this is because of some complicating characteristics of the data bases. Among the characteristics that must be recognized are:

(1) Seasonality: Most water quality variables are affected directly or indirectly by seasonal climatic changes. For instance, water temperature responds directly to air temperature, allowing for some lag to account for heat transfer into and out of the streambed, and the water itself. Dissolved oxygen is affected by water temperature since many biochemical processes in the water body are affected by oxygen deficit, the difference between dissolved oxygen concentration and saturation concentration, and saturation concentration varies with temperature. Nutrients, such as PO_4-P and total P reflect levels of biological processes, such as stream periphyton growth rate and concentrations, which may have large seasonal variability.

(2) Asymetric probability distributions: Most water quality variables are positively skewed, since they cannot be negative, but may occasionally take on large positive values. Exceptions are variables which have small ranges, or coefficients of variation, such as temperature, dissolved oxygen, and pH. These variables are often very nearly symmetric and, if seasonal variations are removed, may be nearly normally distributed. On the other hand, variables such as suspended solids and other measures of sediment loading, bacterial counts, and some biomass indicators may be very highly skewed.

(3) Missing or nonuniformly sampled data: Because of the relatively

recent evolution of the water quality field, major improvements in laboratory and field procedures, and changing ideas as to appropriate sampling strategies, the time sequence of observations of any particular variable at a given location may have many missing data. Sequences of missing data may be for long periods when no samples were taken, such as a year or more, or may occur sporadically throughout the record. Incomplete records may also occur because of changes in sampling frequency. Regardless of the cause, most traditional time series techniques, which assume equal sample intervals, are not applicable to water quality data.

(4) Persistence: Water quality measurements are not, in general, independent, but are instead positively correlated (i.e., small values tend to be followed by small values and large by large), and the correlation usually increases as the sampling interval decreases. Positive correlation between samples arises because fluctuations from the mean tend to continue for a period that is long compared to the sampling interval. Examples are abnormally high air temperature, or low rainfall, which will be reflected as short term variability in many water quality variables. Such variations are, from a statistical standpoint, 'noise', and may obscure underlying trends. Persistence usually is not a major issue when monthly sampling frequencies are used, particularly if the data have been adjusted for flow dependence (discussed below). For higher sampling frequencies, such as biweekly or weekly, it becomes increasingly important.

(5) Streamflow interaction: Hirsch, et al. (1982) have documented the effect that interactions between streamflow and water quality

variables may have on detectability of trends. Some water quality variables display a washoff effect, that is, high flows are accompanied by high concentrations (i.e., solids), while others have a dilution effect (i.e., fecal coliform counts), where high flows tend to coincide with low concentrations. Unless the flow-concentration relationship is neutral, the possibility exists that apparent trends in concentration may be caused by trends in flow, for example, a sequence of several wet years followed by a sequence of dry years.

Before commenting on the particular methods recommended which respond to these considerations, it is worth making a philosophical observation. Water quality trend analysis, and in fact most statistical problems, requires the application of at least some measure of art. Statistical inference is based on the premise that the probability distribution of the data (or certain characteristics thereof) takes on a certain form, i.e., normal, log normal, etc. So long as the distribution holds, specific procedures are available, and hypothesis tests, parameter estimation and other inferences can be drawn from the data. The difficulty, especially for small sample sizes (and water quality samples sizes are inevitably small to moderate by statistical standards) is that one can never be sure that the assumed probabilistic properties actually hold. For instance, a logarithmic transformation of the data will be appropriate if the sample data are log normally distributed, but it is usually very difficult to confirm that the underlying population distribution is in fact log normal as compared to a similar alternative distribution, (e.g., extreme value, Pearson III).

For this reason, we emphasize an approach that makes use of a number of statistical tests and other procedures, some seemingly redundant. We also recommend liberal use of graphical interpretation at as many points in the statistical analysis as possible.

With these considerations in mind, we recommend the use of a family of nonparametric statistical tests, included in Lettenmaier (1977), with the addition of some parametric and nonparametric tests and flow adjustment procedures recommended by Hirsch (1982). Nonparametric tests are advocated where possible because they do not require specific knowledge of the form of the underlying probability distribution, but (in general) only that it be symmetric. By use of appropriate data transformations, approximate symmetry can be achieved, and verified graphically.

TREND, the revised computer program developed to perform the analyses, is described in the following section, and in more detail in Appendix B. Briefly, water quality and streamflow data are entered, screened, and grouped by season (e.g., month). Three general classes of options are then available to the user: (1) data manipulation, i.e., options that perform some operation on the data such as transformation, removal of seasonal means, etc., (2) plotting, and (3) statistical testing. Considerable flexibility is left to the user in determining the sequence of options to be performed. In addition, parallel pathways to achieve the same objective (e.g., removal of seasonal means versus use of a seasonal test directly) exist in some cases. Where these occur, we make recommendations as to the preferred pathway, however it may be best to use both methods and compare the results, as illustrated in Chapter V. The reader who desires to implement the program is strongly urged to carefully review the program documentation of Appendix B and the demonstration examples in Chapter V.

C. <u>TREND - A Computer Program for Water Quality Trend Analysis</u>

TREND is a Fortran IV program capable of performing a number of analyses on water quality time series. In general, these analyses are aimed at processing of the data to account for the various properties discussed in the preceeding section, and ultimately to test for the existence of a trend. The program offers twenty options which allow the user to create time series plots, quantile-quantile plots, (Wilk and Gnanadesikan, 1968) deseasonalize data, and compute various parametric and non-parametric statistics. With the exception of the plotting routines, which are available only at the University of Washington's Academic Computer Center, the program is transportable to any installation that supports Fortran 77.

TREND operates on a channel-option concept (see flowchart - Fig. 2a). Data are stored in channels and various user-defined analyses and operations ("options") may be performed on the data in those channels. This format is particularly convenient and efficient because it allows storage of data on which various manipulations have been performed for future analysis. Six channels are available and a channel may be reused at any time at the cost of overwriting the data previously stored in that channel.

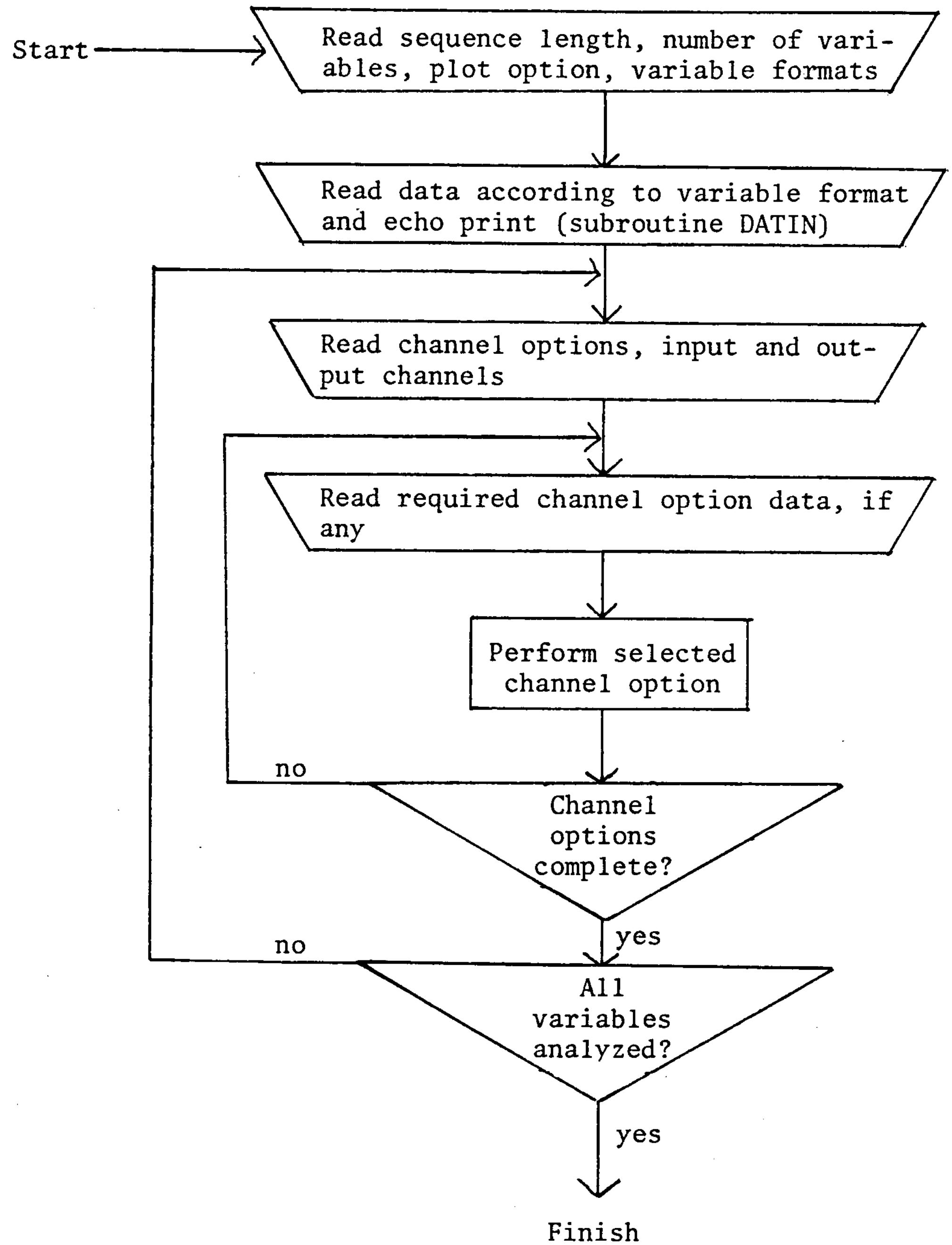

Figure 2a. TREND Program Flowchart

Initially, data are read by the DATIN subroutine which converts the (possibly) irregular time series to a uniform time series with a variable, user-supplied sampling interval. The data input format is compatible with time series data accessed from Metro's automated data handling system (see Appendix B). The program offers two options for converting the irregular series to a uniform time series (e.g., one sample per month): (1) all data within the base time interval are averaged and this mean value is used as the observation for that interval, or (2) the observation closest to the center of the interval is used as the observation for that interval, and the other data are ignored. The preferred option depends on the objectives of the user. In many cases, such as when a monthly sampling interval has been used throughout the data record, the choice is immaterial; it is only of concern when, for instance, there are periods during which several samples per month were collected. Option 1 will provide a smoother time series for, say, plotting but is inadvisable if statistical analyses are desired since the resulting "observations" may have unequal variances. During the data-reading phase all non-numeric items in the data (i.e., "L", "A", "<") are converted to blanks. Up to 6 variables of 250 observations each may be entered and stored by DATIN. The resulting uniform time series are printed on the job output.

Once the data have entered the program up to 20 analyses and/or operations may be performed on each variable. The program is capable of the following analyses and operations (see Appendix B for more detailed description; except where otherwise noted, refer to Lettenmaier (1977) for detailed descriptions):

(1) data transformation - both natural log and power transforms are available,

(2) deseasonalization,

(3) data differencing with an optional lag period,

(4) quantile-quantile plots,

(5) time series plots on either a lineprinter or a CalComp-like device,

(6) transfer of data from one channel to another,

(7) correlation and partial correlation plots,

(8) Cumulative Sum (CUSUM) plots,

(9) removal of up to 16 data points from the data set (can be performed multiple times),

(10) computation of residuals from a moving average,

(11) Mann-Whitney (Conover, 1971, p. 224) or Spearman's rho (Conover, 1971, p. 245) test for trend,

(12) plot of least squares linear or step increase (decrease) in the data,

(13) computation of flow concentration relationships (Hirsch, et al. 1982, p. 108),

(14) Mann-Kendall trend test (Conover, 1971, p. 249),

(15) a seasonal trend test based on Kendall's statistic (Hirsch, et al., 1982, p. 108),

(16) same as (15) with slope estimator (Hirsch, et al., 1982, p. 117),

(17) computation of the first 4 moments of the data (Hirsch, et al., 1982),

(18) seasonal least squares regression (Hirsch, et al., 1982),

(19) standard least squares regression (Hirsch, et al., 1982),

(20) a seasonal rank sum test for trend based on the Mann-Whitney-Wilcoxon statistic (Bradley, 1968, p. 115).

Options 3, 7, 9 and 10 are not usually used for trend analysis. They were retained from an earlier version of the program (Lettenmaier, 1977) in the interest of completeness.

Clearly, there is some overlap between these options. For instance, using option 2 followed by option 12 gives a Mann-Whitney trend test on deseasonalized data which is similar (but not identical) to the test described in option 20. Recommendations and guidelines for circumstances such as this are included in Chapter V.

Execution of TREND is best accomplished by interactive submission of a batch job (i.e., from a remote terminal). Figure 2b conceptually shows the job file structure for such a run of TREND. It is presumed that the program source code has been previously compiled and placed on a file which can be accessed by the job control language (JCL) file.

All job files may exist physically on tape, disk, or in the form of cards. However, since card handling capabilities are being phased out at most installations it is strongly recommended that the use of cards be avoided. Instead, use of disk space for temporary storage and tapes for long term storage of water quality and streamflow data files is recommended. Since the JCL and input data files change for every job, they generally will not be saved for extended periods, and use of disk storage is recommended.

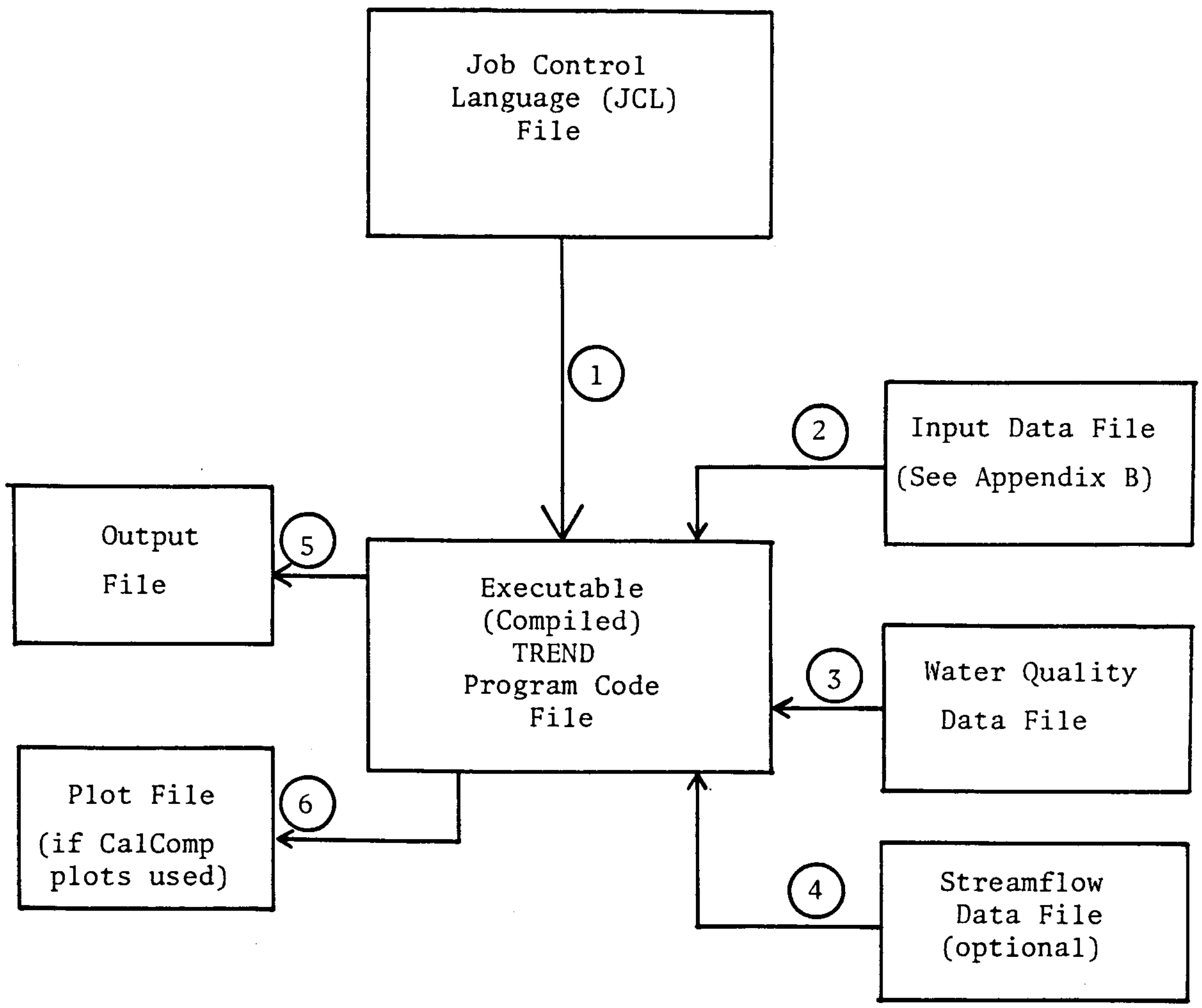

Figure 2b. File Logic Structure to run TREND.

In Figure 2b, the user supplies the JCL, input data (see Appendix B), water quality data, and flow data files (if required), in addition to the executable program code file. Typically, the user does not have access to the program source code and only a command to execute the compiled code is included in the JCL. Alternately, a command can be placed in the JCL to compile the program, but this is a less efficient and more awkward procedure. The water quality and flow data files may be included in the input data file (see Appendix B), or they may be placed on separate disk files which are referenced by the JCL. The latter procedure is preferred. It is, however, recommended that the input file be physically linked to the JCL file (separated by an end of record marker), as this file is usually quite short by comparison to the water quality and streamflow data files.

As with any generalized program, certain limitations and cautions must be kept in mind. Most of the routines will accept missing values and such data are merely excluded from analysis. If a routine cannot accept missing data this is pointed out in the more extensive documentation provided in Appendix B. A limitation of several of the options dealing with seasonality is that there can be only one observation per season, i.e., monthly observations cannot be averaged to obtain quarterly seasonal values within the routine. This may be partially circumvented by the DATIN routine which will average several observations (say, 3 monthly values) into a single value. Finally, the user must realize that TREND has no control over certain Fortran level operations. Incorrect entry of data may cause the program to abort without a clear diagnostic message. However, the program echo prints all input data, so such problems usually can be reduced by verification of the input. Whenever an unexpected error is encountered during the use of TREND the user should carefully check the various program inputs.

CHAPTER III. REVIEW OF EXISTING METRO STREAMS AND RIVERS ROUTINE MONITORING NETWORK

The baseline routine streams and rivers monitoring network evaluated in this chapter consists of 64 stations located throughout the Lake Washington and Green River drainage basins as shown in Figure 3. As described in Chapter I, this network has evolved from various water quality monitoring programs conducted by Metro throughout King County from the early 1960's. Generally, stations have been placed on bridges where possible to allow easy access and to facilitate adequate cross-sectional representation of stream quality. Grab sampling is used exclusively, with a single replicate analyzed from each sample (however, duplicate analyses are conducted on approximately 10% of the samples for quality control purposes).

Appendix A provides descriptions of the subset of sampling stations considered in this chapter, classifying each station by its Puget Sound Council of Governments (PSCOG) subbasin identifier as well as its common identifier. The former is required to link land use projections and drainage areas to the various stations. It should be noted that there are some differences between the station list given in Appendix A which includes 64 stream and river stations and Metro's 1980 and 1981 rosters of stations. These differences reflect absence of PSCOG subbasin identifications, as well as some stations on the Lake Washington Ship Canal and the tidally influenced portion of the Duwamish that are

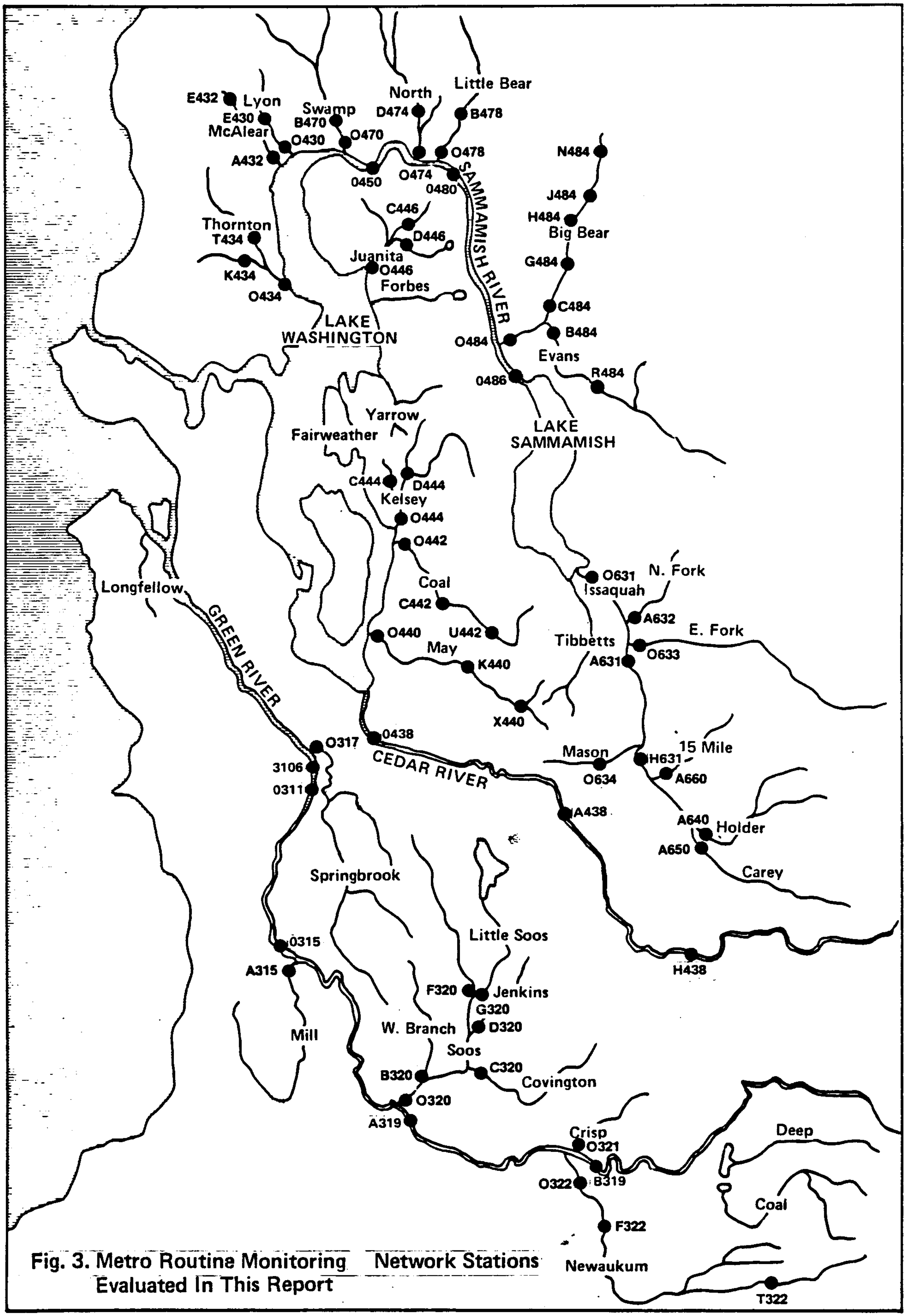

Fig. 3. Metro Routine Monitoring Network Stations Evaluated In This Report

included in the streams and rivers program, but are not formally classified as streams or rivers for this report. These stations are not considered.

Metro's current sampling strategy is to visit each station on a one month interval. At each visit, the full suite of constituents listed in Table 1 is collected, subject to certain exceptions noted. Where possible, analyses are conducted on-site (examples: temperature, dissolved oxygen). Instantaneous streamflow is measured at the stream sites by taking current measurements at approximately 0.6 of the depth at the 1/3 and 2/3 points in the stream transect, and computing flow as the appropriately weighted multiple of velocity and cross-sectional area. Cross-sectional area is estimated by observing an instantaneous stage, and determining the area from a preexisting cross-section survey. Laboratory analyses are conducted at Metro's Seattle water quality laboratories.

One of the primary objectives of this study is to review the existing network with respect to (a) number of stations, (b) sampling frequency, (c) constituents measured, and (d) streamflow monitoring strategy. As noted in Chapter I, there appears to be a conflict between the stated objectives of Metro's routine streams and rivers program, and the information that can be extracted from routine, or trend sampling. The essence of this conflict is the lack of either predictive or forecasting capability inherent in the analysis of trends. Insofar as several of Metro's monitoring objectives are predicated on predictive capability, the primary motivation in the analysis conducted in this

Table 1. Metro Streams and Rivers Routine Monitoring Program - Constituents Monitored and Cost Estimates.

Constituent	Cost Per Analysis, dollars	Notes
Temperature	NA	field
Dissolved Oxygen	0.87	sample fixed on-site
BOD	9.81	
pH	0.68	
Fecal Coliform & Fecal Strep	4.21	
Instantaneous flow	NA	instantaneous velocity reading used in conjunction with stage reading
Suspended solids	1.28	
NH_3-N	2.10	
NO_2+NO_3-N	2.10	
OPO_4-P	2.10	
Total PO_4-P	1.32	
Total Kjeldahl N	included with organic N	
Turbidity	0.60	
Settleable Solids	2.05	
Specific Conductance	0.29	
Organic N	2.62	by difference
Oil & Grease	NA	intermittently selected stations only
Cd		
Cr		
Cu		
Hg	0.46	stations 3106 & 0311 only
Ni		
Pb		
Zn		
Fe	NA	
Chlorine residual	NA	stations 3106 & 0311 only

Total less oil & grease, Fe, chlorine residual = $32.19 (includes $1.70 for supplies)

Total based on lab time allocation $61

chapter is to suggest a redesign of the existing network compatible with this aim. It is the authors' thesis that this can best be achieved by reducing the resources allocated to the routine monitoring program, and reallocating them to intensive surveys that can be used to support dynamic basin level water quality modeling. Therefore, this chapter will emphasize possibilities for (a) reducing the number of routine monitoring stations, (b) reducing sampling frequency, and (c) reducing the number of constituents sampled.

A. Sample Station Selection

As noted above, the existing routine rivers and streams monitoring network station locations have been determined by an ad hoc evolutionary process. Ideally the station allocation procedure would be a global optimization, with the objective function a technical statement of the network objectives. For instance, for a trend network, Lettenmaier (1975) devised a method for allocating stations within a basin using a trend detectability criterion. This methodology presupposes that there is no existing network. The assessment of Metro's network undertaken here is a somewhat different problem. First, many basins are involved, and a key element is the necessity to allocate sampling stations among basins. Second, the preexisting network is areally extensive, and it is desirable to retain existing stations wherever possible. Also, the existing stations usually have been located at bridges or other structures facilitating the gathering of cross-sectionally representative samples, as well as measurement of streamflow. In consideration of the desire to reduce the number of stations, and the areal extensiveness of the existing network, a design methodology was selected that constrains the stations in the revised network to be a subset of the existing network.

Having determined that the design algorithm to be used must select optimal subsets of the existing network, it is necessary to define an objective function. Primary considerations are that (a) the objective function must reflect Metro's dominant water quality management concerns, including those objectives noted in Chapter I which are relevant to a trend monitoring network, and (b) that the network be effective in detecting trends.

As noted in Chapter I, Metro has designed swimmability and fishabiliity indices (Swartz, et al., 1980) to quantify two of its principal water quality concerns. Therefore, a major consideration for monitoring design is that sampling be conducted in those streams that are rated relatively low with respect to swimmability or fishability, as defined by the indices. Ideally, these indices might be used directly as criteria for station selection. However, the existing data are not complete enough to allow computation of both indices at all stations. Therefore, surrogates for the indices, specifically fecal coliform counts (swimmability) and the stream walk index (fishability) were selected. The specific values used were geometric mean summer (April - September) fecal coliform counts for the period 1979-81, and the summer, 1979 stream walk indices. In both cases, availability of data was an important consideration in determining the year or years used.

The swimmability/fishability criteria are useful in identifying streams and river reaches that may bear particular scrutiny on the basis of existing undesirable quality. Another criterion is necessary to identify basins or subbasins that presently have high quality, but that may be adversely affected by future land use changes. Harper-Owes (1981) identified a flood index defined as the average ratio (over years) of instantaneous maximum flow to daily maximum flow, which appeared to be the best predictor, considering data availability, of coho salmon abundance for small streams within the Metro service area. This index can be related to impervious area, therefore projected impervious area change is a useful surrogate for susceptibility of a basin to a range of water quality/quantity problems.

PSCOG has provided land use information (under separate contract to Metro) on a watershed level that can be used to estimate impervious area changes that may be associated with each of the routine monitoring stations listed in Appendix A. The PSCOG projections provide predicted land use changes in several categories. For each category, a per cent imperviousness can be estimated, following the results of a study of urban hydrology performed by the American Society of Civil Engineers (1969). Although the methodology is not precise, its accuracy is compatible with that of the land use change projections. Harper-Owes (1981) made use of the ASCE information on imperviousness for various land use types to estimate per cent imperviousness for 1980 conditions in the PSCOG subbasins. In the interest of consistency, the particular values for imperviousness for each of the PSCOG land uses (which represent the midpoint of the ranges from the ASCE study) were also used here. By summing the products of projected number of areas in each land use by fractional imperviousness for that land use, estimates of 1980 and 2000 equivalent impervious acres were derived for each of the drainages associated with the 64 stations given in Appendix A for 1980 and 2000. Where more than one station existed with a PSCOG subbasin, an estimate was made of the distribution of the projected areas upstream of each station. Appendix C contains detailed estimates of impervious area derived from the PSCOG data.

The use of fishability/swimmability, and projected land use change should identify stations on the basis of either low ratings in current water quality or of potential for future changes. One final candidate, which is a surrogate for objective 6 of Chapter I (public awareness of Metro programs), is the drainage area associated with each station. In the absence of differences in the first three criteria, maximization of accountability for water quality changes throughout Metro's service area dictates that a station draining a large area is preferable to a station draining a small area. Drainage areas are available directly from the PSCOG land use data.

Given the four critera for each station (summer 1979-81 geometric mean fecal coliform counts, projected impervious area increase, drainage area, and 1979 stream walk index), a single station score was desired. This necessitated some method for weighting and combining each of the four criteria, or some transformation thereof, to form a single score. In the absence of preference information not available to us, the use of equal weights was considered appropriate. However, care was required to avoid the domination of the score by any single criterion due to either differences in magnitude or variability. Therefore, suitable transformations of the raw data were considered. Figures 4a-d present stem and leaf diagrams (Tukey, 1977) of the raw data. Stem and leaf diagrams amount to a quick method of estimating empirical probability density functions for the data. For the purposes of what follows, it is important that the data take on a density function that approximates the normal distribution, a necessary (but not sufficient) condition of which is symmetry. It is immediately clear from Figures 4a-d that the stream walk index is approximately symmetric without transformation. This is to be expected, since the index is the sum of several elements which can be treated as random variables - therefore the central limit theorem would suggest normality. For the other variables, logarithmic transformations were employed. In the case of the coliform data, a tenuous argument for normality of the logarithms can be made based on the central limit theorem; for drainage area and projected impervious area change the logarithmic transformation must be viewed entirely as an operational tool. For the purposes of this analysis, it should be emphasized that approximate normality is sufficient, so a detailed analysis of appropriate transformations is not in order.

The ultimate objective of the analysis of the distribution of the four criteria is to obtain a score which equally weights the four criteria. One way of achieving this is to invoke a second transformation of each of the (possibly logarithmically transformed) criteria to a domain in which they will be uniformly distributed. Convenient limits of such a transformation are (0,1) or (0,100). If the

Figure 4a. Stem and Leaf Diagram for Stream Walk Index.

0*																							
1																							
2																							
3																							
4																							
5*	8	9																					
6	0	0	0	1	1	2	2	4	4	4	5	5	6	6	6	7	7	7	7	8	8	8	8	9
7	0	0	0	1	3	4	4	4	4	6	6	7	8	9	9									
8	0	0	2	9	9	9																		
9																							
10*																							

Figure 4b. Stem and Leaf Diagram for Geometric Mean Summer Fecal Coliform

0**	10	10	20	20	30	30	30	30	40	40	50	50	50	60	70	80
1	00	10	10	10	10	20	20	20	30	30	30	30	40	50	70	
2	00	00	20	30	40	90										
3	20	30	30	30	40	40	50	50	70							
4	10	30	40	60	70	70	80									
5**	00	40														
6	90															
7	00	00	90													
8	60															
9	20	50														
10**																
11																
12	00															
13																
14																
15**	30															

Figure 4c. Stem and Leaf Diagram for Projected Impervious Area Increase (acres).

0**	01 02 04 20 20 20 20 20 20 20 30 30 40 40 40 40 40 50 50 50 50
0	60 60 60 60 70 70 80 80 80 80 80 80 90 90 90 90 90 90
1	30 30 40 60 60 60 60 70 90
2	00 10 50
3	20 40 40 40 60
4	50 50 90
5**	
6	00
7	60
8	
9	
10**	00
11	
12	
13	
14	20
15**	70
16	

Figure 4d. Stem and Leaf Diagram for Drainage Area (acres).

0***	800 800 900
1	000 100 100 200 200 500 500 600 700 800 900 900
2	000 000 100 100 100 100 100 200 300 800 900 900
3	000 000 000 200 300 400 600 700 800 800
4	400 400 800
5	300 400 800 900
6	000 000 100 300 500
7	
8	200
9	000 100 600
10***	400
11	
12	400
13	100 200
14	500 900
15	000
16	
17	900
18	
19	
20***	
21	000 300
22	
23	
24	

latter is used, and the intermediately transformed data are normal, the inverse standard normal distribution function (which is related to the error function, erf(•), see National Bureau of Standards, 1964) will achieve this. The transformation may be represented as

$$Y_{ijk} = \begin{cases} 100 \cdot P(t_{ijk}); & t_{ijk} \geq 0 \\ 100 \cdot (1 - P(|t_{ijk}|)); & t_{ijk} \leq 0 \end{cases}$$

where $t_{ijk} = \dfrac{X_{ijk} - \overline{X}_i}{S_i}$, $i = 1, \ldots 4$, which are the criterion

and where $\overline{X}_i$ and S_i are the sample mean and standard deviation, respectively, of criterion i, and j is the station number in primary basin k. P(•) is the standard normal cumulative distribution function, computed in most elementary statistical texts.

For the j'th station in basin k, the score S^*_{jk} is simply the average of the Y_{ijk}, $S^*_{jk} = 1/4 \sum_{i=1}^{4} Y_{ijk}$. An exception is made when no stream walk index is available for a particular station (e.g., the river stations) in which case S^*_{jk} is the average of the remaining three criteria.

The effect of these manipulations is to define a score, ranging from zero to 100, for each of the 64 stations. To achieve the ultimate aim of the analysis, which is to specify optimal or near optimal n-station subsets of the 64 station grid analyzed here, it is necessary to determine the optimal p-station subsets of the existing N_k stations in each of the k = 1, ... 20 primary basins. For instance, within the Issaquah Creek basin, which presently has N_k = 8 stations, there are $\binom{8}{p} = \frac{8!}{(8-p)!p!}$ p-station subsets. For p = 4, this amounts to 70 possible four-site configurations. One approach to this problem would be to select the p-station subsets, p = 1, ... 8 (for Issaquah Creek) which have the maximum summed score, $S^{**}_{pk} = \sum_{j=1}^{p} S^{*}_{jk}$. The difficulty with this approach is that the criteria measures Y_{ijk} are dependent on the specific configuration of the stations, therefore, for example, for p = 4 in Issaquah Creek, projected impervious areas, drainage areas, stream walk indices, and fecal coliform counts would have to be identified and repeated for all 20 primary basins. This tedious process would clearly involve enumeration of many inferior alternatives. For this reason, an alternate, ad hoc approach was taken, which should result in near optimal within basin allocations. This ad hoc approach is defined as follows: For p = 1, the station nearest the outlet (usually having an "0" prefix) was always used. For p > 1, an ad hoc approach was used. The procedure, which is subjective, was based on a preference to have approximately equal projected impervious area changes assigned to each station. In assigning criteria values to each station for $p < N_k$, recorded coliform counts at each station were used directly for each station. Likewise, drainage areas were computed directly by summing the upstream area associated with stations not included in the given p-station configuration. Stream walk indices were estimated by taking the weighted sum of recorded stream walk indices for the given station and all upstream existing stations not included in the specified configuration, where the weights were the square root of the areas drained by each existing station included. The rationale for these weights is that the streamwalk index represents stream bed conditions per unit length of stream, and the square root of drainage area is a characteristic stream channel length.

The results of this aggregation process for the k'th primary basin, for example, were N_k station configurations, where N_k is the present number of stations in basin k, k = 1, ... 20. The results of this preliminary analysis are given in Appendix D, which includes the raw criteria values for each configuration.

Having completed the within-basin analysis, the problem becomes one of allocating stations among basins. For example, if a 60-station network is desired, this could be achieved by reducing the existing number of stations in primary basins number 5, 10, 15, and 20 by one each. The score associated with this network would be $S^{***} = \sum_{k=1}^{20} \sum_{j=1}^{p_k} S^*_{jk}$. The optimal network is that having the maximum S^{***} subject to the constraint that $\sum_{k=1}^{20} p_k = n = 60$. This problem is well-suited to dynamic programming, an optimization technique described in most introductory operations research texts (e.g., Hillier and Lieberman, 1967; Chapter 8). In the formulation used here, the primary basins were stages, and the scores associated with each p_k-station configuration were the states. The output of this analysis is the specific number of stations allocated to each basin for each value of n, as given in Table 2. For any desired value of n, Appendix D can be consulted to determine the particular stations in the existing network to be retained. The program used to perform the optimization is included as Appendix E.

As described earlier in this chapter, the approach pursued here is to reduce the allocation of resources to the routine monitoring network, and to re-allocate the savings to a type b/c network in the interest of upgrading Metro's ability to predict future water quality problems. The routine network retained, however, must meet Metro's objectives with respect to long term trend assessment as outlined in Chapter 1. A review of Table 2 reveals that reasonable coverage of the 20 primary basins is provided by a network with n = 30 stations, i.e., at least one station is included in all but one of the primary basins. Such a network represents elimination of slightly more than 50% of the 1980 network, and as shown in Section E, should be sufficient to allow implementation of a viable type b/c (model parameterization/cause-effect) monitoring network and related modeling effort.

For these reasons, our recommendation is to retain a 30 station routine monitoring network, with stations allocated to the primary basins as shown in Table 2 for n = 30, and in Figure 4e. We suggest that Metro carefully review the specific stations to be retained, taking into account factors that may not hve been incorporated into the site selection process. These include the quality of the historic record at the sites to be retained, availability of stream gage data, and any peculiarities of the physical sites that might affect the representativeness of results. The important recommendation of this section is a 30 site network, and the allocation of these 30 stations to

Table 2. Optimal n station subsets of baseline 64 station network (entries are p_k, number of stations allocated to each primary basin)

Number Stations, n	PSCOG, Primary Basin Identifier, k (See Appendix A) 1	2	3	4	5	6	7	PSCOG 8	9	10	11	12	13	14	15	16	17	18	19	20	Score
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	86.1
2	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	85.1
3	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	84.6
4	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	83.1
5	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	0	0	0	0	0	82.0
6	0	0	0	0	0	0	1	2	0	0	0	1	0	1	1	0	0	0	0	0	81.0
7	0	0	0	0	0	1	1	2	0	0	0	1	0	1	1	0	0	0	0	0	80.1
8	0	1	0	0	0	1	1	2	0	0	0	1	0	1	1	0	0	0	0	0	79.2
9	0	1	1	0	0	1	1	2	0	0	0	1	0	1	1	0	0	0	0	0	78.5
10	1	1	1	0	0	1	1	2	0	0	0	1	0	1	1	0	0	0	0	0	77.8
11	1	1	1	0	0	1	1	2	0	0	0	1	0	1	1	1	0	0	0	0	77.1
12	1	1	1	0	0	1	1	2	0	0	0	1	0	2	1	1	0	0	0	0	76.5
13	1	1	1	1	0	1	1	2	0	0	0	1	0	2	1	1	0	0	0	0	76.0
14	1	1	1	1	0	1	1	3	0	0	0	1	0	2	1	1	0	0	0	0	75.5
15	1	1	1	1	1	1	1	3	0	0	0	1	0	2	1	1	0	0	0	0	74.9
16	1	1	1	1	0	1	1	3	0	0	0	1	0	2	1	1	0	2	0	0	74.3
17	1	1	1	1	1	1	1	3	0	0	0	1	0	2	1	1	0	2	0	0	73.8
18	1	1	1	1	1	1	1	3	0	0	0	2	0	2	1	1	0	2	0	0	73.3
19	1	1	1	1	1	1	1	3	0	0	0	2	0	2	1	1	0	2	1	0	72.9
20	1	1	1	1	1	1	1	3	0	0	0	2	1	2	1	1	0	2	1	0	72.4
21	1	1	1	1	1	1	1	3	0	0	0	2	1	3	1	1	0	2	1	0	72.0
22	1	1	1	1	1	1	1	3	0	0	0	2	1	3	1	1	0	2	1	1	71.5
23	1	1	1	1	1	1	1	3	0	0	1	2	1	3	1	1	0	2	1	1	71.1
24	1	1	1	1	1	1	1	3	1	0	1	2	1	3	1	1	0	2	1	1	70.7
25	1	1	1	1	1	1	1	3	1	0	1	2	1	3	1	2	0	2	1	1	70.3
26	1	1	1	1	1	1	2	3	1	0	1	2	1	3	1	2	0	2	1	1	69.8
27	1	1	1	1	1	1	2	3	1	0	1	2	2	3	1	2	0	2	1	1	69.3
28	1	1	1	1	1	1	2	3	1	1	1	2	2	3	1	2	0	2	1	1	68.9
29	1	1	1	1	1	2	2	3	1	1	1	2	2	3	1	2	0	2	1	1	68.2
30	1	1	1	1	1	2	2	4	1	1	1	2	2	3	1	2	0	2	1	1	67.6

Table 2. (Continued)

Number Stations, n	PSCOG, Primary Basin Identifier, k (See Appendix A) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Score
31	1	1	1	1	1	2	2	4	1	1	1	2	2	3	1	2	0	2	1	1	67.0
32	1	1	1	1	2	2	2	4	1	1	1	3	2	3	1	2	0	2	1	1	66.4
33	1	1	2	1	2	2	2	4	1	1	1	3	2	3	1	2	0	2	1	1	65.8
34	1	1	2	1	2	2	2	4	1	1	1	3	2	3	1	2	0	2	2	1	65.2
35	1	1	2	1	2	2	2	4	1	1	1	3	3	3	1	2	0	2	2	1	64.6
36	2	1	2	1	2	2	2	4	1	1	1	3	3	3	1	2	0	2	2	1	64.1
37	2	1	2	1	2	2	2	4	1	1	1	3	3	3	1	2	0	2	2	2	63.6
38	2	1	2	1	2	2	2	4	1	1	3	3	3	3	1	2	0	2	2	1	63.1
39	2	1	2	1	2	2	2	4	1	1	3	3	3	3	1	2	0	2	2	2	62.6
40	2	1	2	1	2	2	2	6	1	1	3	3	3	3	1	2	0	2	2	1	62.1
41	2	1	2	1	2	2	2	7	1	1	3	3	3	3	1	2	0	2	2	1	61.6
42	2	1	2	1	2	2	2	7	1	1	3	3	3	3	1	2	0	2	2	2	61.2
43	2	1	2	1	2	2	2	7	2	1	3	3	3	3	1	2	0	2	2	2	60.7
44	2	1	2	1	2	2	2	7	1	1	3	3	3	3	1	2	0	4	2	2	60.3
45	2	1	2	1	2	2	2	7	1	1	3	3	3	3	1	2	0	5	2	2	60.0
46	2	1	2	1	2	2	2	7	2	1	3	3	3	3	1	2	0	5	2	2	59.6
47	2	1	2	1	2	3	2	7	2	1	3	3	3	3	1	2	0	5	2	2	59.1
48	2	1	2	1	2	3	2	7	2	1	3	3	3	3	1	2	1	5	2	2	58.7
49	2	1	2	2	2	3	2	7	2	1	3	3	3	3	1	2	1	5	2	2	58.2
50	2	2	2	2	2	3	2	7	2	1	3	3	3	3	1	2	1	5	2	2	57.7
51	2	2	2	2	2	3	2	7	2	1	3	3	4	3	1	2	1	5	2	2	57.3
52	2	2	2	2	2	3	2	7	2	1	3	3	4	3	1	2	1	5	3	2	56.9
53	2	2	2	2	2	3	2	7	2	1	3	3	4	4	1	2	1	5	3	2	56.4
54	2	2	2	2	2	3	2	7	2	1	3	3	5	4	1	2	1	5	3	2	55.9
55	2	2	2	2	2	3	2	7	2	1	3	3	6	4	1	2	1	5	3	2	55.3
56	2	2	2	2	2	3	2	7	2	1	3	3	7	4	1	2	1	5	3	2	54.9
57	2	2	2	2	2	3	2	7	2	1	3	3	7	4	1	2	1	6	3	2	54.3
58	2	2	2	2	2	3	2	7	2	2	3	3	7	4	1	2	1	6	3	2	53.7
59	2	2	2	2	2	3	2	7	3	2	3	3	7	4	1	2	1	6	3	2	53.0
60	2	2	2	2	2	3	2	7	3	3	3	3	7	4	1	2	1	6	3	2	52.4
61	2	2	2	2	2	3	2	7	3	3	3	3	7	4	1	2	1	6	3	2	51.8
62	2	2	2	2	2	3	3	7	3	3	3	3	7	4	1	2	1	6	3	3	51.2
63	2	2	2	2	2	3	3	7	2	2	2	2	9	4	1	2	1	6	3	2	50.6
64	2	2	2	2	2	3	3	7	3	3	3	3	9	4	1	2	1	6	3	3	50.0

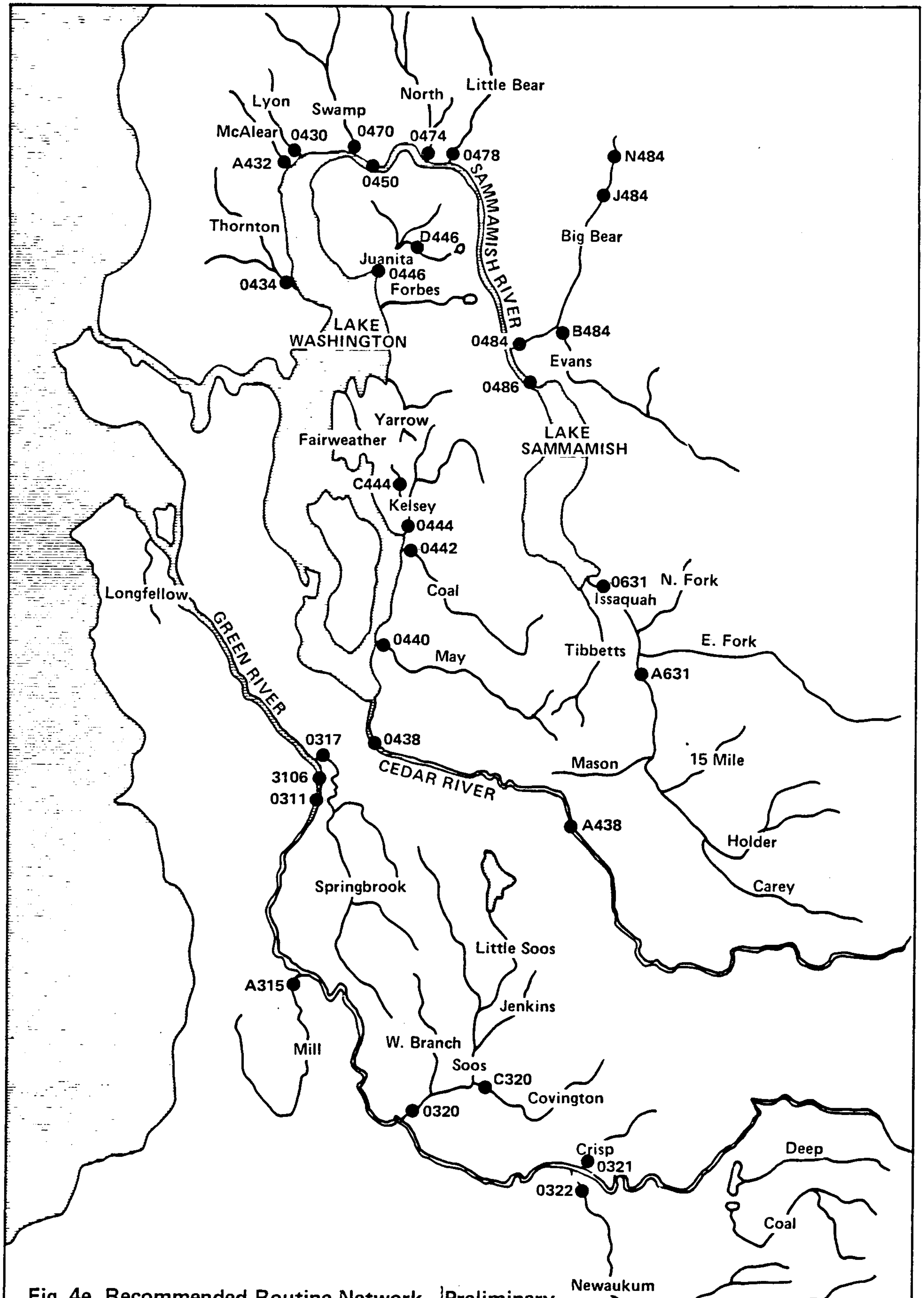

Fig. 4e. Recommended Routine Network - Preliminary

the 20 PSCOG primary basins; the analysis does not preclude some adjustment in the particular stations to be retained within each primary basin.

B. Parameters Monitored and Sampling Cost Analysis

Table 1 lists the water quality variables collected at Metro's routine monitoring stations, and estimated laboratory cost information provided by Metro. For comparison purposes, the list of parameters and sampling costs provided by William Yake of the State of Washington Dept. of Ecology (DOE) for DOE's statewide ambient stream monitoring program are given in Table 3. The DOE program includes six stations on the Green/Duwamish, Cedar, and Sammamish Rivers which are specified in Table 4. The apparent duplication in effort represented by the DOE and nearby Metro stations is addressed in Section E of this chapter. In this section, the comparison of concern is the water quality variables sampled, and laboratory analysis costs for each. Comparison of Tables 1 and 3 indicates that the DOE list includes all elements on the Metro list with the exception of metals, BOD, settleable solids, and oil and grease (which Metro collects only intermittently). The DOE list includes color, which is not on the Metro list. DOE also monitors Cu, Cr, Pb, Zn, Cd and Hg at its lower Green and Duwamish stations; Metro monitors these metals as well as Ni and Fe at all stations, and chlorine residual at stations 3106 and 0311, which bracket the Renton wastewater treatment plant discharge.

Metro laboratory analysis costs are about $32 for its entire suite, based on material costs and labor from a time and motion study of laboratory performance. This compares with DOE costs of about $73 for primary variables only, and another $82 for secondary variables. At least two caveats should be placed on these estimates. First, the Metro costs are based very specifically on the time required to complete various analytical tasks; they do not necessarily result in full allocation of personnel time. A second approach, reported in Table 5, was taken in estimating Metro laboratory labor costs allocated to the routine sampling program on a per suite basis. This was accomplished by attributing all labor to various categories (travel time, sample time, analysis time, see Table 5), based on personnel scheduling data provided by Metro. On this basis, assuming an average wage including all expenses of $25/hr, the cost per suite of samples per site per survey is about $66. This does not include depreciation on equipment, cost of facilities maintenance, etc.

The DOE costs are updated from 1977 information using approximate inflation rates. This may result in an upper estimate, as improvements in laboratory procedures would be expected to reduce costs somewhat in constant dollars. The DOE estimates are based on analyses of the samples at an EPA lab, so they undoubtedly include full allocation of personnel, equipment depreciation, maintenance, etc. Even accounting for such differences in reporting, it appears that Metro's sample analysis costs are comparatively low, and do not represent an important candidate for program cost savings.

The parameters sampled in the routine program appear to be representative of the types of water quality problems present in Metro

Table 3. Washington State Department of Ecology - Ambient Stream Monitoring Program Laboratory Costs (updated from April 1977 estimates).

Primary Variables

Constituent	Cost Per Analysis	Comments
Instantaneous flow	field	a
Temperature	field	
pH	$ 3.25	b
Fecal coliform	8.25	
NO_3-N	8.25	
NO_2-N	8.25	
NH_3-N	8.25	
OPO_4-P	8.25	
Total PO_4	12.25	
Specific conductance	3.25	
Turbidity	4.00	
Color	3.25	
Suspended Solids	5.75	
Dissolved Oxygen	field	
	$73.00	

Secondary Variables

Constituent	Cost Per Analysis	Comments
Total Kjeldahl Nitrogen	$ 8.25	
Hardness	NA	
Cu	12.25	c
Cr	12.25	c
Pb	12.25	c
Zn	12.25	c
Cd	12.25	c
Hg	12.25	c
	$81.75 (excluding hardness)	

[a] if sampling site is coincident with U.S. Geological Survey stream gaging station, time is recorded and instantaneous flow retrieved directly from USGS records, if site is in proximity of USGS gage, time is recorded and instantaneous flow estimated by routing from USGS gage, otherwise instantaneous stage is recorded via wire weight, staff, or other reference at site and flow estimated by application of rating curve.

[b] also measured in field

[c] analysis performed by U.S. Environmental Protection Agency

Table 4. State of Washington Department of Ecology Ambient Stream Quality Monitoring Stations in King County

DOE #	Location	Nearest Metro Station
09A060	Duwamish RM 8.3, Allentown bridge	0307, 0309, 3106, 0311
09A090	Green R near Kent RM 18.3	0315
09A190	Green R near Kanaskat RM 57.6	B319
08C110	Cedar R near Landsburg	H438
08C070	Cedar R at Renton RM 1.0	0438
08B070	Sammamish R at Bothel	0480

streams and rivers, with only a few exceptions. The exceptions are Kjeldahl nitrogen, turbidity, and settleable solids. The Kjeldhal procedure is time consuming, and results in concentrations that are highly variable and difficult to reproduce. Further, there does not appear to be any water quality condition that can be directly interpreted from Kjeldahl N or Organic N, given the sample of NH_3-N and NO_2 + NO_3-N and the other water quality variables sampled. Turbidity is a discrete measure with increments so coarse (typically $\sim$ 5 Jackson turbidity units) that any trends that might be present are usually masked in truncation error. Further, joint investigation of suspended solids and specific conductance will usually pick up trends also appearing in turbidity. A similar argument can be made for elimination of settleable solids at the river stations. For selected stream stations where bank erosion is, or is expected to be, a major problem, this variable should be retained however.

A final cost consideration is transportation and sampling time. Tables 5 and 6 contain information on transportation time for the DOE program statewide, and for the Metro program. Average travel distances are much larger for the DOE program, and travel speeds are higher as well, as population densities are much higher in the Metro program area. However, Metro crews appear to spend about the same time at the site (about 36 labor-minutes on average versus about 40 estimated from Table 6 for DOE) despite the larger number of variables sampled. It does not appear, therefore, that there is much potential for reducing the time allocation to the sampling and transportation process.

Table 5. Metro Sample Crew Time Allotment

Region	# Sites	Travel Time/Site Labor-hours/crew	Sample Time/Site[a] Labor-hours/crew	Average[b] Distance
North	17	0.34	0.76	2.2
Southeast	13	0.36	0.74	2.9
Ship Canal	10	0.27	0.39	4.4
Green-Duwamish	10	0.31	0.40	5.2
South	14	0.52	0.74	5.1

[a]includes 9 L-H set-up time allocated equally to each site

[b]assumes actual distance is approximately 1.25 x straight line

Laboratory time estimate = (Total technician time allocated)* - (Field Time)** = (350 - 96.5) = 253.5 labor days/year.

Converted to dollars on a per site per survey basis, Lab labor cost is approximately $66/site/survey.

* Total technician labor estimate for routine monitoring - 1982 = 350 labor days

**(Total travel time/survey/year + sample time/survey/year) = 96.5 labor days

Table 6. DOE Sample Crew Time Allottment

Region	Avg Travel Distance	Avg LH
Northwest	26 mi	1.08
Southwest	31	1.36
Northeast	68	1.98
East	70.5	1.99

assume time is approximately c + a x travel

therefore, c is approximately 0.68 hr; a is approximately 0.019 hr/mi

The equation, which represents a best linear fit to the data in the table, suggests that the constant time per site is about 40 minutes, and the average travel velocity is about 50 mph. The velocity appears a bit higher than would be expected realistically; this is confirmed by comparison of the 40 minute at-site time as compared with the 20-30 minutes estimated independently by DOE.

C. Sampling Frequency

Various studies have been conducted to determine the most appropriate sampling frequency for long term trend detection. Lettenmaier (1975) showed that there is an upper limit on the effective independent sample size as sampling becomes continuous, and, as a result, that very high sampling frequencies are usually not cost effective. However, samples taken at 30 day increments are essentially independent under any reasonable assumption as to persistence structure. The concern therefore becomes one of total sample size. Detectability of trends increases as the total sample size (e.g., number of years of record times samples/year) increases; as a rough rule it is difficult to detect a trend magnitude much less than the standard deviation of the time series (or its transform) for samples smaller than 50-100. However, to make use of the flow adjustment methods discussed in Chapter II, and included in the computer program TREND (Appendix A), it is desirable to have a representative range of wet and dry years. If, for example, an alternative of doubling the sampling frequency were considered, the total number of years to detect a trend of fixed size would decrease, but the representativeness of the flow record might become a problem. Further, the number of stations would have to be reduced by one-half to keep the same level of sampling effort, and areal coverage would be inadequate. On the other hand, decreasing the sampling frequency to bimonthly would increase the number of years required to detect a marginal trend (e.g., a trend requiring 50-100 samples to detect) to upwards of ten years, which is probably too long to meet management objectives. Therefore, it is recommended that the present, monthly sampling frequency be retained.

One final comment on sampling frequency is the desirability of maintaining continuity in the sample collection process. The existing data base, as noted in Chapter I, contains numerous gaps in the records at the various stations. It is strongly recommended that the monitoring program, i.e., station locations, sampling frequency, and variables analyzed, stay fixed or nearly fixed until a sufficient record accumulates at each site to allow assessment of trends. As a guideline, this period of time should be on the order of five years. At that time, the network should be reassessed, and stations added or dropped as appropriate to meet evolving changes in underlying causative factors such as land use. Such revisions should not take place annually, as is presently the case; this is too short a period of time and encourages fragmentation of the data, which in turn greatly reduces its utility for trend assessment. On the other hand it is recommended that the intensive program, outlined in Section E, undergo annual review, as the streams being intensively monitored should respond to shorter term priorities in Metro's water quality management strategy.

D. Stream Gaging

Instantaneous streamflow is one of the variables measured in the routine monitoring program. The method of measurement is use of a current meter to obtain instantaneous velocity at one or more points laterally across the stream, and measurement of stage, used in combination with prior stream survey information to determine cross-sectional area. If care is taken to assure uniform procedures and velocity measurement, and the same equipment is used, the results should be of accuracy comparable with those obtained by the U.S. Geological

Survey at its gages. For small streams, this is typically a 'fair' rating which corresponds to mean absolute error on the order of ten percent for daily average flows. Measurement error for instantaneous flows will be higher. It is important to note that bias, ie., consistent over- or underestimation, does not affect the trend assessment procedure, so long as the bias does not change. Variability in flow measurement, however, reduces the effectiveness of the flow adjustment procedure.

For the purpose of intensive monitoring, and support of predictive modeling, continuous stream gaging information is needed. This need arises from the necessity to predict streamflow as an interim step in the water quality modeling process. Dynamic water quality models usually consist of two submodels: a runoff model driven by precipitation at time intervals on the order of one hour or less, whose output is runoff, and a quality model which is driven by the runoff model, and whose output is in-stream concentrations of various water quality constituents. Both models have a number of basin-specific parameters that must be estimated by comparison of recorded and predicted values. In the case of the runoff model calibration is performed against (continuous) runoff data, and for the quality model, calibration is performed against time sequences of quality measurements within a specific event period, such as a storm. The availability of continuous stream gage information is an essential part of this process.

The U.S. Geological Survey, in cooperation with several local agencies, operated a fairly extensive gaging network for small streams in lowland King County throughout the 1960's and 1970's. Much of this effort was related to the RIBCO study mentioned in Chapter I, wherein an attempt was made to inventory a number of small streams that had never been gaged. Many of these gages have since been discontinued. Appendix F summarizes the status of stream gages in the lower Cedar and Green/Duwamish basins. Excluding gages on the main stem of the Cedar and Green/Duwamish, active gages remain only on Big Soos Creek, Issaquah Creek, Kelsey Creek, Newaukum Creek, and Swamp Creek.

Discussions were held with Mr. Ed McGavock of the U.S. Geological Survey's Tacoma District Office to obtain approximate stream gaging installation cost estimates. For small streams, an average figure is $4000 which includes installation of a weir, if necessary, stilling well and protective housing for the stage recorder. Also included in this figure is the field time and analysis required to obtain an initial rating curve. Once installed, operation costs, including periodic site visits, data processing, reporting and data transfer to the Geological Survey's WATSTORE computerized data handling system, and updating of rating curves is on the order of $4000 annually. The stilling well and protective housing remain at the site for several of the inactive stations. Reactivation of these sites, assuming that the weir is servicable, should cost on the order of $500.

The current policy of the USGS with respect to stream gaging is to bill the full cost to the sponsoring agency, unless the station is considered essential to the Survey's mission. The likelihood of such a judgment for any stations in King County beyond the existing active network appears minimal, as the Survey undertook a recent program review to reduce the extent of its network. A second exception exists, however, in cases where the gaging supports a research or development need. This might be the case for some basin studies where, for example, there is an opportunity for development or extension of models, or where the application is in some sense unique (as for the Bellevue urban streams program). In these cases, some or all of the costs may be born by the USGS.

From the standpoint of the routine monitoring program, the existing method of measuring instantaneous flow appears to be adequate, and there is no apparent need to expand the lowland streams gaging network. For the purposes of an intensive monitoring program suggested in the following section, it will be necessary to implement a stream gaging program similar to that performed by the Geological Survey in cooperation with Metro on May Creek (Hauschild, et al., 1982) to support basin modeling. This typically would include installation and maintenance of a gaging network on the primary tributaries within a basin for a period of 12 to 24 months during which several intensive water quality collection efforts would be undertaken. Some general considerations for such a program are discussed in the following section.

E. Recommended Network

The recommended routine monitoring network as outlined in Section A of this chapter consists of the 30 stations shown in Figure 4e, and specified in Table 2 and Appendix D. Some minor modifications to this network are suggested; first, Tibbets Creek, which lacked land use data to allow prioritization, should be reviewed; it is possible that station A630 at the mouth of Tibbets Creek should be retained, with the lowest ranking station from Table 2 dropped in its place. Also, it is recommended that negotiations be conducted with DOE to eliminate duplication in the stations specified in Table 4. A review of the 30 stations to be retained indicates that all the duplicate stations are included, therefore a cooperative plan might shift responsibility for three of Metro's stations to DOE, while assuming responsibility for 3 DOE stations which are essentially identical to existing Metro stations. This would represent a net savings to Metro of three stations, leaving 27 to be sampled at the monthly frequency.

Metro's current allocation of labor (in labor-days per year) to the routine monitoring program, based on 1982 budget information, is as follows:

	Professional	Technician
Field and Lab Coordination	51	350
Program Management	16	1
Data Analysis and reporting	108	--

Based on an average wage rate of $25 per hour (including fringe and overhead), and assuming an average of two weeks' vacation per year, eleven holidays, and ten sick days, the total labor cost of the program at present is about $120,000 annually. For the purposes of what follows, it should be noted that equipment costs, supplies, and other incidentals are not included, however this omission is not of great concern since such costs will stay essentially constant as resources are shifted from the routine monitoring program to the suggested intensive program. Assuming an agreement can be reached with DOE to transfer responsibility for three stations and eliminating the variables noted in section C, the recommended routine monitoring program should require about $45,000 per year. Therefore, about $75,000 should be available for funding of an intensive monitoring program. It is our recommendation that this amount or the labor so represented, be used to fund an intensive monitoring program. The remainder of this chapter is directed toward estimation of the level at which such a program could operate given existing funding constraints.

Consider a 'typical' small stream of concern to Metro. From Figure 4d, such a stream (e.g., median drainage area) drains about 3400 acres, or slightly over five square miles. A typical main stem channel length for such a basin is 2-3 miles. A representative intensive monitoring network would consist of approximately ten stations, with samples taken over the rise and fall of a storm hydrograph, say at four hour average intervals for forty-eight hours. Therefore, one event, or storm sampling sequence, would consist of 120 sample suites. From the analysis conducted of the existing routine program, the cost to analyze each suite should be about $60, therefore sampling costs for two events would be about $15,000. Allowing twenty man-days per event for field time, data reporting, and logistics, adds about $8000 to the program cost. Stream gaging costs, including installation and maintenance of three gages by the USGS, would be about $24,000. Allowing 60 labor-days, or $12,000 for model implementation, calibration, and verification, the total cost per basin would be about $60,000 for a program extending over one year.

This estimate represents an upper bound, as some economies of scale should be realizable in data collection as compared to the routine program, and many storms are of duration less than 48 hours. Also, stream gage installation and maintenance costs will be reduced if USGS matching funds can be acquired. In any event, it should be possible to do a thorough job of monitoring and modeling one basin per year, and three basins in two years is a reasonable goal. Finally, this analysis assumes that all funds that can be allocated to intensive surveys must come from the existing routine program, however intensive monitoring may meet some other existing internal requirements. With this in mind, it is suggested that a budget review be conducted to identify other possible funding sources.

Little has been said as to the selection of basins for intensive monitoring. It appears that a scoring system, similar to that used in review of the routine monitoring program in Section A of this chapter, would be appropriate. An attempt should be made to include all small streams throughout the Metro service area in such a scheme, not only those with existing water quality data bases. The scoring scheme should also reflect land use characteristics and other measures of impact or potential impact, as well as the length of time since the last monitoring/modeling effort. At a rate of one to two basins per year, the most important basins should be assessed on a ten to fifteen year rotation. Clearly, it would be advantageous to reduce this, perhaps to the range five to ten years. In any event, we conclude that within the general confines of the existing funding potential, a viable program of intensive stream quality surveys and related modeling effort in support of water quality prediction can and should be implemented.

CHAPTER IV. WATER QUALITY INDICES AND TREND ASSESSMENT

One difficult problem in assessing trends in water quality is the multivariate nature of water quality descriptors. There is no single measure of water quality, nor is there even a universally agreed upon list of water quality constituents. As shown in Chapter III, different agencies have different perceptions of the water quality variables of most importance. There is a sound basis for this diversity; the variables measured must reflect the problems or potential problems of a particular water body, which may vary by site and with the objectives of the managing agency. Nevertheless, the assessment of trends in multivariate processes provides considerable potential for confusion. For instance, can anything conclusive be said about a stream that has a statistically significant decreasing trend in temperature, and a significant increase in fecal coliform counts? Such anomolies, or apparent anomolies, do occur, and are apparent, for example, in the assessment of river quality performed for DOE by Lettenmaier (1977).

Such confusion is a particular problem for water quality managers, who must convey the results of trend analyses to higher level management and public officials, and ultimately the taxpayer, most of whom do not have technical backgrounds. From this perspective, a single measure, or index of water quality would be extremely useful. The hope is that a water quality index could perform much the same as an index of the economy; which, while not giving a full indication of the condition of the economy as a whole, may reflect whether it is 'healthy' or 'sick' and whether it is improving or worsening.

The difficulty with water quality indices, as noted in Chapter II, is that anomolous results can occur for certain combinations of rating curves (the transformations relating water quality measurements in technical units to the index) and relative changes in moments of the constituent variables. (Note that the mean is the first moment of a probability distribution, the variance is the second central moment, equal to the second moment less the mean squared, the coefficient of skewness is related to the third central moment, and so on.)

As discussed in Chapter II, Landwehr (1979) has noted situations where water quality indices can indicate anomalous trends, for instance changes in the mean and variance of a variable may result in changes in the index that are at odds with the common interpretation. In this chapter, an analysis of the form of the water quality indices used by Metro (Swartz, et al., 1980) is made, along with a review of selected Metro data used in the indices. Finally, recommendations are made for procedures to be used if attempts are made to analyze trends in the indices, rather than in the constituent variables.

A. Background: Metro Water Quality Indices

Swartz, et al. (1980) describe the water quality indices, including both a fishable and a swimmable index, used by Metro for assessment of river and stream quality. These indices are based upon a general form developed by Dunnette (1979), which is a linear combination of transformed water quality constituents, or variables. The constituent transform curves themselves are generally log-linear in nature, and are defined graphically by Swartz, et al. (1980). The constituents themselves and their associated weights are given in Table 6.

The numerical weights given in Table 7 are attached to the transformed water quality constituents before summing to obtain the value of the index. In addition, it should be noted that the Fishable Index has different weighting schemes for rivers and streams to account for differences in predominant species and habitat in these two environments.

Both indices are of the form $\bar{y} = \sum_{i=1}^{n} w_i y_i$, where y_i are the transformed water quality constituents, and the w_i's are the weights. Landwehr (1974; 1979) has discussed some of the general statistical properties of indices like those of Dunnette. She has emphasized potential problems, described in Chapter II, with indices of the form $\bar{y}$. Hence, it is necessary to investigate distributional characteristics of certain constituents of Metro's indices to see how they might influence the resulting behavior of the indices.

In reviewing the two Metro indices, we originally desired to analyze changes in the lower moments, specifically the coefficient of variation (ratio of standard deviation to mean) of all the constituents of the two indices. This attempt, however, was frustrated by a paucity of long term data for many of the constituents listed in Table 7. Therefore, the analysis was limited to two basic water quality

Table 7. Weights for Metro Fishable and Swimmable Water Quality Indices

Fishable Index

Constituent No.	Constituent Name	Units	Weight Rivers	Weight Streams
1	Temperature	^oF	0.231	0.176
2	Dissolved Oxygen	mg/l	0.231	0.176
3	Streambed Spawning and Rearing potential index[a]	--	0.231	0.176
4	Benthic Population[a]	--	0.0	0.118
5	Periphyton C[a]	mg/m^2	0.0	0.118
6	Dissolved Oxygen Percent Saturation	--	0.153	0.118
7	Specific Conductance	mh_o/cm	0.077	0.059
8	pH	std units	0.077	0.050

Swimmable Index

Constituent No.	Constituent Name	Units	Weight
1	Fecal Coliform	counts/100 ml	0.50
2	Ratio Fecal Coliforms/Fecal Streptococci	--	0.33
3	pH	std units	0.17

[a]see Swartz, et al. (1980) for details

constituents: temperature and fecal coliform counts. Temperature is one of the main contributors to the fishable index for both rivers and streams. Similarly, fecal coliforms are the dominant constituent in the swimmable index.

The rating curve for temperature has the general shape given in Figure 5. As shown in Figure 5, the rating decreases rapidly for values outside an optimal range. For fecal coliform counts, the rating curve is decreasing on a logarithmic scale as shown in Figure 6. Hence there are two constituents whose rating curves are different in form; consequently the statistical properties of the transformed values have a different effect on the indices.

B. <u>Rating Curves for Metro Indices</u>

Landwehr (1974; 1979) has investigated rating curves of the form

$$y = Axe^{-x/c}$$

where the curves are not dissimilar to the parameter transform curve for temperature, in the principal sense that values decrease on both sides of the maximum. The Metro rating curve for temperature (Swartz, et al., 1980) is as follows:

$$y = \begin{cases} 2.0, \text{ if } x < 30^{\circ}F \\ 0.0984e^{-.100x}, \text{ if } 30^{\circ}F \leq x \leq 46^{\circ}F; \\ 10.0, \text{ if } 46^{\circ}F < x < 54^{\circ}F \\ 736e^{-.0800x}, \text{ if } 54^{\circ}F < x \leq 74^{\circ}F \\ 2.0, \text{ if } x > 75^{\circ}F \end{cases}$$

Landwehr (1974; 1979) has noted some specific properties regarding the expected behavior of water quality indices for rating curves like

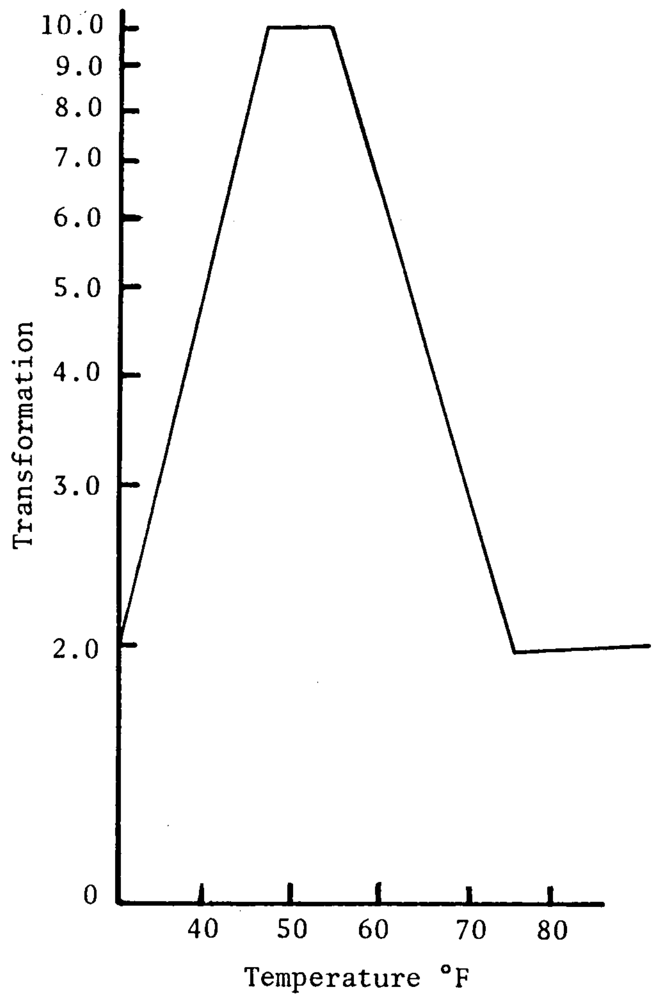

Figure 5. Transformation Curve for Temperature.

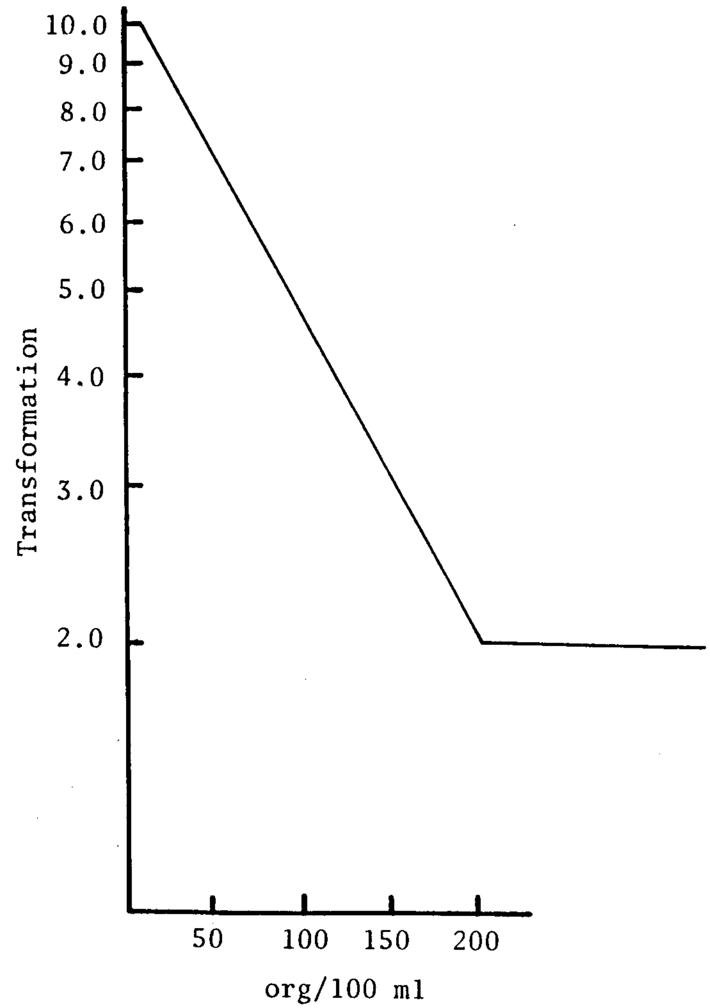

Figure 6. Transformation Curve for Fecal Coliform Counts.

those for temperature. For instance, as the true population mean for temperature increases, the expected value of transformed temperature first increases, then decreases, as would be hoped. There is considerable overlap among different specified rating curves in the area of the maximum, but this is expected due to the form of the curves. Away from the maximum, different rating curves produce disjoint results.

The sensitivity of such an index to changes in the coefficient of variation (C_v) depends upon which side of the maximum the population mean happens to lie. On the left hand side of the curve (the increasing portion), y decreases in expected value as C_v increases. On the right hand side (the decreasing portion) of the curve, y increases in expected value as C_v increases. Hence the relationship between y in expected value and the C_v may be direct or inverse depending on the actual value of the population mean. For the particular rating curve for temperature, values less than 46^oF (7.8^oC) are on the left hand side, while values exceeding 54^oF (12.2^oC) are on the right hand side of the curve. For values between 46^oF and 54^oF, the rating curve is constant, and hence would not be influenced by changes in C_v.

If the population mean stays fixed but the standard deviation (and therefore C_v) increases, y will behave "well" (that is, reflect the behavior of the population mean accordingly) for low values of C_v (e.g., 0.25 - 0.50), but will tend to some non-zero constant if C_v exceeds 1.0. Hence for larger C_v, the change in the expected value of the index to shifts in the population mean is slower. Such properties of the behavior of a water quality index including a rating curve like that for temperature urge the use of caution when interpreting long-term behavior of such an index. More specific results using actual temperature values from Metro's data are discussed later in this chapter.

Landwehr (1974; 1979) has also discussed monotonically decreasing rating curves of the following form:

$$y = Be^{-x/c}$$

The specific rating curve for fecal coliforms is

$$y = \begin{cases} 10.0, \text{ if } x < 10 \\ 10.9e^{-.00846x}, \text{ if } 10 \leq x \leq 200 \\ 2.0, \text{ if } x > 200 \end{cases}$$

(The curve is derived from Figure 9, Swartz, et al., 1980 and the discussion on fecal coliform counts.) This kind of rating curve is a little simpler in form than the one for temperature, and thus the expected behavior of the index is somewhat more predictable. If the C_v remains fixed in value, the expected value of y tends to increase, particularly if the C_v values exceed 1.0. The tendency for y to rise with higher C_v values could give possibly misleading results, indicating improved water quality when the situation has simply increased in variability. In such a case, it would then be important to check the values of the standard deviations and C_v's over time from the data to ascertain the nature of any trend. This sort of issue is of natural concern for coliform data, which are known to vary widely even under unchanging water quality conditions.

Because of the distributional behavior of coliform data (it is generally recognized to have a log-normal distribution), any analysis usually focuses on the logarithms of the values rather than the coliform values themselves. The rating curve itself is a negative exponential one. The comparison here will be between an ordinary logarithmic transformation and a negative exponential rating curve with constant values on both ends. The flat ends may affect the long-term trend analysis in the sense that if there are many coliform values in the extremes (e.g., > 200) log (coliform) will still reflect the changing values, while the rating curve will remain constant.

C. Analysis of Metro Temperature Data

To illustrate the effect of rating curves on water quality constituents, monthly temperature data from January, 1971 through September, 1981 were examined. These data are from Station 3106 on the Green River; this station was chosen precisely because it had long records amenable to trend analysis. The trend analysis was performed via three approaches: (1) on the (seasonally adjusted) temperatures themselves, (2) on seasonally adjusted temperatures which were then transformed, and (3) on transformed temperatures which were then seasonally adjusted. Results of the three analyses follow later in this chapter.

Recalling the transformation curve for temperature, there are ranges of rating values such that either a high or low temperature value maps into the same rating. Also, the curve is constant in the middle. Figures 7 and 8 display the behavior of the raw and the transformed temperature values respectively from January 1971 through September 1981.

Figure 8 has about twice as many peaks as Figure 7, due to the nature of the rating curve. In fact, the high temperatures in Figure 7 tend to correspond to valleys in the transformed data, as temperatures above 63°F (17.2°C) correspond to rating values below 5.0, which generally occur at the end of summer. Of course, there are valleys in Figure 8 during winter months also, at temperatures below 39°F (3.9°C) these also correspond to rating values below 5.0. Hence, one phenomenon that occurs for water quality constituents like temperature with the given rating curve is that the plot of transformed values (i.e., index of values) over time has more peaks and valleys and in general oscillates more. The presence of the seasonal component for temperature is evident from either plot.

Now consider plots of the standard deviation and the C_v of temperature over time. Figure 9 shows the behavior of the monthly observed standard deviations; Figure 10 shows the behavior of the monthly C_v's. While the standard deviations certainly vary quite a bit, the C_v time plot shows little "regularity" in the following sense:

4/129 (3.1%) of the values exceed 50%;

6/129 (4.6%) of the values exceed 40%;

15/129 (11.6%) of the values exceed 30%.

The rest are below 30%. And as previously discussed, for C_v values on the lower end of the scale, the transformed values should be fairly sensitive to changes in the population mean.

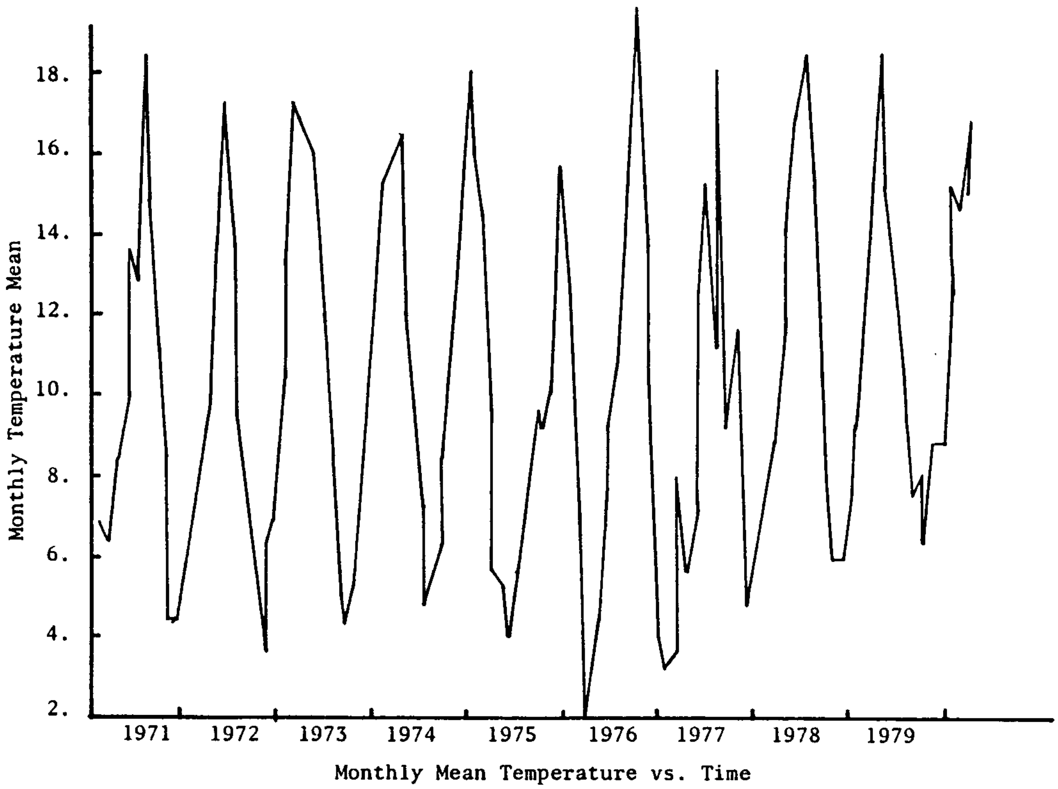

Figure 7. Monthly Mean Temperature vs. Time.

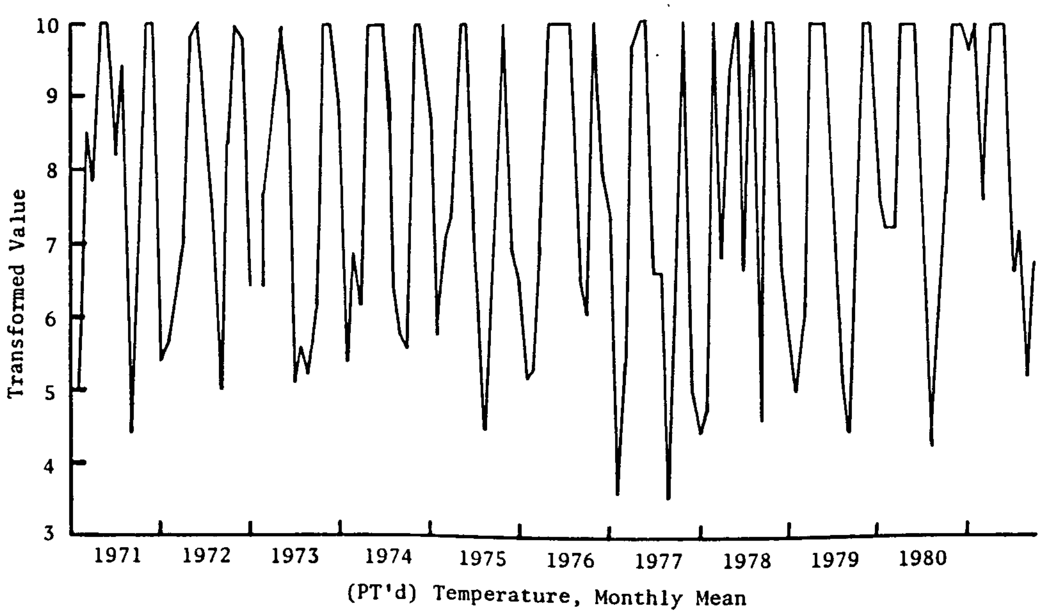

Figure 8. Transformed Monthly Mean Temperature vs. Time.

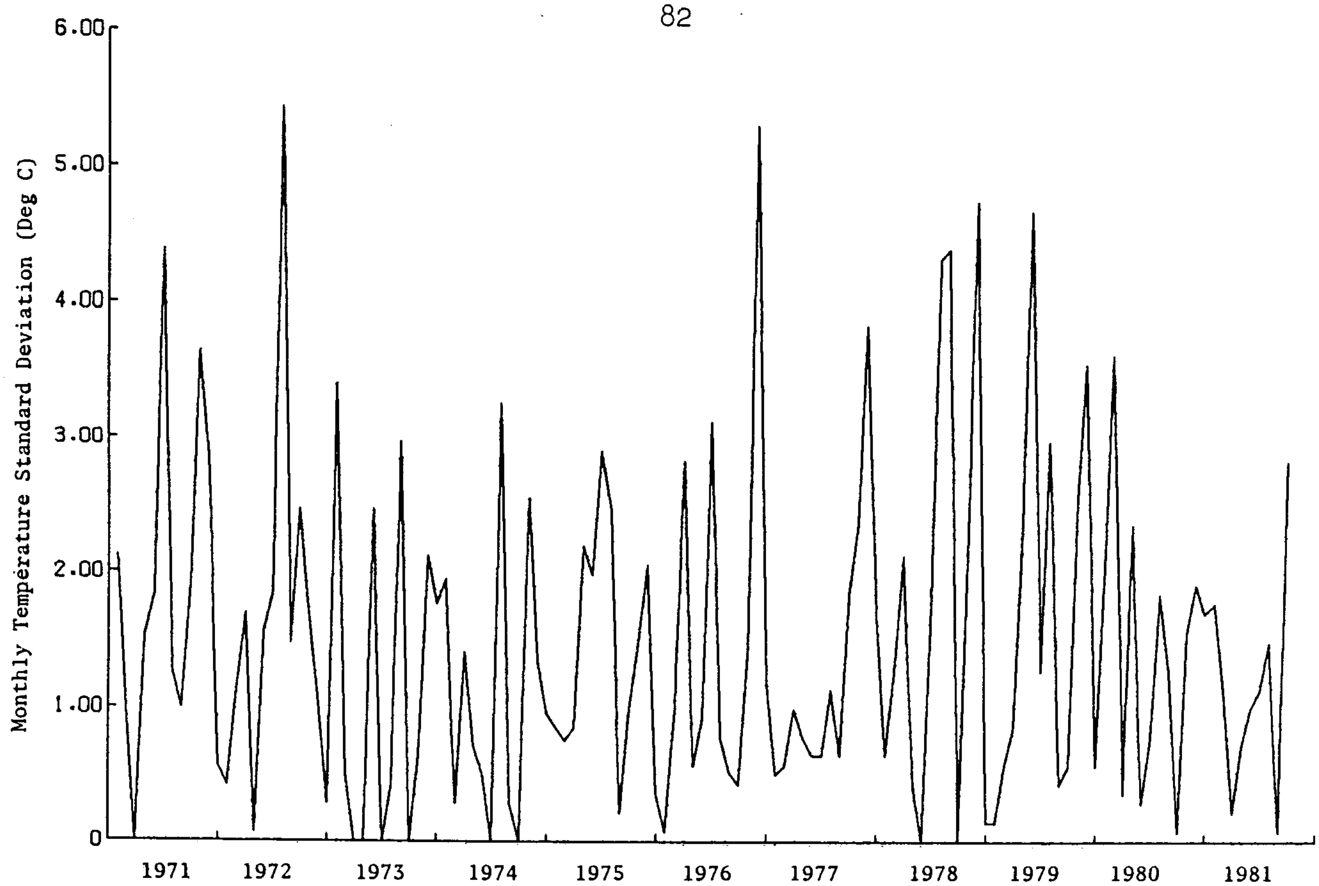

Figure 9. Monthly Temperature Standard Deviations vs. Time.

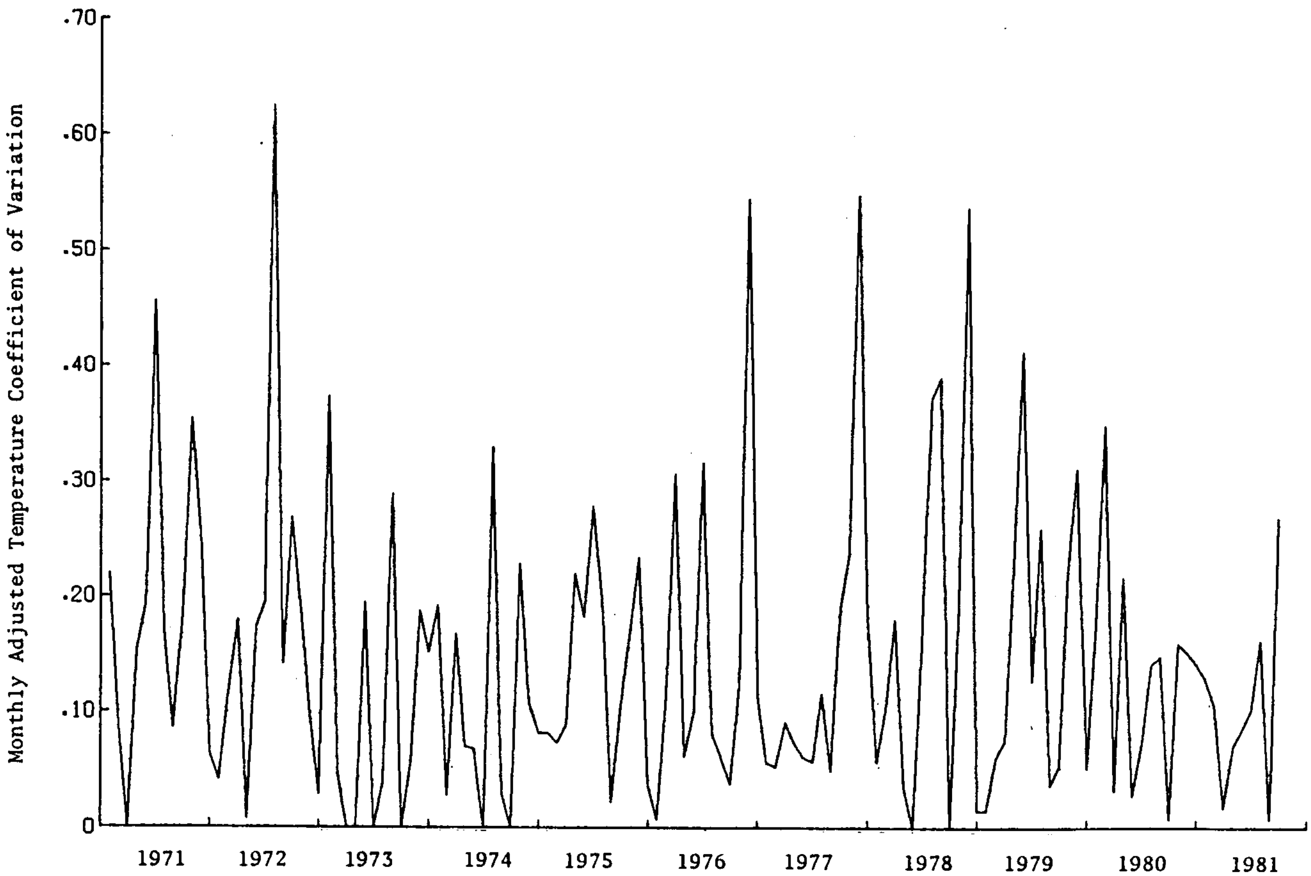

Figure 10. Monthly Adjusted Temperature Coefficient of Variation vs. Time.

Trend analysis on temperature data was performed by various approaches. To keep the data as consistent as possible, the values used were those closest to the middle of the month. (These values were actually quite similar to the previous monthly means.) The three approaches to the long-term trend analysis were as follows:

(1) untransformed, seasonally (monthly) adjusted temperatures,

(2) monthly adjusted, then transformed, temperatures, and

(3) transformed, then monthly adjusted temperatures.

By "transformed" is meant the index value after having gone through the parameter transform curve for temperature.

Figures 11 - 15 display the temperature data over time with various combinations of seasonal adjustment and/or transformation. Figure 11 shows the ordinary temperature values over time; this, not surprisingly, bears a strong resemblance to Figure 7, the monthly means over time. Here the seasonality is again evident; the adjusted values in Figure 12 have the seasonality component removed. The transformed temperatures, (Figure 13) again due to the nature of the transformation (which maps both high and low temperatures into low values) show more oscillations in their behavior than the ordinary temperatures themselves. The transformed temperatures also display many "flat tops", corresponding to temperatures in the optimum range 46^{o} - $54^{o}F$ (7.8^{o} - $12.2^{o}C$). Figures 14 and 15 illustrate a striking difference when the order of seasonalization and transformation is reversed. The "icicle" effect in Figure 13 results from many of the original temperature values falling into the optimum range after deseasonalization (refer to Figure 12). The transformation process then maps these values into the highest

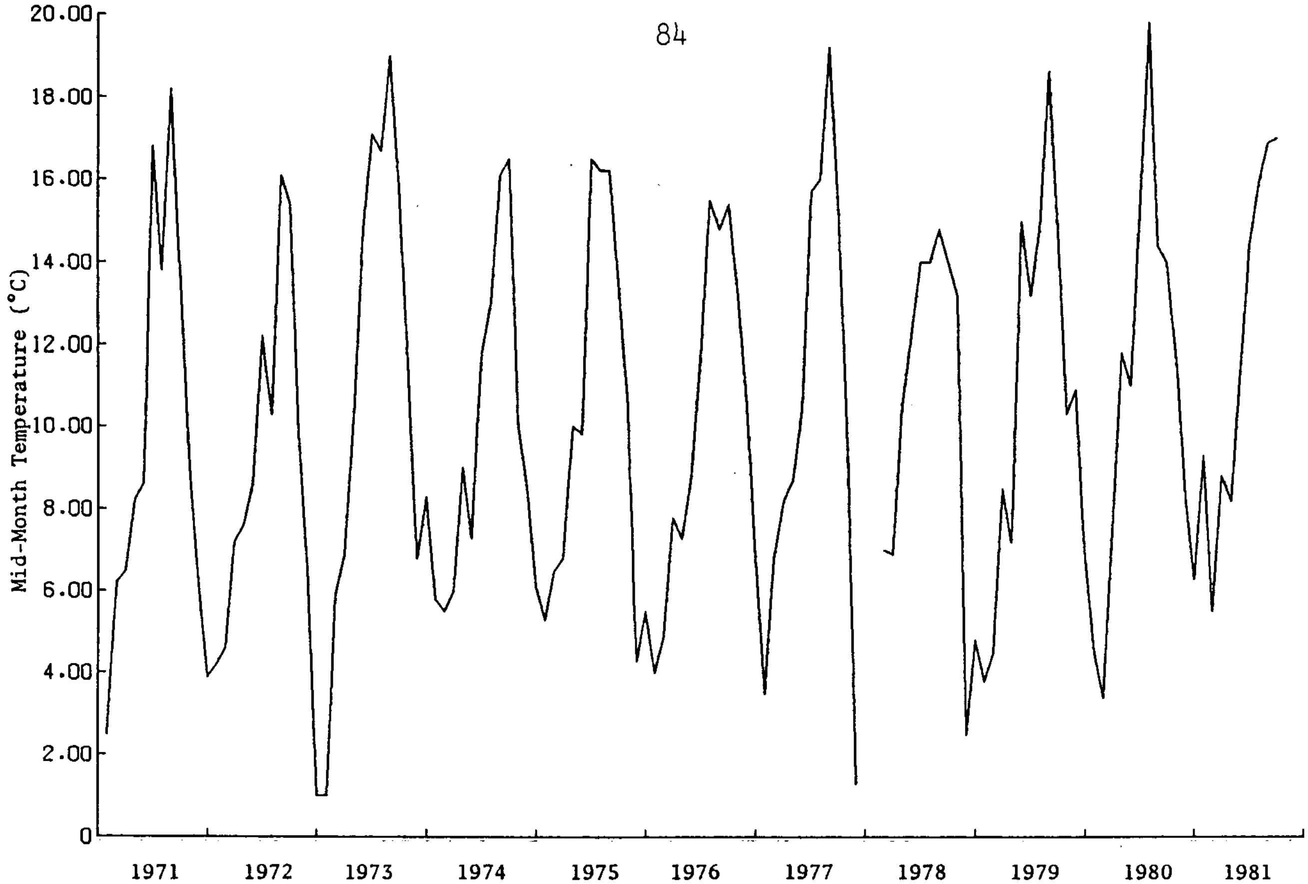

Figure 11. Mid-Month Temperature vs. Time.

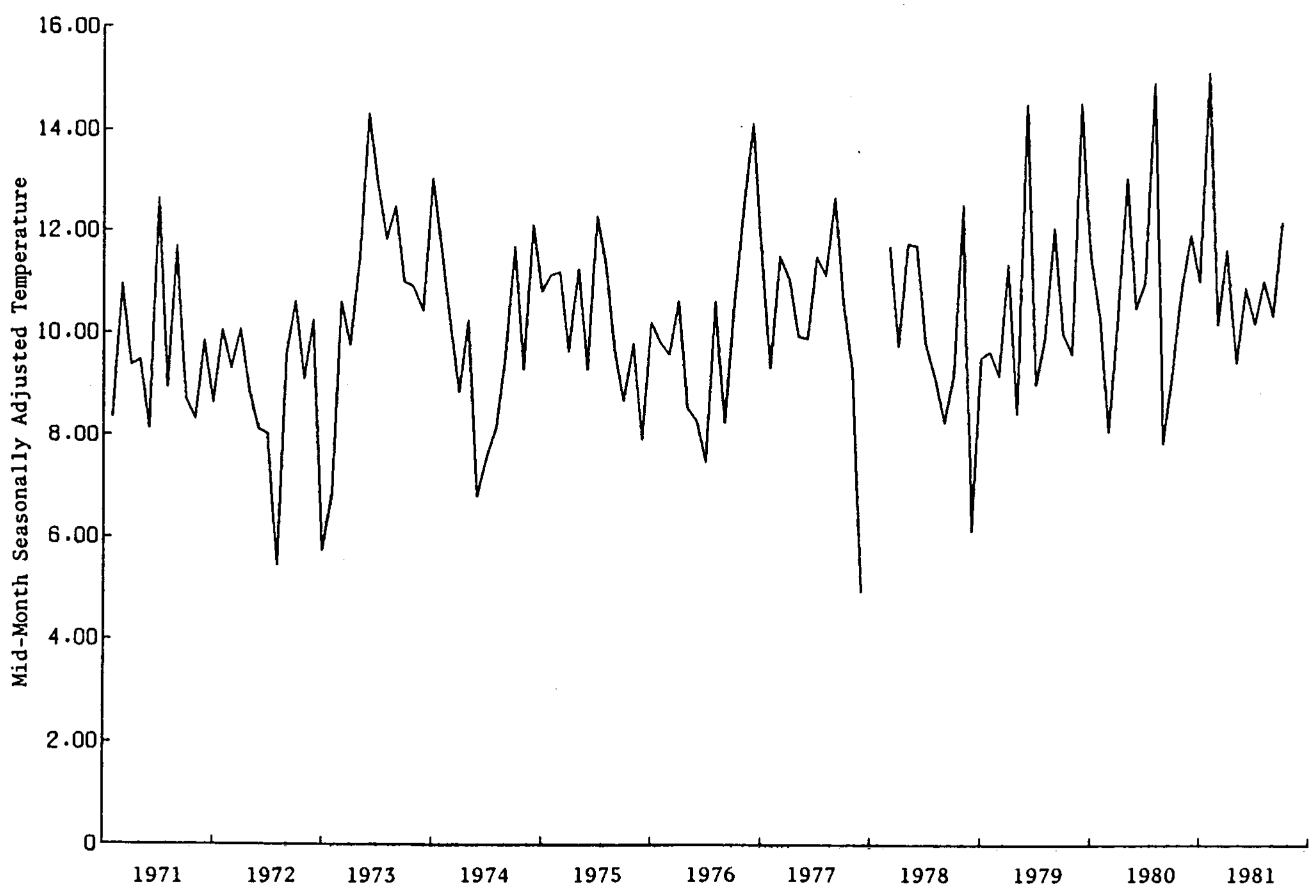

Figure 12. Mid-Month Adjusted Temperature vs. Time.

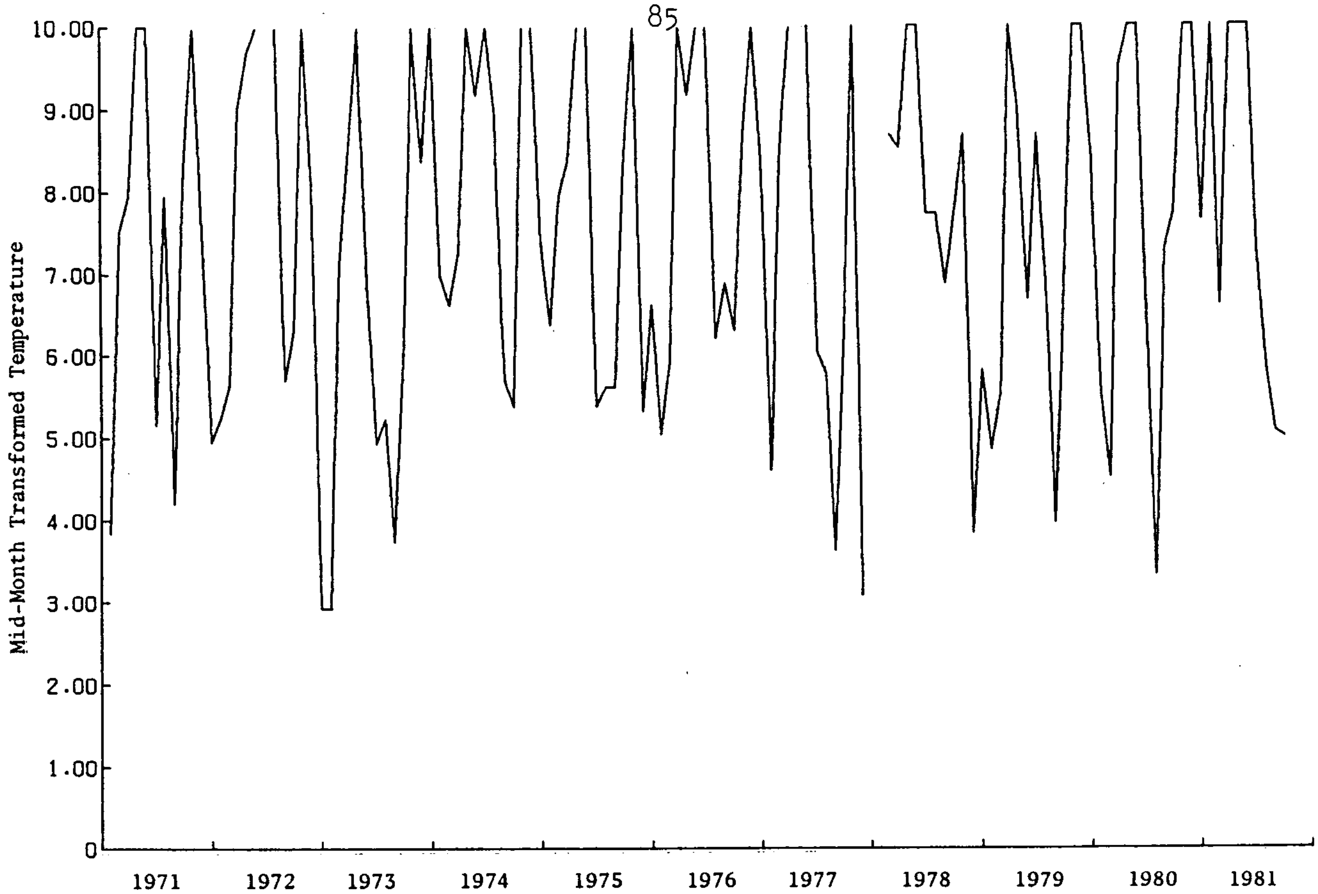

Figure 13. Mid-Month Transformed Temperature vs. Time.

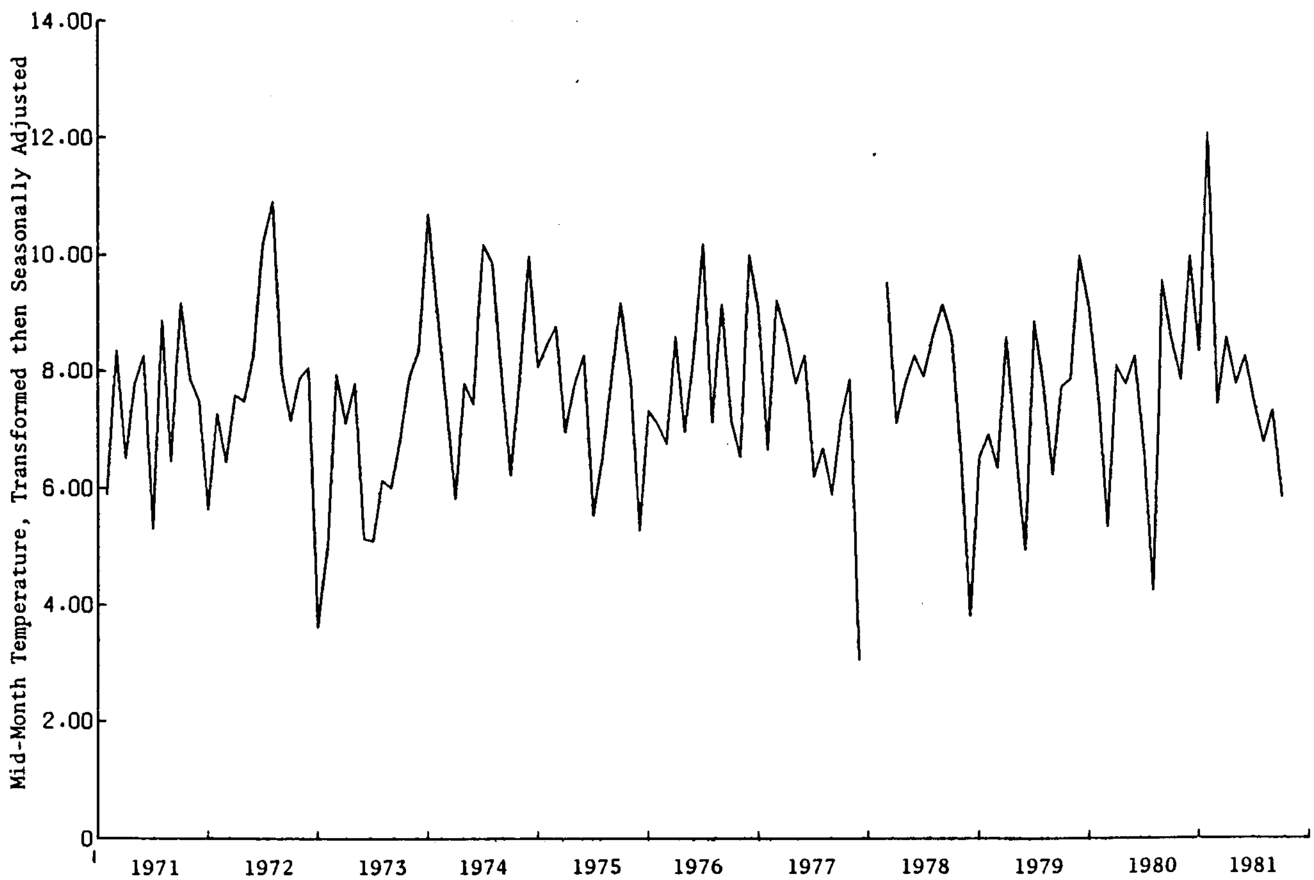

Figure 14. Temperature Transformed then Adjusted vs. Time.

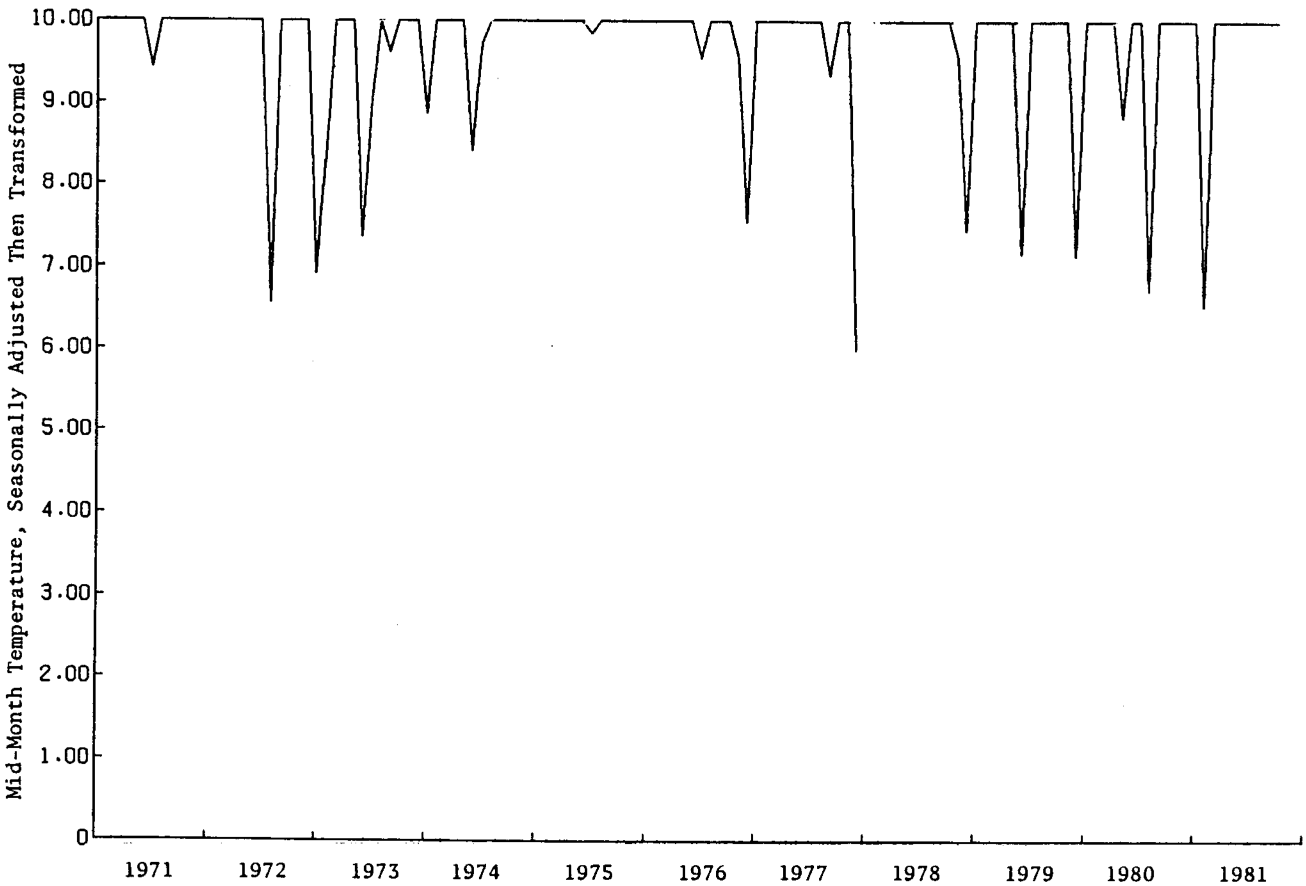

Figure 15. Temperature Adjusted Then Transformed vs. Time.

rating. Numbers falling outside the optimum range are assigned lower values, resulting in the "icicle" appearance when transformation is performed following deseasonalization.

Figure 14 shows temperature values over time when the values are transformed first and the seasonal component then removed. This gives results very different from those in Figure 13, and the general pattern is not too different from that in 12, the ordinary (adjusted) temperatures.

To analyze statistically whether or not a gradual trend was present in the temperature data, Lettenmaier's (1977) nonparametric Spearman's rho test was run on the data in its various forms. Table 8 shows the results of the tests.

For the ordinary adjusted temperatures, the value of the nonparametric correlation coefficient is significant at the .01 level, and a mild upward trend can be viewed in the right hand portion of Figure 11. The transformed temperatures (followed by adjustment) apparently have lost this trend, as Spearman's rho dropped to a nonsignificant .065. This is consistent with Figure 14. The significant result in (c) of Table 8 is not consistent with the graph in Figure 15, and there is a reason for this. The computed Spearman's rho has not been adjusted for ties, and there are clearly many tied values in Figure 15. With this large sample size, a few tied values will not affect the behavior of Spearman's rho. But the temperatures in Figure 15 do have several tied values; in fact, all but 19 of them have a rating curve value of 10. This has caused the spurious rho-value of .314, which is clearly inconsistent with Figure 15.

For temperature, then, transformation before seasonal adjustment masks the formerly significant trend for the untransformed values. In addition, the spurious result of (c) in Table 8 illustrates the potential danger of using statistical test results without first checking the graphical data display. The lack of wisdom in seasonally adjusting before transformation is clearly shown in Figure 15, but this would not have been noticed from the Spearman's rho results.

Table 8. Results of Trend Tests on Temperature (n = 127).

	Spearman's Rho	Level of Significance, P
a. Temperature, Monthly Adjusted	.228	.01
b. Temperature Transformed, Adjusted	.065	.50
c. Temperature Adjusted, Transformed	.314	.001

D. Analysis of Metro Fecal Coliform Data

Fecal coliform measurements from January, 1971 through September 1981 were also examined for Station 3106 on the Green River. Figures 16 and 17 show the behavior of the log coliforms and the transformed coliforms over time. (Recall that Metro's constituent transformation curve is a negative exponential one.) The seasonality component is much less in evidence here, although there are good biological reasons for

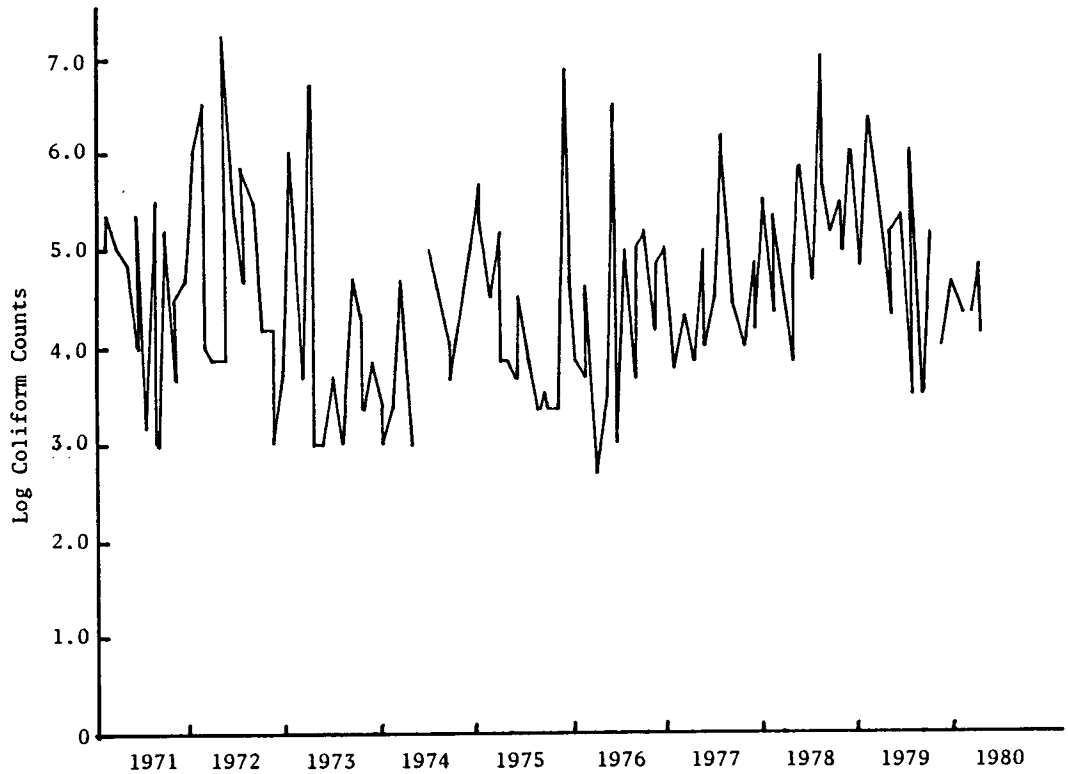

Figure 16. Monthly Log Coliform Counts vs. Time.

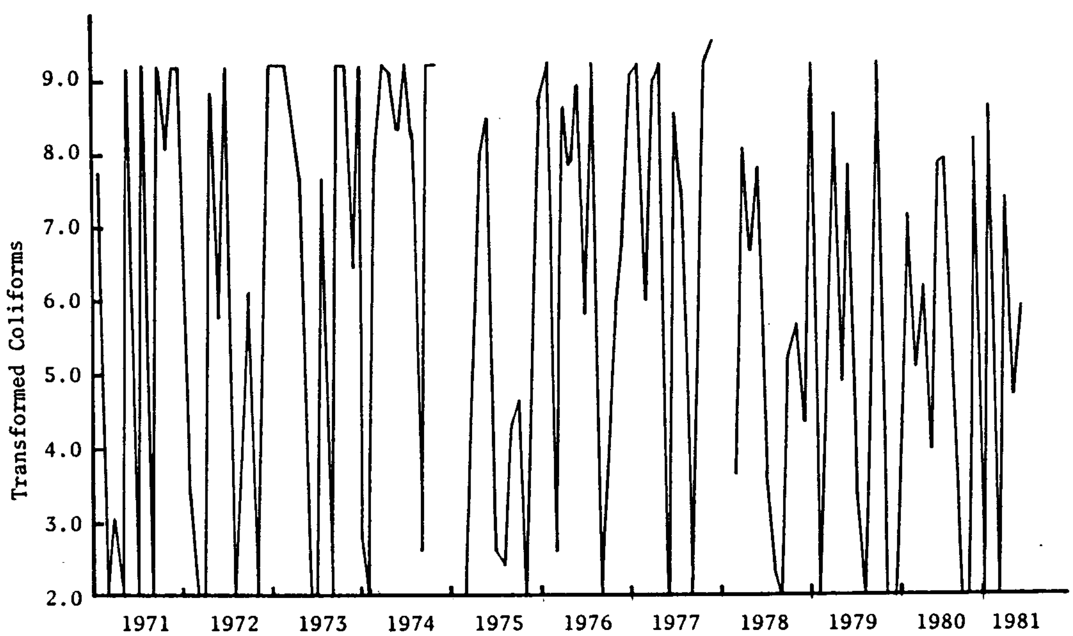

Figure 17. Transformed Monthly Coliform Counts vs. Time.

one (e.g., higher coliform values in the summer). There may be a trend beginning around 1978 (this hypothesis is tested statistically below).

Since Metro's transformation curve for fecal coliforms is inversely related to coliform values, Figure 16 and 17 tend to be inversely related because the log is an increasing function of the coliform counts. Also, Figure 17 has more flat places at the lower end of the rating scale (corresponding to the high coliform values) due to the flat ends of the transformation curve for coliforms. Note that the contrast between these two plots is not nearly as great as that for temperature, due to the fact that the transformation curve for coliforms is much simpler.

Next we investigate behavior of standard deviations and the C_v's. Figures 18 and 19 show the plots of the standard deviations and the C_v's over time. The standard deviations again vary quite a bit without displaying any definite trend, and the C_v plots look similar. For the 110 C_v values,

3/110 (27%) exceed 50%

7/110 (6.4%) exceed 40%

18/110 (16.4%) exceed 30%

and the rest are below 30%. (The highest C_v value is 0.62.) These results are encouraging in light of previous statements for generally low (0.25 or 0.50) C_v values: the behavior of the transformed coliforms should reflect changes in the population mean.

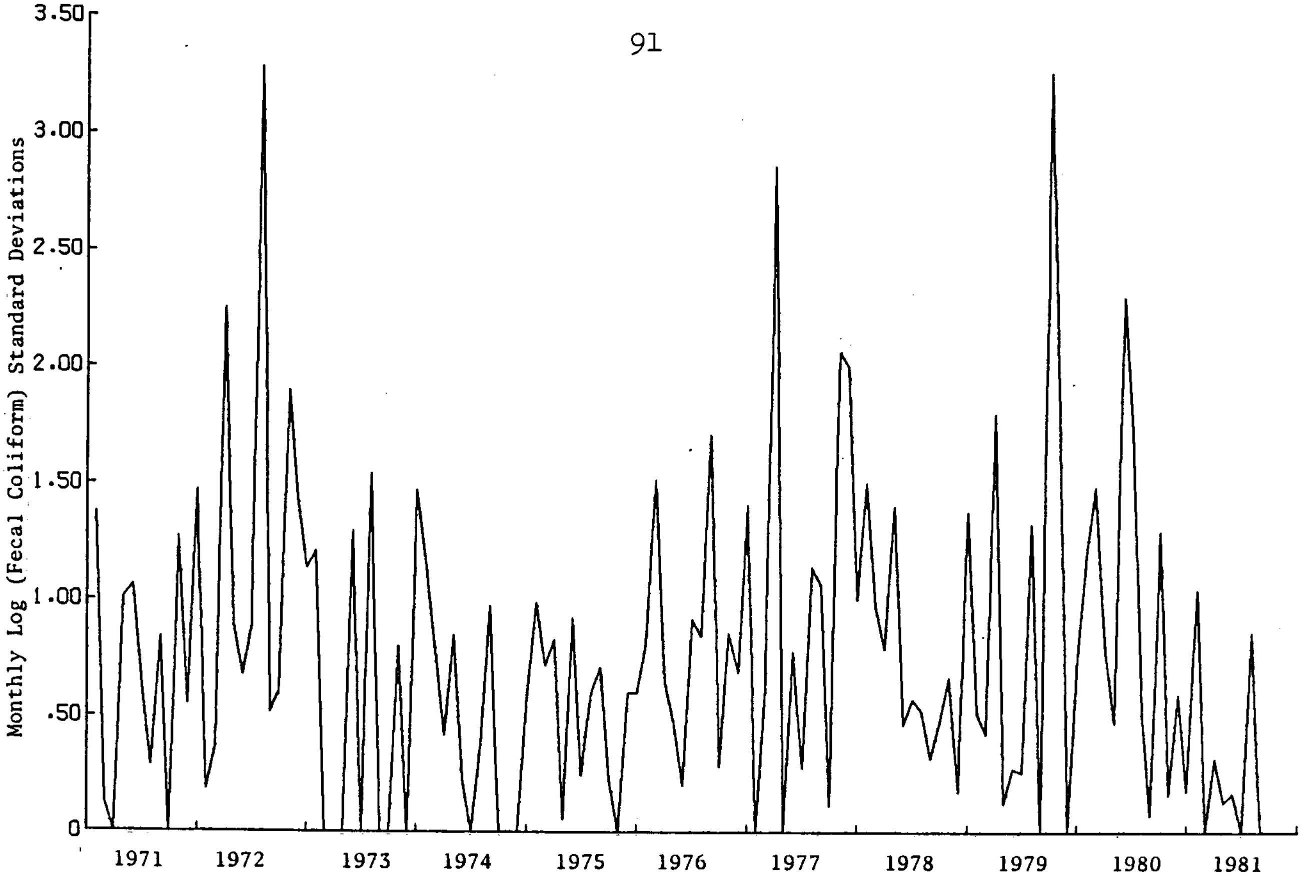

Figure 18. Monthly Log Coliform Standard Deviations vs. Time.

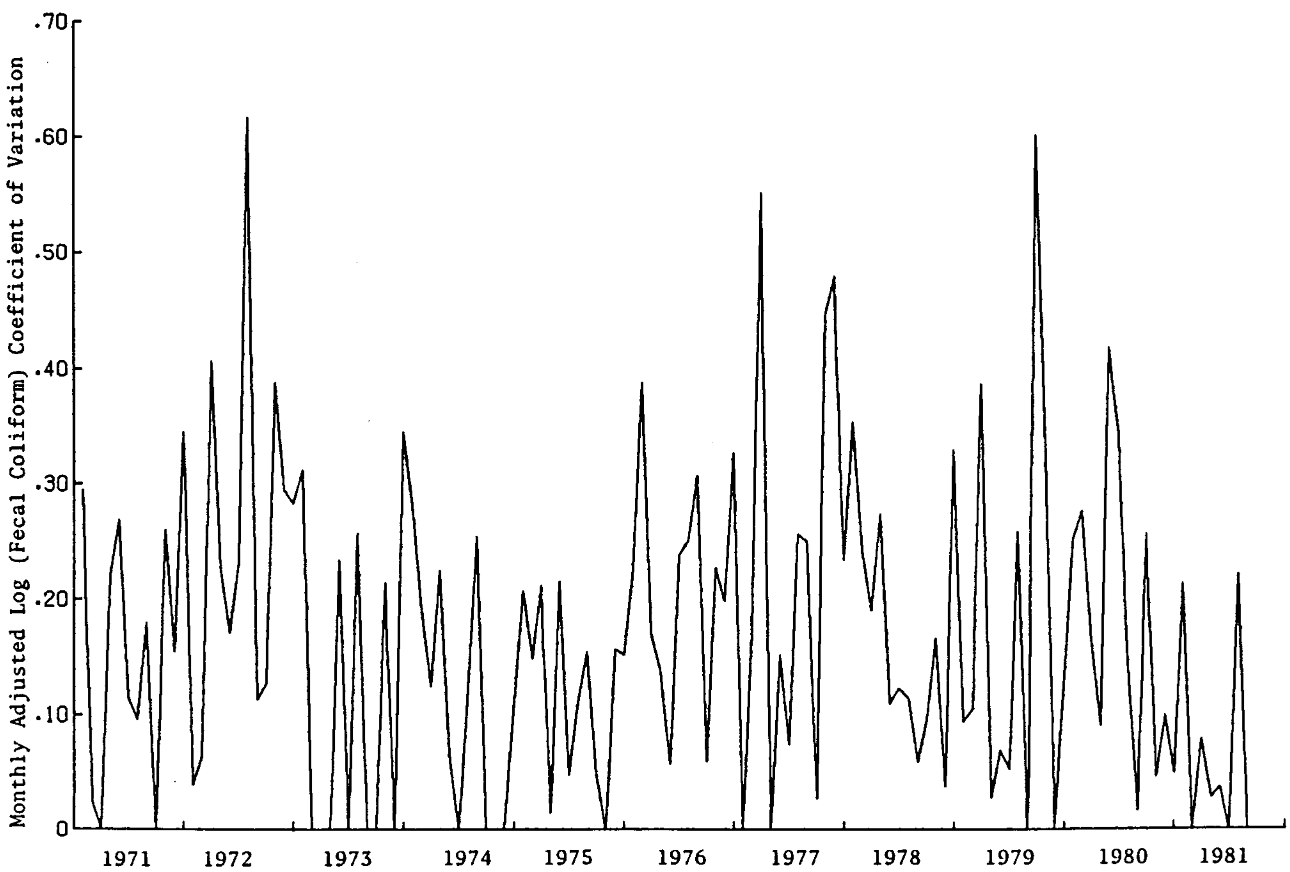

Figure 19. Monthly Adjusted Log Coliform Coefficient of Variation vs. Time.

Trend analysis for the coliform data was performed with the three approaches used for temperature. Mid-month values were again chosen for analysis to ensure data consistency. To reiterate, the three approaches are:

(1) seasonally (monthly) adjusted log coliforms,

(2) monthly adjusted, then transformed, coliforms, and

(3) transformed, then monthly adjusted, coliforms.

Approach (2) is really not appropriate due to the log-normal (thus highly varying) nature of coliform data: the data should always be transformed first before doing any seasonal adjusting. This approach is included mainly for completeness.

Figures 20 through 24 show the coliform data over time. Figures 20 and 21 show the unadjusted and adjusted log coliform values. Apart from the phenomenon that the adjustment appears to have pulled the values down somewhat, the two graphs are similar in appearance. Both resemble Figure 16, as might be expected. The transformed coliforms are shown in Figure 22. Note that these values have several flat places at 2.0 and around 9.2. The value 2.0 of course corresponds to coliform values of 200 or more; the transformation function never goes below this value. The reason for the apparent flatness at 9.2 is that these are ratings that correspond to coliform values of 20.0 and there are several of these. In Figure 20 these coliform values are mapped onto the value 3.00; hence the appearance of several flat places at this value. Figure 23 displays the coliform values after they have been transformed and then seasonally adjusted. As a result, the flat places in Figure 22 have disappeared, and the slight downward trend during the later years

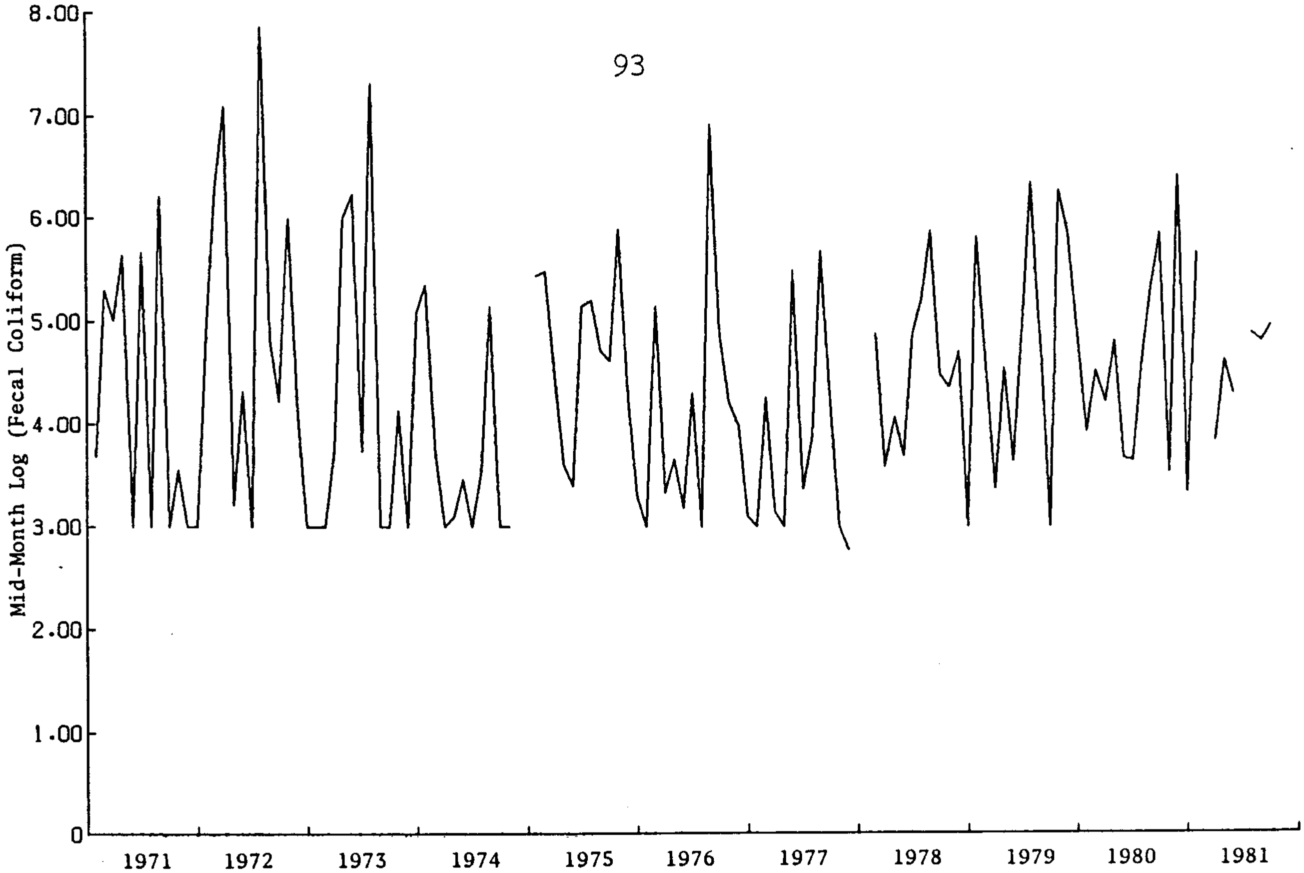

Figure 20. Mid-Month Log Coliform vs. Time.

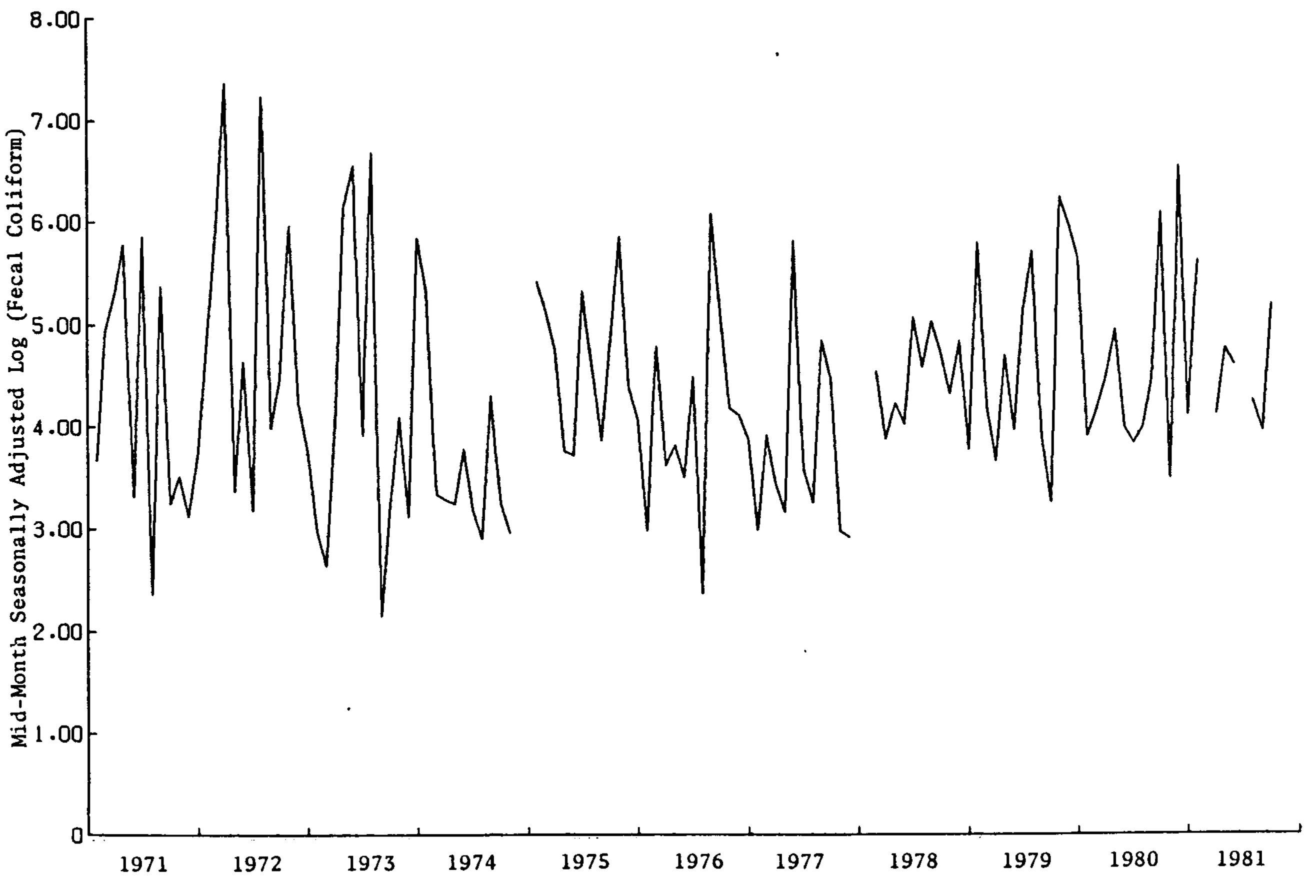

Figure 21. Mid-Month Adjusted Log Coliform vs. Time.

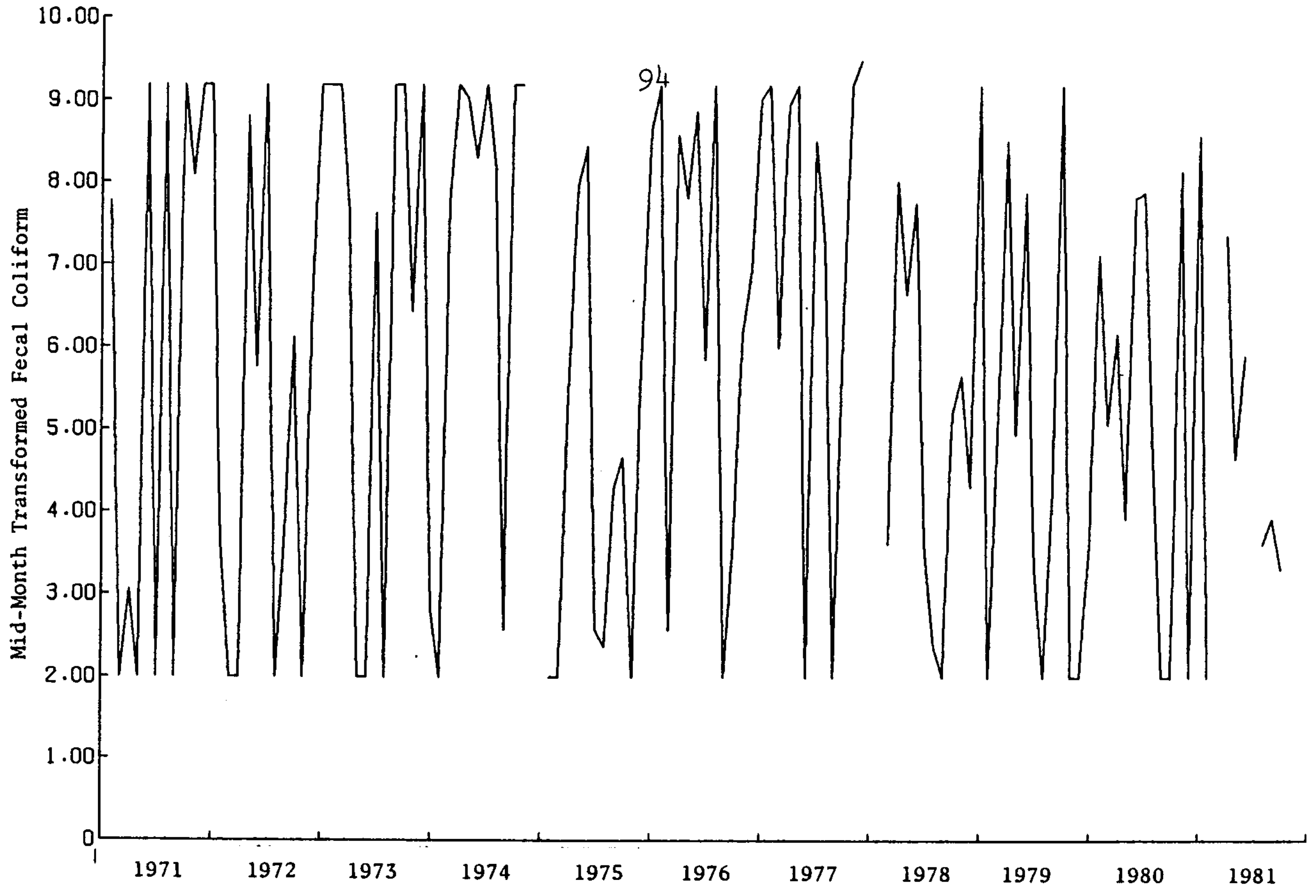

Figure 22. Mid-Month Transformed Coliform vs. Time.

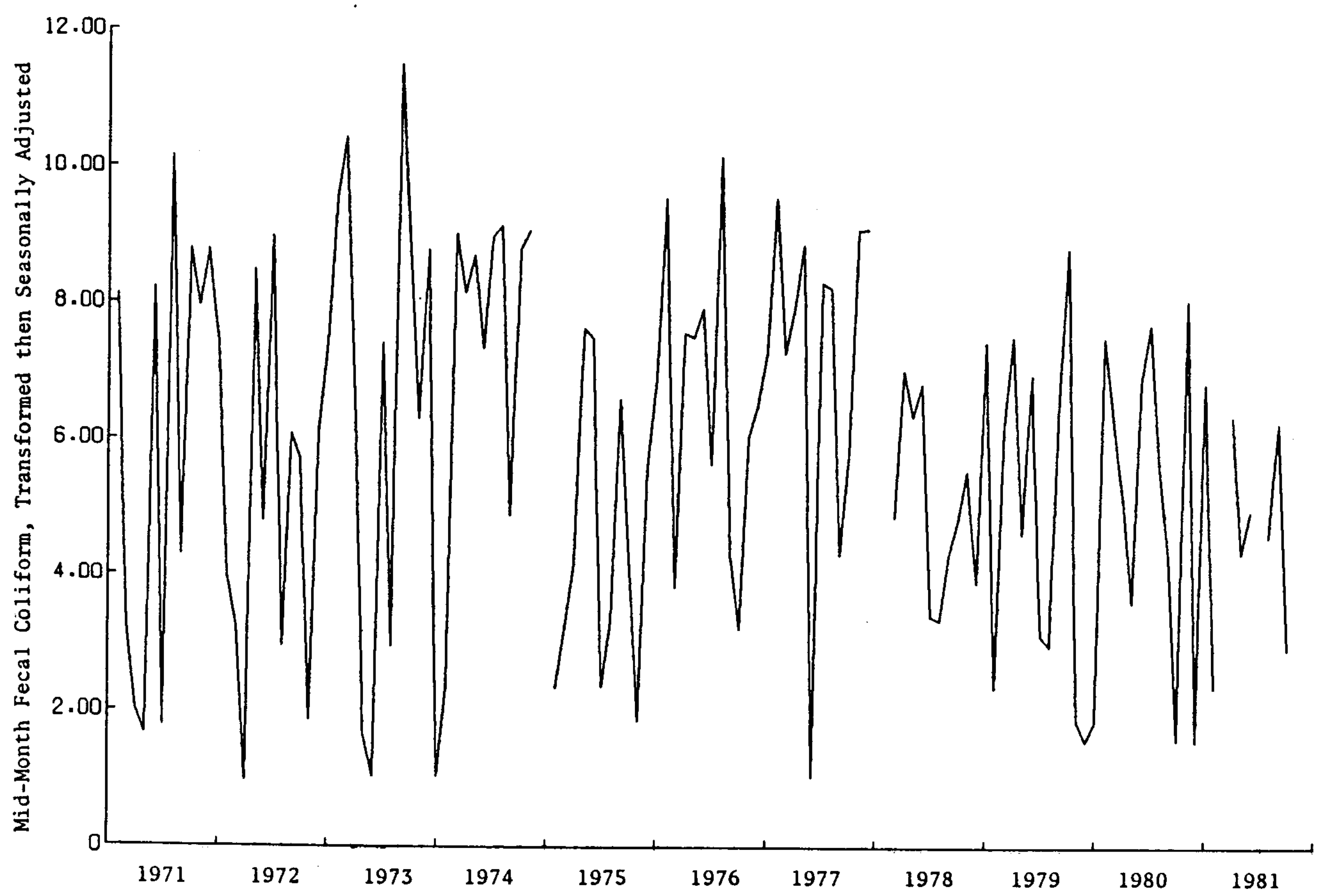

Figure 23. Mid-Month Coliform Transformed Then Adjusted vs. Time.

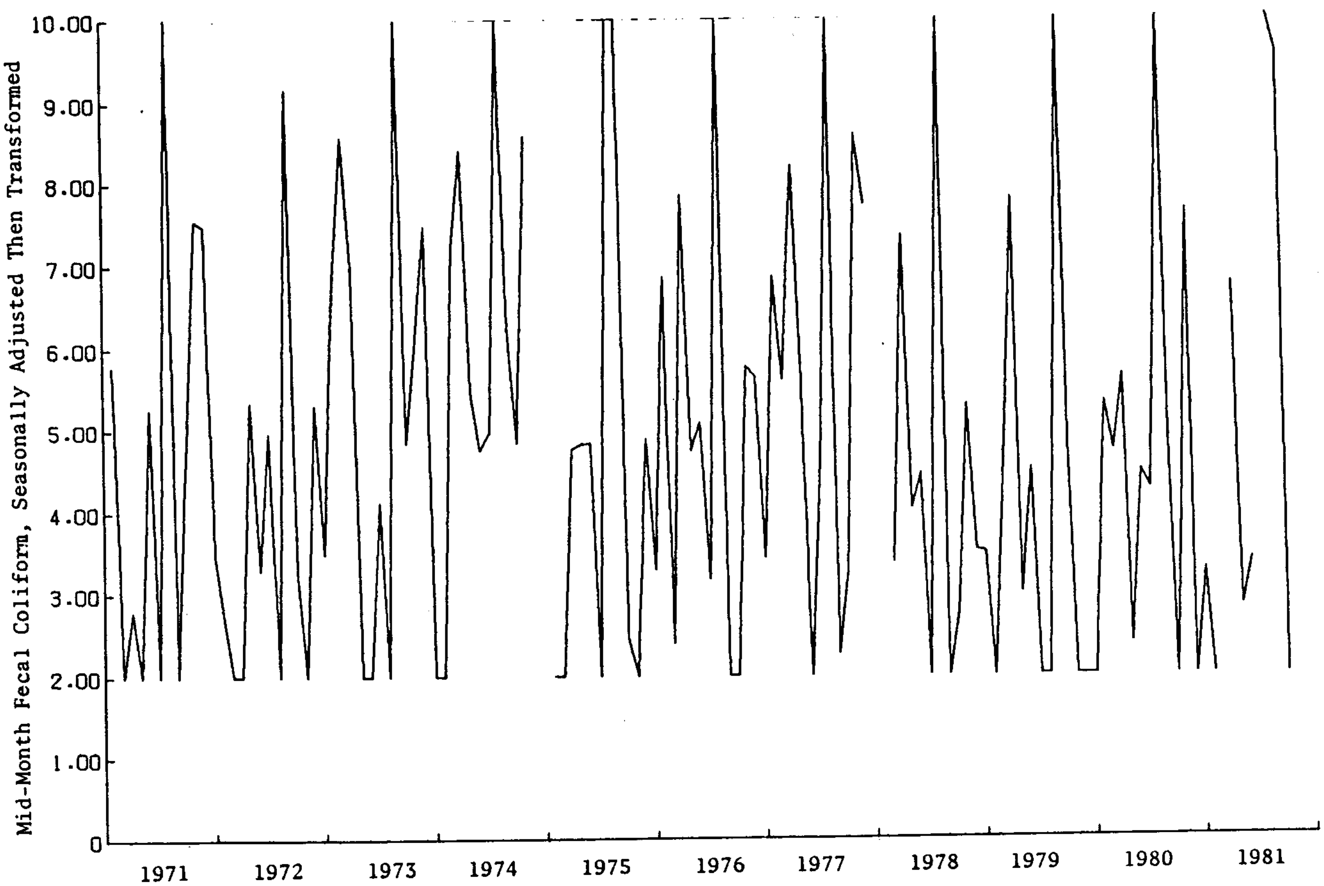

Figure 24. Mid-Month Coliform Adjusted Then Transformed vs. Time.

(1978) is apparent. If the coliform values are adjusted first and then transformed (Figure 24), many of the adjusted values will fall below 10/100 ml and hence be mapped to a rating value of 10. (In fact, many adjusted coliform values that were low to begin with may fall below zero.) Hence the appearance of several 10.0 values, in addition to the 2.0 minimum values of the curve.

Test for Trend, Coliforms Data

Lettenmaier's (1977) statistical test for trend was also applied to the coliforms data. Results are shown in Table 9.

The lack of wisdom to approach (c) (Figure 24) is readily apparent, largely due to the high variability of the raw coliform data. With coliforms, the first step is clearly a logarithmic or negative exponential transformation of some sort to bring down the very high values and restore an approximate normal distribution.

Approach (b) showed slightly stronger results than (a), but the range of the P-values remains unchanged. Of course, the difference in sign is to be expected, since (a) features an increasing function and (c) a decreasing one.

Because the presence of a seasonality component was in question regarding the coliforms data, the tests were re-run without adjustment for seasonality. Table 10 shows the results of the two tests.

Table 10 shows that although the P-value range did not change, the

Table 9. Trend Analysis for Station 3106 Fecal Coliform Data (n=123 values)

	Spearman's Rho	Level of Significance P
a. Log_e Fecal Coliform, Monthly Adjusted	.119	.10 < P < .20
b. Coliforms Transformed, then Adjusted	-.136	.10 < P < .20
c. Coliforms Adjusted, then Transformed	-.001	NS

Table 10. Trend Analysis on Station 3106 Fecal Coliform Data Without Adjustment (n=123)

	Spearman's Rho	Level of Significance P
a. Log_e Fecal Coliforms	.127	.10 < P < .20
b. Transformed Fecal Coliforms	-.118	.10 < P < .20

absolute value of Spearman's rho went in a different direction depending upon the approach. For the log coliforms, the rho-value increased slightly without seasonal adjustment (.127 vs. .119). For the transformed coliforms the absolute value decreased (.118 vs. .136). The P-values remained in the same nonsignificant range, but for constituents like fecal coliforms where seasonality may or may not appear, the particular data set must be evaluated on its own merits.

E. Conclusions

The two water quality constituents investigated here gave some encouraging results, but caution must be exercised. The standard deviations and C_v's for the most part showed few really outlying values. For temperature, results on the transformed data masked the previously statistically significant trend observed with the untransformed data. For fecal coliforms, similar results were obtained whether the log transformation or Metro's negative exponential rating curve was used. If any seasonal adjusting is called for, it should be done after data transformation has occurred. In particular, for variables like temperature and pH, for which the rating curve values decrease rapidly on both sides outside an optimum range, seasonal adjusting first before transformation would tend to place many of the values into the optimum range and lead to a graph with an "icicle effect". This could easily wipe out any trend which might otherwise be evident. It could also lead to spurious results in doing a test for trend, as was shown here for temperature.

A major concern is what happens when different trends of the various water quality constituents are combined (via a linear combination of transformed values) into one index value. Suppose the quality is increasing for one constituent and decreasing for another. When the two are combined, the index itself may fail to show a change. In this analysis, there were not enough data to study full index behavior over time; hence temperature and fecal coliform counts were chosen as representative of each index. It was shown that the rating curves exhibited fairly regular behavior as far as the transformed data were concerned. In relation to an entire index, however, the different ratings may cancel each other and give misleading results.

In addition, there is no mechanism for flow adjustment in either the fishable or swimmable index. This could prove to be very important with a constituent like streambed condition, which is directly affected by streamflow. Streambed condition is equally weighted with dissolved oxygen and temperature for the fishable index, but since it tends to be so much more variable than the other two, it can strongly influence the index outcome. Furthermore, seasonal adjustment (which would seem a necessary requirement) is not possible for many rivers and streams, since a streamwalk evaluation is done only once a year for many locations. To get some idea of the seasonality component, one approach might be to combine baseline data for rivers and streams within a given region and use the resulting regional estimates to make a year-to-year correction on the streambed condition.

In addition to long term trend assessment, Metro's water quality indices might be used for cross basin comparisons at fixed points in time. The previous remarks regarding combination of improving and deteriorating conditions into a single index which might then register a value somewhere in the middle apply here also. Caution is recommended for another reason: the highly varying nature of most water quality constituents causes difficulty in making cross-basin comparisons at a single point in time. It would be much better to compare the nature of trends in water quality at two or more locations. And, even if the trends in an overall index for two locations showed both rising or both falling over time, it would still probably be necessary to investigate and compare the trends in the respective constituents to discover which were contributing to the index trend.

F. Practical Considerations

If any of Metro's water quality indices are used for trend analysis, it is highly recommended that the behavior of the standard deviations and C_v's of each constituent also be checked as part of the process. It is also recommended that a separate trend analysis be done for the respective constituents; the results of these analyses should (1) be consistent with the long-term behavior of the index and (2) assist in assessing why the index is behaving as it does. Metro's indices may turn out to be quite useful as a public information tool - that is, in reporting general water quality to the public on a scale that is fairly easy to grasp and that does not require one to understand, for example, what periphyton growth or conductivity is. In meeting water quality legal requirements, however, it is advisable that any trend analyses done on an index be backed up by trend analyses on each of the separate constituents also. After all, if the quality of the water (as measured by the index) is changing, one would want to know why it is doing so.

The occurrence of missing values must also be kept in mind. In analyzing a single constituent (like temperature) for trend using these nonparametric techniques, missing values do not confound the analysis in any way except to decrease the sample size. But for an index, a missing value of a single constituent will cause the entire index to be missing for that time period. This will simply result in more missing values for the index, which could prove to be bothersome if the missing values for the constituents are spread out over the entire time period. Clearly, the more constituents that make up an index (like the fishable index), the more likely there is to be at least one missing value that will eliminate the index for that unit of time.

CHAPTER V. IMPLEMENTATION OF TREND ASSESSMENT TECHNIQUES

In this chapter, the trend analysis procedures recommended in Chapter II, and included in the computer program TREND (Appendix B) are applied to selected Metro streams and rivers stations. The objectives of this exercise are twofold; first to provide a tutorial in use of the computer program and interpretation of results and second to provide an overview of any problems that might be associated with analysis of Metro's existing data base.

A. Data Screening

Five stations were selected by Metro personnel for analysis in this chapter; included were station 0450 (Sammamish River), 0470 (Swamp Creek), 0474 (North Creek), 0484 (Evans Creek), and 0631 (Issaquah Creek). The selection of stations represented a compromise between the desire to provide the longest possible record lengths, and to assess trends at stream stations which Metro viewed as most significant from a management standpoint. The stations specified and number of observation dates at each station for the period 1971-81 are given in Table 11. The number of observations given represents the maximum that can be used for trend analysis, since the data must be assigned to an evenly spaced (monthly is most appropriate for the Metro data base) collection frequency. This process is performed internally in TREND, and results in a reduction of the effective sample size for records with more than one observation date per month, as occurred during the early 1970's for some of the records.

Clearly, there is some minimum sample size below which it is not appropriate to conduct a trend analysis. Perhaps the most important determinant of a minimum sample size is year to year variability, caused by climatic differences, which may be associated with differences in runoff, temperature, light, nutrient concentrations (particularly for the Sammamish River site, which reflects water quality conditions in Lake Sammamish) and other processes affecting water quality. Therefore, an important issue is the number of years of data in a record as well as the total number of observations. Although rules of thumb can be dangerous, and should not be applied unthinkingly, a rough guideline based both on the experience and subjective judgement of the authors is that five years of reasonably complete record should be considered a minimum. This is compatible with the record lengths analyzed by Lettenmaier (1977) for DOE.

Application of the five year minimum criterion eliminated Evans Creek and Issaquah Creek from consideration. This was unfortunate, as these drainages are undergoing rapid population growth and are sensitive from the standpoint of fisheries production. A review of Table 11 suggests that, had greater attention been paid to establishing records suitable for trend assessment, an analysis of trends might have been possible for these stations; for instance at station 0484, of 13 observation dates in 1974, only four fall in separate months, hence nine of the thirteen observations are of no use for trend analysis. It should be noted that such problems have been greatly reduced by upgrading of the routine monitoring network from 1979 on, and it should be possible to

Table 11. Data Availability (number of visits per year) for Selected Metro Routine Monitoring Stations.

Station No.	Location	1971	72	73	74	75	76	77	78	79	80	81
0450	Sammamish River	1	2	0	0	0	16	18	19	21	6	9
0470	Swamp Creek	1	13	19	10	0	2	2	0	14	12	9
0474	North Creek	1	13	18	14	0	2	2	0	14	12	9
0484	Evans Creek	1	2	0	13	0	2	2	0	14	12	9
0631	Issaquah Creek	0	3	0	0	3	2	0	0	13	12	9

conduct a meaningful analysis of trends for many of the stations with presently inadequate data bases within one to two years.

Variables selected for testing were to be constituents of the Metro swimmability and fishability indices (see Chapter IV). Of the variables included in the indices, reasonably complete records exist for the following: temperature, dissolved oxygen, pH, fecal coliform counts, and specific conductance. A derived variable, dissolved oxygen per cent saturation, could be computed from temperature and dissolved oxygen data, however this was not included since the computation had not been performed on the data files provided by Metro, from which TREND reads data directly. However, both temperature and dissolved oxygen records were analyzed, so minimum additional information would be provided by analysis of dissolved oxygen per cent saturation.

One final preliminary comment should be made on the availability of streamflow data for use in the flow adjustment techniques in TREND (option 13). As noted in Chapter III, Metro currently measures instantaneous flow at the time water quality samples are taken. However, accurate measurements (as opposed to more subjective estimates) have only been taken since 1979. Therefore, average daily streamflow at selected USGS gaging stations, which is available in magnetic tape form from the USGS, was used instead. Although daily flows are less desirable than instantaneous measurements, this appeared to be the only viable option under the circumstances. Two USGS stations were used: station 12-1271 (Swamp Creek near Kenmore) for Metro station 0470, and station 12-1252 (Sammamish River near Woodinville) for Metro stations 0450 and 0474. In retrospect, the absence of good streamflow data did not appear to be a major limitation, since the flow dependence of the variables assessed appeared to be weak. However, this is an area that may merit further analysis.

B. Demonstration Application

Three variables were selected for the demonstration application of TREND: fecal coliform counts (FCX) for stations 0450 and 0470, and dissolved oxygen for station 0474. An initial analysis was performed to suggest appropriate transformations of the data, if any, and to suggest what trends might exist in the data.

Quantile-Quantile plots (Option 4 of TREND) are the primary tool for determining whether a transformation of the data is needed. Figures 25-27 show the Quantile-Quantile (Q-Q) plots of the data generated by TREND for stations 0450, 0470, and 0474, respectively. If the data were normally distributed, the Q-Q plots would be straight. Although the normal transformation is not necessary for most of the trend tests

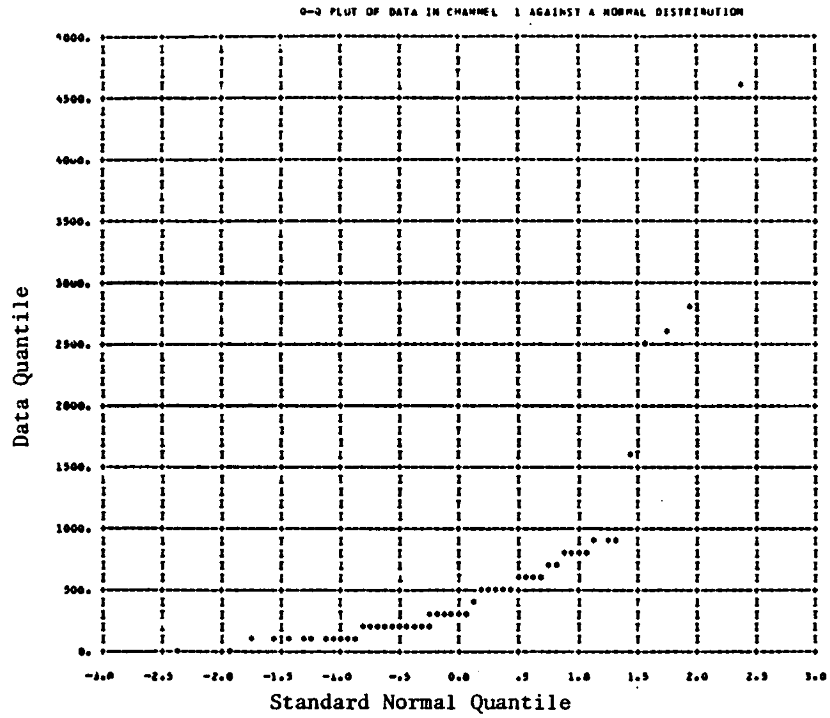

Figure 25. Q-Q Plot for Fecal Coliform Counts, Sammamish River Station 0450.

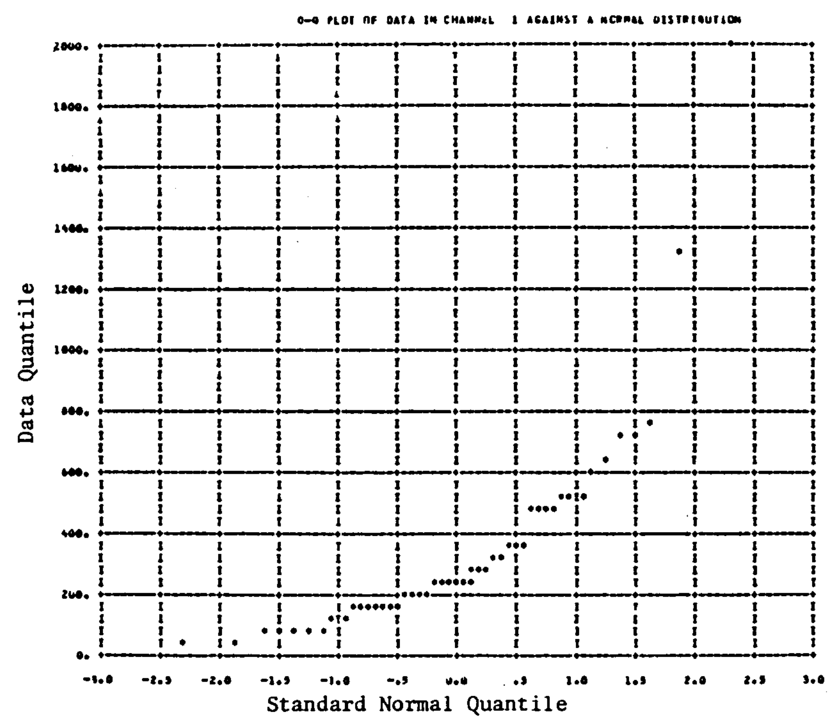

Figure 26. Q-Q Plot for Fecal Coliform Counts, Swamp Creek Station 0470.

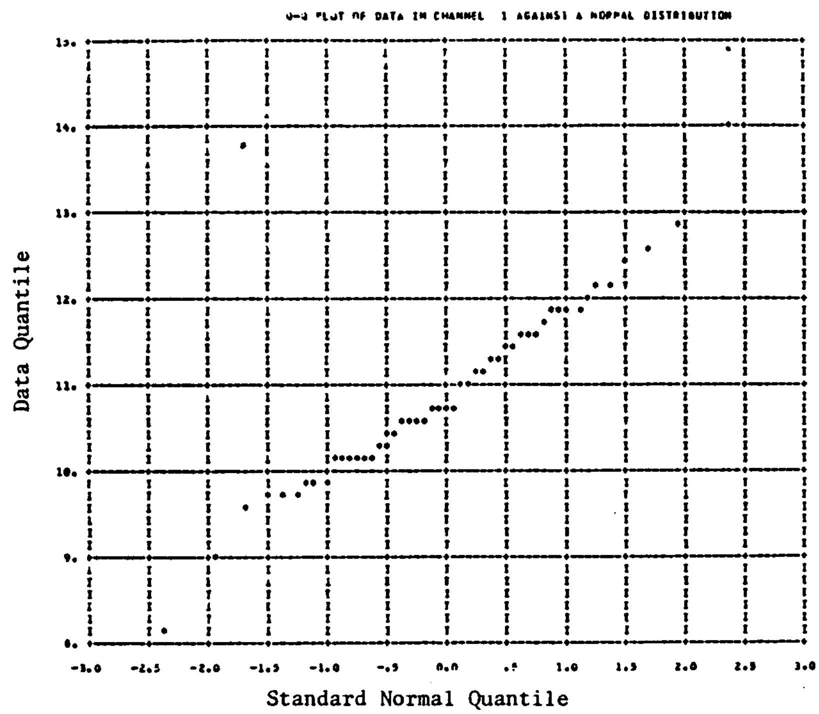

Figure 27. Q-Q Plot for Dissolved Oxygen Concentrations, North Creek Station 0474.

included in TREND, some of the tests do require that the data be symmetrically distributed, which would be evidenced by radial symmetry about the ordinate on the Q-Q plots (i.e., "S" shape). In practice, however, most adequate transformations will result in approximate normality, i.e., straight line on the Q-Q plot.

The station 0474 dissolved oxygen concentrations (Figure 27) appear to be approximately normal without transformation, however FCX for both stations 0450 and 0470 is highly assymetric (Figures 25 and 26). Both observations are common; dissolved oxygen, as well as such other parameters as temperature and pH usually do not require transformation. For FCX, the appropriate transformation is logarithmic, which can be accomplished by using Option 1 in TREND.

One other issue that should be addressed at the same time as transformation is deseasonalization. In the case of FCX, very high values tend to occur in the summer, therefore it may be necessary to adjust the raw sequences seasonally to avoid corruption of underlying trends with seasonal changes. This can be accomplished by implementing Option 2, which adjusts each observation to account for the difference between the seasonal mean and the annual mean. Figures 28 and 29 show the results of logarithmic transforming and deseasonalizing (in that order; as noted by Lettenmaier (1977) , the order is important) FCX concentrations for stations 0450 and 0470. In both cases, this results in an approximately normal distribution for the transformed data.

The next step is to identify possible trends and their direction.

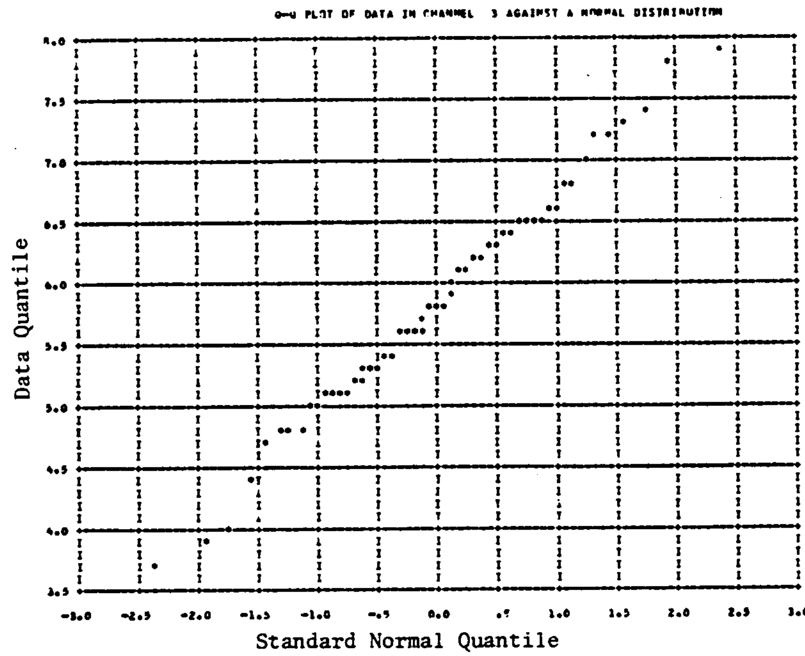

Figure 28. Q-Q Plot for Deseasonalized Fecal Coliform Logarithms, Sammamish River Station 0450.

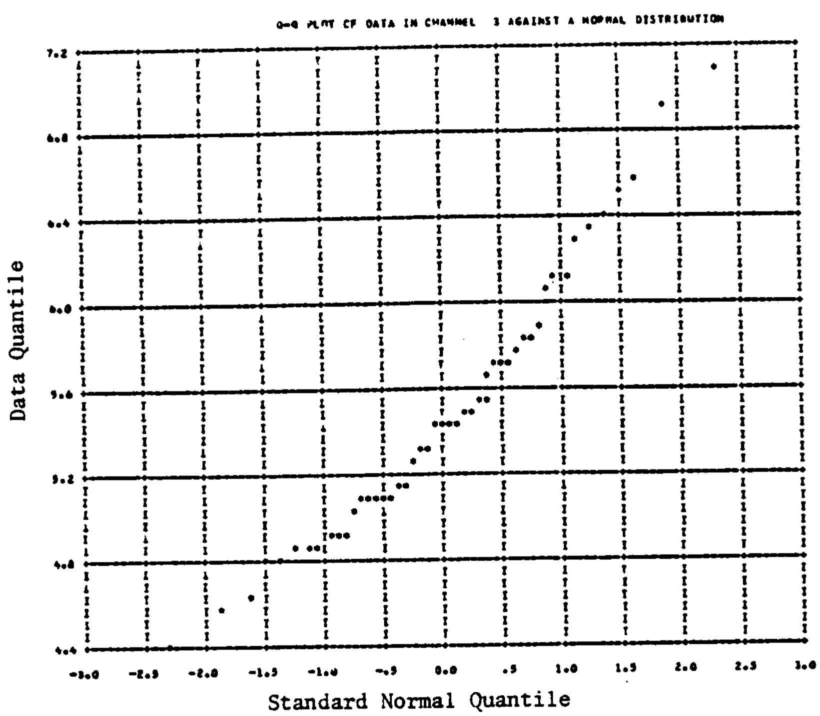

Figure 29. Q-Q Plot for Deseasonalized Fecal Coliform Logarithms, Swamp Creek Station 0470.

This can be done by use of cumulative sum (CUSUM) plots, using Option 8 of TREND, and time series plots, using Option 5. It is best to perform this preliminary screening on the transformed and deseasonalized data, if either of these operations is necessary. The CUSUM option requires specification of an observation number at which a change is presumed to have occurred. The location of this point is somewhat arbitrary, however, if there is some natural break in the data, it should be used. Alternately, if some particular intervention is known to have occurred, such as installation of a pollution control facility, the date of installation should be used. In the absence of any information of this sort, use of the midpoint of the data sequence is suggested. A review of Table 11 shows that for both stations 0470 and 0474, a natural break is between the period 1971-74 and 1979 on; during 1975-78 few samples were collected. Therefore, for these stations observation number 50 was specified for NDP in Option 8 (see description in Appendix B). Note that for reference purposes, the data index NDP is in terms of the number of time periods (months) from the initial observation; the program consolidates multiple observations per time period and enters an appropriate indicator for missing observations. Therefore, for those records (e.g., 0450, 0470, and 0474) where the initial observation was in December, 1971 and the final observation in September of 1981, the record is referenced as a sequence of 1 + 12(1980 - 1972 + 1) + 9 = 118 values, even although the actual number of observations is considerably less.

For station 0450, a reasonably complete observation sequence began in 1976 and continued through 1981, however very few samples were taken prior to 1976. In this case, NDP = 80 was used, which corresponds to

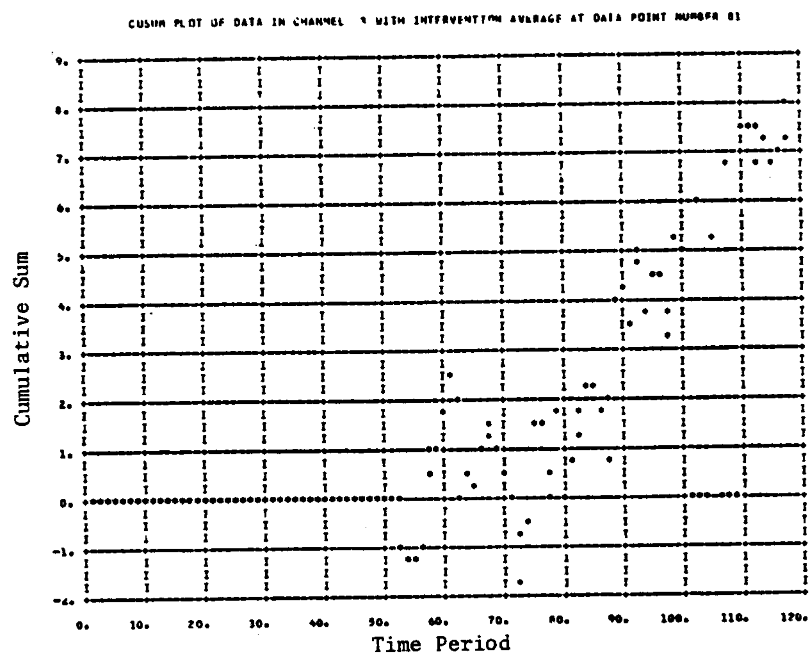

Figure 30. CUSUM Plot of Deseasonalized Fecal Coliform Logarithms, Sammamish River Station 0450.

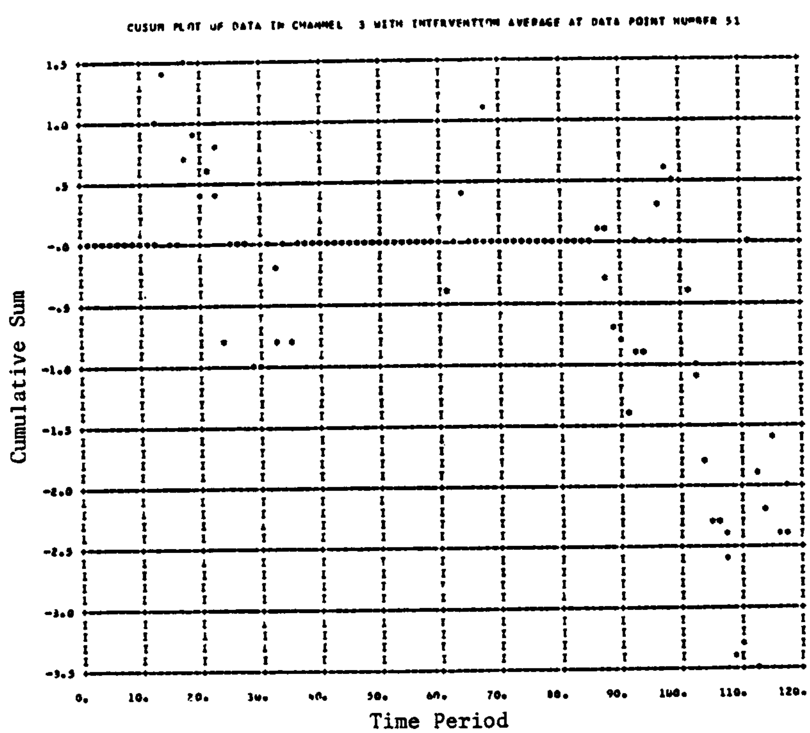

Figure 31. CUSUM Plot of Deseasonalized Fecal Coliform Logarithms for Swamp Creek Station 0470.

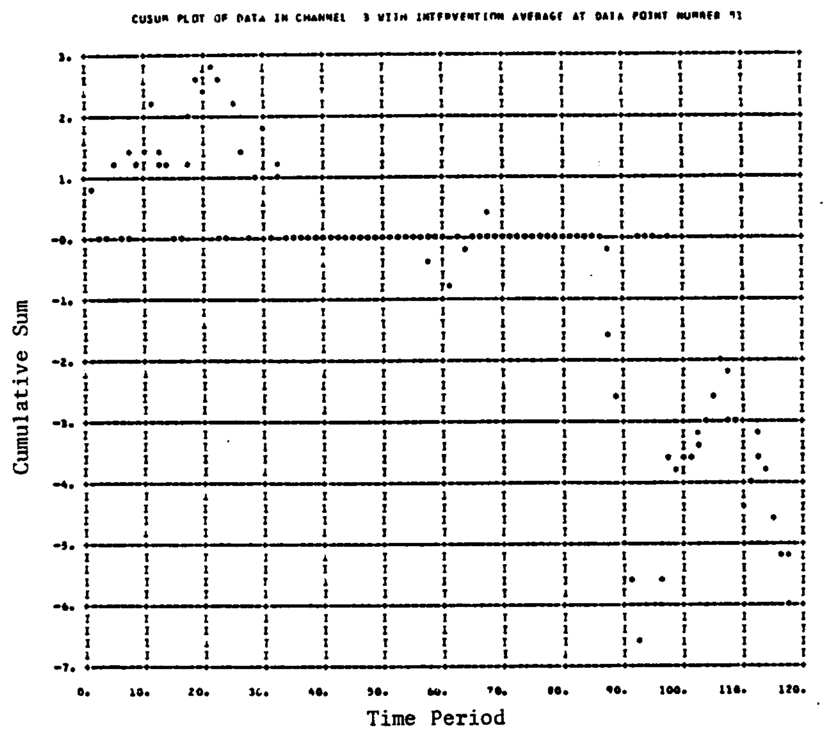

Figure 32. CUSUM Plot of Deseasonalized Dissolved Oxygen Concentrations, North Creek Station 0474.

July, 1978, approximately one-half way through the period of most complete record. Figures 30-32 show the CUSUM results produced. Figure 32 for station 0474 is somewhat inconclusive showing no consistent trend (note that CUSUM is an integrator, so a trend in the observation sequence should be characterized by a definite drift with few or no reversals) in the CUSUM. The CUSUM for Swamp Creek FCX (Figure 31) suggests a decline in the latter part of the record, while Figure 30, the CUSUM for Sammamish River FCX, suggests an increasing trend in the second half of the record. It should be emphasized that the results of the CUSUM plots are preliminary and only suggest possible trend directions and locations, they give no indication of statistical significance. Frequently, the CUSUM plots indicate possible trends that cannot be confirmed statistically, that is, the CUSUM's tend to be somewhat oversensitive to natural variations in the data, however this is a desirable feature for a screening test.

The next step in the trend assessment process is to conduct statistical tests for trend. The preferred options in TREND are 11 (Mann Whitney's and Spearman's tests, from the original version of TREND described by Lettenmaier (1977)); 14 (Kendall's test), 15 (seasonal Kendall's test), and 20 (seasonal Wilcoxon/Mann Whitney). The last three options are taken from programs described by Hirsch, et al. (1982); specific references are given in Chapter II. Options 11 and 14 should be applied to the (transformed) deseasonalized data (output from Option 2) while options 15 and 20 should be applied directly to the (transformed) data. For Option 20, the data subsequences must have lengths that are even multiples of the number of observations per year (12), while no such

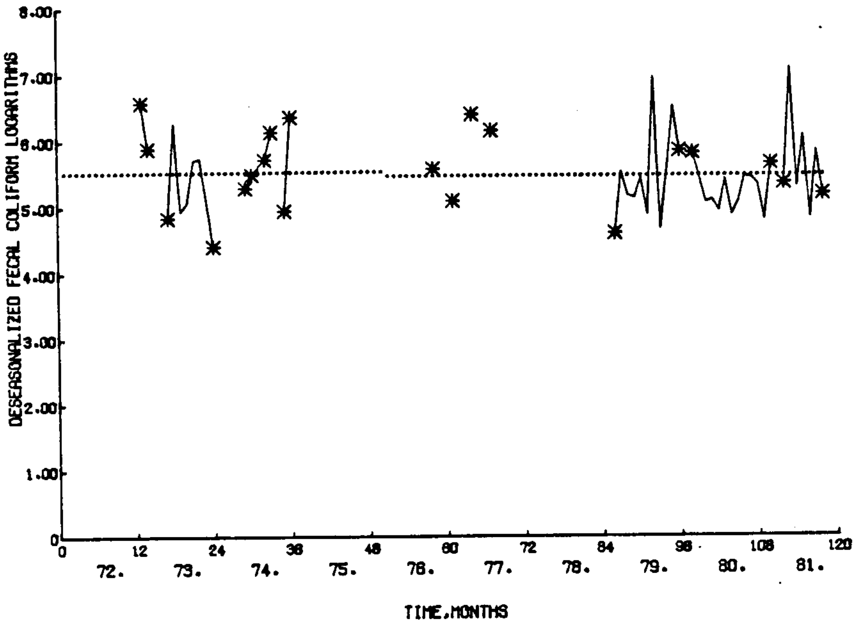

Figure 33. Deseasonalized Fecal Coliform Logarithms, Swamp Creek Station 0470 with Estimated Trend (not significant).

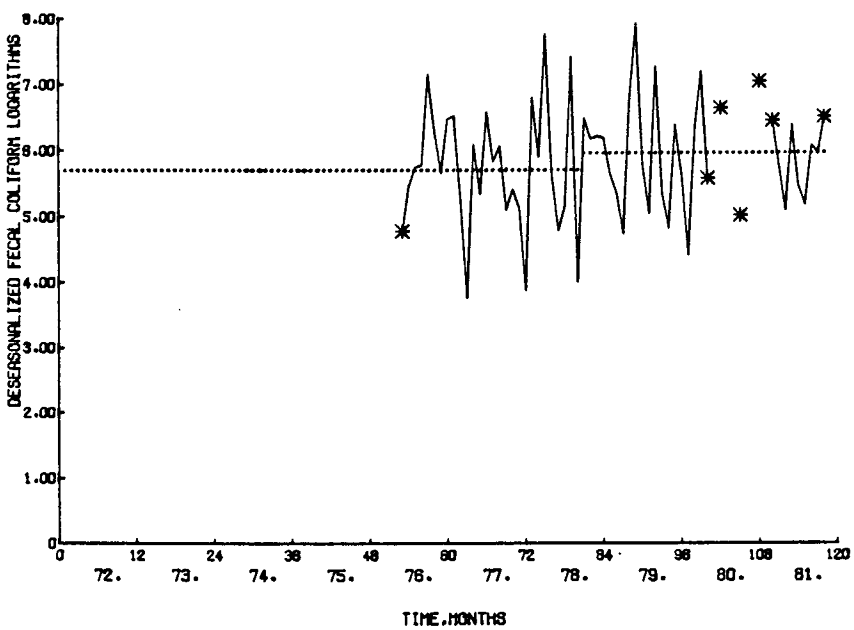

Figure 34. Deseasonalized Fecal Coliform Logarithms, Sammamish River Station 0450 with Estimated Trend (not significant).

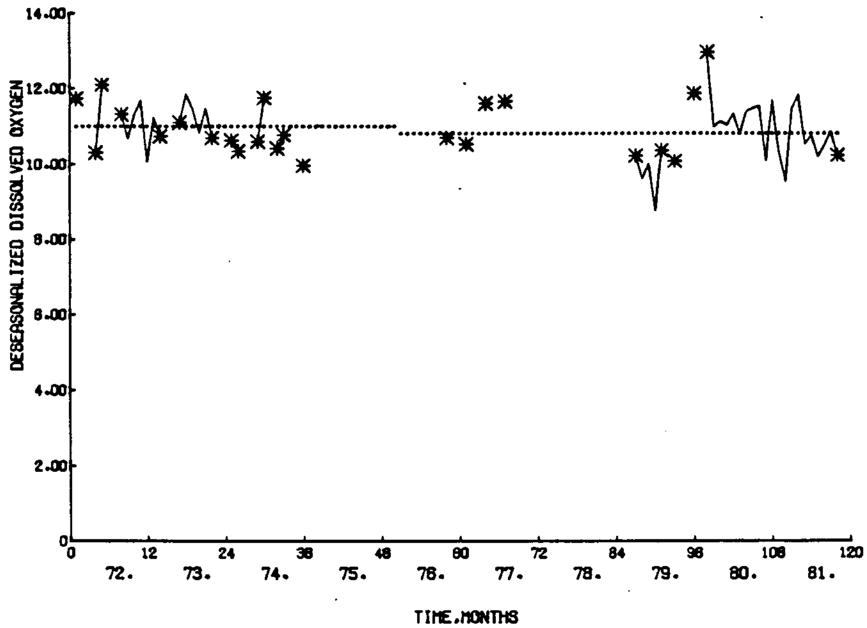

Figure 35. Deseasonalized Dissolved Oxygen Concentrations, North Creek Station 0474 with Estimated Trend (not significant).

restrictions apply to the other tests. Another option that may be useful is Option 12, which plots the data and computes and plots step or linear trends. Option 12 plots for the three test sequences are shown in Figures 33-35. The plots are identical to those produced by Option 11, which should be used if it is not desired to superimpose the estimated trends.

It should be noted that Mann Whitney's and Wilcoxon's tests (Options 11 and 20) are most powerful for abrupt, or step changes, while Spearman's and Kendall's tests (Options 11, 14, and 15) are most effective for gradual changes. However, when there is no apriori information to suggest the kind of trend that may be present, it is wise to use both types of tests.

Each of the statistical tests discussed above was applied to the three demonstration sequences, with results noted in Tables 12a-c. A threshold significance level of 0.20 was used; this corresponds to a 20% chance that a trend would be identified even if none really existed. More conclusive evidence is usually considered desirable, for instance a significance level of 0.05, corresponding to a 5% chance of incorrectly identifying a trend (known as a Type I error in statistical terminology) is a common threshold. In interpreting Tables 12a-c, therefore, a significance level of greater than 0.20 is suggestive of a trend, <0.10 is moderate evidence of a trend, and <0.05 is reasonably conclusive. On this basis, Table 12a shows that the Mann Whitney test suggests the possibility of a dissolved oxygen decline in North Creek between 1971-74 and 1979-81, and the seasonal Kendall's test fairly conclusively indicates a trend in the same direction (test applies to the entire record). On the other hand, the seasonal Wilcoxon and Kendall's tests indicate no trend for the same period, while Spearman's test applied to the latter part of the record only also indicates no trend. Taken together, the results suggest only modest evidence of a downward trend in dissolved oxygen concentrations.

Table 12a. Summary of Trend Test Results for Dissolved Oxygen, North Creek

Test	TREND Option	Subsequence 1 Begin	Subsequence 1 End	Subsequence 2 Begin	Subsequence 2 End	Test Statistic	Significance level	Direction
Mann Whitney	11	1	50	51	118	420	<0.20	decrease
Seasonal Wilcoxon	20	1	48	49	108	-	>0.20	-
Kendall	16	1	118			-0.110	>0.20	-
Seasonal Kendall	15	1	118			-0.264	<0.05	decrease
Spearman	11	50	118			-0.007	>0.20	-

Tables 12b and 12c show that one test (Mann Whitney's) indicates weak evidence for an increase in fecal coliform counts at station 0450, while one test (seasonal Kendall's) indicates modest evidence for a decreasing trend in fecal coliform for station 0474. All other tests showed no trend at a significance level of 0.20. These results should demonstrate the value of applying as many tests as possible to a given

Table 12b. Summary of Trend Test Results for Fecal Coliform Counts, Sammamish River.

Test	TREND Option	Subsequence 1 Begin	Subsequence 1 End	Subsequence 2 Begin	Subsequence 2 End	Test Statistic	Significance level	Direction
Mann Whitney	11	1	80	81	118	389	<0.20	increase
Seasonal Wilcoxon	20	1	72	73	108	-	>0.20	-
Kendall	16	1	118			0.048	>0.20	-
Seasonal Kendall	15	1	118			0.074	>0.20	-
Spearman	11	80	118			0.063	>0.20	-

Table 12c. Summary of Trend Test Results for Fecal Coliform Counts, Swamp Creek.

Test	TREND Option	Subsequence 1 Begin	Subsequence 1 End	Subsequence 2 Begin	Subsequence 2 End	Test Statistic	Significance level	Direction
Mann Whitney	11	1	50	51	118	305	>0.20	-
Seasonal Wilcoxon	20	1	48	49	108	-	>0.20	-
Kendall	16	1	118			-0.06	>0.20	-
Seasonal Kendall	15	1	118			-0.25	<0.10	decrease
Spearman	11	50	118			-0.039	>0.20	-

record; when strong trends exist they should be detected by most or all of the tests included in TREND, while an indication of a trend, even if at a relatively low significance value, for only one test should suggest that caution be taken in interpretations of the results.

Finally, it should be emphasized that an indication of trend is relative to the numerical sequence analyzed and cannot be assumed apriori to apply to water quality in the stream or river. For instance, if measurement techniques have changed, a statistical test may detect 'trends' that are really only an indication of procedural changes. Therefore, when trends are indicated by the tests, a careful investigation of causality should also be made.

C. Summary of Demonstration Application

The procedures suggested in the preceeding section were applied to the remaining variables for stations 0450, 0470, and 0474. The results are summarized in Tables 13-15. There is some evidence of an increase in pH in Swamp Creek, and an increase in fecal coliform counts in North Creek, and fairly persuasive evidence of a decrease in dissolved oxygen concentrations in the Sammamish River. For some of the remaining variables, individual tests indicated changes but there appeared to be no consensus.

In interpreting the results, it should be kept in mind that the strength of the conclusions that can be drawn is directly affected by the quality of the data records. If more complete records had been available, it would be possible to reduce the detection threshold, i.e., the smallest level of change that could be detected at a given

Table 13. Swamp Creek Trend Test Summary

Parameter	Test	Deseason-alize	log Transform	Begin	End	Begin	End	Signi-ficant	Level	Direction
Temperature	Mann Whitney	yes	no	12/71	1/75	2/75	9/81	no	>.20	
	Seasonal Wilcoxon	no	no	12/71	11/74	12/74	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	1/75	9/81			no	>.20	
Dissolved Oxygen	Mann Whitney	yes	no	12/71	1/75	2/75	9/81	no	>.20	
	Seasonal Wilcoxon	no	no	12/71	11/74	12/74	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	1/75	9/81			yes	<.20	increase
pH	Mann Whitney	yes	no	12/71	1/75	2/75	9/81	yes	<.20	increase
	Seasonal Wilcoxon	no	no	12/71	11/74	12/74	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			yes	<.10	increase
	Seasonal Kendall	no	no	12/71	9/81			yes	<.10	increase
	Spearman	yes	no	1/75	9/81			yes	<.20	increase
Specific Conductance	Mann Whitney	yes	yes	12/71	1/75	2/75	9/81	no	>.20	
	Seasonal Wilcoxon	no	yes	12/71	11/74	12/74	11/80	no	>.20	
	Kendall	yes	yes	12/71	9/81			no	>.20	
	Spearman	yes	yes	1/75	9/81			no	>.20	

Table 14. North Creek Trend Test Summary

Parameter	Test	Deseason-alize	log Transform	Begin	End	Begin	End	Signi-ficant	Level	Direction
Temperature	Mann Whitney	yes	no	12/71	1/75	2/75	9/81	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	1/75	9/81			yes	<.20	increase
Dissolved Oxygen	Mann Whitney	yes	no	12/71	7/78	8/78	9/81	no	>.20	
	Seasonal Wilcoxon	no	no	12/71	11/74	12/74	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	1/75	9/81			no	>.20	
Fecal	Mann Whitney	yes	yes	12/71	1/75	2/75	9/81	yes	<.20	increase
	Seasonal Wilcoxon	no	yes	12/71	11/74	12/74	11/80	yes	<.20	increase
	Kendall	yes	yes	12/71	9/81			yes	<.20	increase
	Seasonal Kendall	no	yes	12/71	9/81			no	>.20	
	Spearman	yes	yes	1/75	9/81			no	>.20	
	Mann Whitney	yes	yes	12/71	7/78	8/78	9/81	no	>.20	
	Kendall	yes	yes	12/71	9/81			no	>.20	
	Seasonal Kendall	no	yes	12/71	9/81			no	>.20	
	Spearman	yes	yes	1/75	9/81			no	>.20	

Table 15. Sammamish River Trend Test Summary

Parameter	Test	Deseason-alize	log Transform	Begin	End	Begin	End	Signi-ficant	Level	Direction
Temperature	Mann Whitney	yes	no	12/71	7/78	8/78	9/81	no	>.20	
	Seasonal Wilcoxon	no	no	12/71	11/77	12/77	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	7/78	9/81			yes	<.05	increase
Dissolved Oxygen	Mann Whitney	yes	no	12/71	7/78	8/78	9/81	yes	<.05	decrease
	Seasonal Wilcoxon	no	no	12/71	11/77	12/77	11/80	yes	<.01	decrease
	Kendall	yes	no	12/71	9/81			yes	<.05	decrease
	Seasonal Kendall	no	no	12/71	9/81			yes	<.05	decrease
	Spearman	yes	no	7/78	9/81			no	>.20	
pH	Mann Whitney	yes	no	12/71	7/78	8/78	9/81	yes	<.20	increase
	Seasonal Wilcoxon	no	no	12/71	11/77	12/77	11/80	no	>.20	
	Kendall	yes	no	12/71	9/81			no	>.20	
	Seasonal Kendall	no	no	12/71	9/81			no	>.20	
	Spearman	yes	no	7/78	9/81			no	>.20	
Specific Conductance	Mann Whitney	yes	yes	12/71	7/78	8/78	9/81	no	>.20	
	Seasonal Wilcoxon	no	yes	12/71	11/77	12/77	11/80	no	>.20	
	Spearman	yes	yes	7/78	9/81			yes	>.10	

significance level. Within the confines of the existing data base, there is only limited evidence of water quality trends in the basins assessed. It is recommended that this assessment be repeated as more data become available within the next two years.

The reader may have noticed that not all of the options in TREND were applied in the demonstration analysis. Those not used include Option 3 (data differencing), 6 (data transfer), 7 (time series model identification), 9 (data censoring), 10 (residuals from moving average), 13 (flow adjusted concentration), 16 (Kendall's test with slope estimator), 17 (moment computation), 18 (seasonal regression), and 19 (linear regression).

Option 3 is included from an earlier version of TREND, and along with Options 7, 10, and 17 can be used for some aspects of time series model identification (e.g., Box and Jenkins, 1970). The primary reason these options are rarely used is that the types of models to which they are applicable require relatively few missing data and data gaps, which is rarely the case with water quality data. If the nonparametric tests described in this chapter are used, these four options need never be called.

Option 6 is a utility option which allows transfer of data from one channel to another. It is most useful when many options are applied in a single run, so that the maximum number of data channels is reached. Option 9 (data censoring) is not normally used unless isolated observations are considered suspect, possibly due to errors in recording or at the sample analysis stage, in which case Option 9 treats the observation(s) as if it (they) were missing. Options 13, 18, and 19 are all used in connection with the flow adjustment procedures suggested by Hirsch, et al. (1982). They were not used here because preliminary tests showed the flow dependence of the variable sequences analyzed to be weak and also because, as noted earlier in this chapter, instantaneous flow data were not available at most of Metro's routine monitoring stations until 1979. One suggested upgrade to TREND is to include a graphical display of the raw flow/concentration data and the fitted models.

Finally, Option 16 was not used, as Option 15, which is identical with the exception of the slope estimator, was used instead. Both of these options are from the Hirsch work. One possible improvement to this option would be to plot the Kendall slope estimator along with the data, to allow comparison with the linear regressions that can be obtained using Option 12.

To briefly summarize the suggested approach to the use of TREND:

(1) Determine whether data transformation and/or deseasonalization are needed by examination of the raw data (Option 11), and Q-Q plots (Option 4).

(2) If transformation is required, apply Option 1; if deseasonalization is required, apply Option 2.

(3) Review Q-Q plots; verify that data plot is approximately straight.

(4) Review time series plots (Option 5) and CUSUM plots (Option 8) to obtain preliminary indications of the type and direction of trends

that may be present.

(5) Apply Option 12 to view graphically the magnitude of fitted linear or step trends.

(6) Apply statistical tests (Options 11 and 14 to (transformed) deseasonalized data; Options 15, 16, and 20 to (transformed) data directly.

(7) If flow adjustment of data is desired, apply Option 13 prior to step 5.

CHAPTER VI. SUMMARY AND CONCLUSIONS

The work reported herein addresses four topics relevant to Metro's existing routine water quality monitoring network. These include (1) a review of the literature on water quality trend assessment and recommendation of a specific method, including a computer program (TREND) to perform trend analysis, (2) a review of Metro's existing routine monitoring network with respect to number of stations, number of variables monitored and sampling frequency, (3) an assessment of potential problems in assessing differencies in water quality indices in either space or time as indicators of trend or for a comparison of water quality conditions in different drainages, and (4) a limited analysis of selected Metro water quality records for trends. The principal conclusions and recommendations resulting from this work are:

(1) There is some apparent confusion as to the ability of the data base collected from the routine monitoring network to support forecasting, or prediction of future water quality conditions. The information provided from analysis of the existing data base such as that conducted in Chapter V is entirely limited to assessment of past conditions. It is extremely dangerous to try to extrapolate trends into the future or to draw analogies from past conditions particularly since the analyses conducted in Chapter V generally provide no statistically conclusive evidence of water quality trends (see Conclusion 7). The approach recommended to provide the basis

for prediction is to implement the revisions to the existing network recommended in Chapter III and summarized in Conclusion 3 below, to support basin level water quality modeling efforts which allow prediction of future conditions as a function of predicted land use. The remaining, reduced routine network will continue to support retrospective analysis of past trends, but cannot support prediction or forecasting of future conditions.

(2) To assess trends in the existing data base and in the future as higher quality records become available a computer program (TREND) was developed which incorporates the elements of an earlier trend analysis program (Lettenmaier, 1977) and some additional statistical tests proposed by Hirsch, et al., (1982). This program is documented in Appendix B and a tutorial application is provided in Chapter V.

(3) The existing Metro routine monitoring network was reviewed. A primary concern in view of Conclusion 1 was to reduce the scope of the network to provide sufficient resources to allow implementation of an intensive monitoring program in support of basin water quality monitoring and prediction efforts. In so doing it was necessary to prioritize the stations in the existing network. This was done via a dynamic program, which selected optimal subsets of an existing 64 station baseline network using a score made up of a nondimensional prioritization of each baseline network station according to (1) drainage area, (2) expected increase in impervious drainage area in the period 1980 to 2000, (3) summer 1979-81 fecal coliform counts, and (4) summer 1979 stream walk index. The results of this analysis are the specific stations to be included in any subset of the

baseline network. Our recommendation is to reduce the existing routine monitoring network to 30 stations, retaining the stations specified in Chapter III. A review of sampling frequency and the parameters monitored was also conducted. It is recommended that the existing monthly sampling frequency be retained and that the existing variable suite continue to be collected, with the exception that Kjeldahl nitrogen and turbidity should be dropped, and settleable solids should be dropped at the river stations.

(4) A comparison of laboratory and field manpower costs for the Metro routine network and the State of Washington Department of Ecology's ambient water quality monitoring program was made. Metro's laboratory analysis costs are less than DOE's and Metro's at-site crew time is comparable to DOE's. Metro's travel times per unit distance are higher than DOE's but this is attributable to differences in highway conditions. This analysis suggests that Metro's program is relatively efficient with respect to manpower and that large cost savings are probably not possible here.

(5) It is suggested that three of the 30 stations to be maintained in the revised routine network be supported by DOE via a cooperative agreement to eliminate duplication in existing stations on the Green/Duwamish, Cedar and Sammamish Rivers. This would result in 27 stations actually monitored by Metro, with a net cost reduction of about $75,000 per year as compared to the existing program. These funds should be used to implement an intensive monitoring program in support of basin level water quality monitoring. At this level of effort approximately one basin per year and perhaps three basins in two years could be included in the program. It is recommended that

additional funding be sought to allow inclusion of two basins per year in the intensive program. At this level the most development-sensitive basins could be reassessed every five to ten years. It is also recommended that a ranking scheme be devised to prioritize basins for the intensive program, along the lines of the scoring scheme used in Chapter III. Taken together, recommendations 1, 3, and 5 would result in a data collection program capable of supporting both retrospective trend analysis and water quality prediction, whereas the existing routine monitoring network supports trend assessment only.

(6) A review of the fishability and swimmability indices used by Metro was made to determine what problems might result from assessment of temporal and spatial differences in index values. In the absence of sufficient data to compute long sequences of the indices, fecal coliform was used as a surrogate for the swimmability index, and temperature as a surrogate for fishability. Analysis for possible trends in the coefficient of variation, which could corrupt identification of trends in the indices themselves, was conducted for both variables using data from station 3106 on the Duwamish River. The results showed no significant trend in the coefficient of variation of either variable. Nevertheless it is strongly recommended that whenever trends in the indices are assessed, a parallel assessment of trends in the constituent variables be conducted. Finally, it should be emphasised that no more information is present in indices computed for two time periods (e.g., average index value for subsequent years) than is present in the constituent variables, and that differences in small numbers of

observations are usually statistically insignificant. It is recommended that the general guideline suggested in Chapter V, that trend analysis not be conducted where less than 5 years of reasonably complete data records are available, also be observed for assessment of the indices.

(7) A demonstration analysis of five selected stream and river stations for trend was inconclusive, due largely to the paucity of data available. Although some sampling at the selected stations was conducted in the early and mid-1970's, data problems such as collection of multiple samples in selected months, with no sampling in others, reduce the effective sample size in the early part of the records. Improved sampling protocol from 1979 on, however, offers encouragement that meaningful trend analyses for many stations may be conducted by the end of 1982, or at the latest, 1983 where no pre-1979 data record is available. From the standpoint of this project, however, the primary value in the assessment conducted is to act as a tutorial in use of the computer program TREND.

(8) In summary, the recommended monitoring revisions will address the six Metro program objectives given in Section B of Chapter I as follows: 1) (To detect trends in water quality over time) This objective will be addressed by retaining a (30 station) routine monitoring network. The trend analysis computer program TREND will enhance the ability of the existing and evolving data base to assess trends. 2) (To determine whether existing water quality conditions constitute problems or potential problems) The development of an intensive monitoring program will support predictive tools, such as water quality models, which will allow better identification of

evolving water quality problems. It should be emphasized, however, that this report has not addressed the problem of establishing criteria or standards, which defines particular sets of conditions that constitute problems. 3) (To identify water quality conditions which the public may perceive as problems) The areal extensiveness of the routine monitoring network allows Metro personnel to maintain at least a perception of water quality conditions throughout the Metro service area, and can give rise to specific actions if severe problems, such as spills, are observed. It should be emphasized, however, that contact with the public remains an essential element of the water quality monitoring and management process. 4) (To determine cause effect relatioships for water quality) The development of an intensive monitoring program will address this objective directly. 5) (To recommend mitigation and abatement measures) Intensive surveys will allow assessment of the effectiveness of mitigation strategies. 6) (To provide public awareness of Metro efforts in the field) Both routine and intensive monitoring efforts will result in a visible presence of Metro personnel in the field, evaluating current water quality conditions.

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APPENDIX A. Metro Routine Monitoring Program Baseline Network

Station Number	PSCOG Primary Basin Descriptor	Primary Basin Number	Subbasin Descriptor	Location
0470	Swamp Cr #1	1	Swamp Cr Mouth	USGS gaging station near Bothell Wy & 80th Av NE
B470	Swamp Cr #2	1	Swamp Cr County Line	Bridge on NE 205th near 73rd Av NE
0474	North Cr #1	2	North Cr Mouth	Upstream Side Freeway Bridge, SE 1/4 of NE 1/4 Sec 8 T26N R 5E
D474	North Cr #2	2	North Cr County Line	Bridge on NE 205th near 120th Av NE
0478	Bear Cr #1	3	Little Bear Creek	Bridge adjacent to parking lot, Woodinville Prairie Market
B478	Bear Cr #2	3	Little Bear Creek County Line	NA
A432	McAleer Cr #1	4	McAleer Cr Mouth	NE 170th & Bothell Wy NE
E432	McAleer Cr #2	4	McAleer Cr County Line	Culvert on NE 196th E of 15th Av NE
0430	Lyon Cr #1	5	Lyon Cr Mouth	Bridge inside gate at Lake Forest Park Civic Club
E430	Lyon Cr #2	5	Lyon Cr County Line	3700 Block NE 204th St
C446	Juanita Cr #1	6	Juanita Cr N Brch	Bridge on NE 128th E of 100th NE
0446	Juanita Cr #2	6	Juanita Cr Mouth	USGS gaging station north of Juanita Park at Kenmore
D446	Juanita Cr #3	6	Totem Lake Tributary	Downstream of pond behind Juanita High School
0450	Sammamish R	7	Sammamish R Mouth	Bridge on 68th Av NE in Kenmore
0480	Sammamish R	7	Sammamish R above Little Bear Cr	NE 173rd Pl in Woodinville
0486	Sammamish R	7	Sammamish R nr Lake Sammamish	Marymoor Park Bridge
N484	Evans Cr #1	8	Cottage Lake Creek	Bridge on Avondale Rd near Brookside Golf Course
J484	Evans Cr #2	8	Bear Cr above Cottage Lake Cr	Bridge on Seidel Rd E of Bear Cr Rd
G484	Evans Cr #3	8	Bear Cr below Cottage Lake Cr	Bridge on NE 116th St E of Avondale Rd

C484	Evans Cr #3	8	Bear Cr near confluence with Evans Creek	Bridge on NE 95th St E of Avondale Rd
0484	Evans Cr #4	8	Bear Cr near Mouth	Railroad bridge S of Redmond-Fall City Rd in Redmond
B484	Evans Cr #5	8	Evans Cr near Mouth	Bridge on Union Hill Rd W of 185th Av NE
R484	Evans Cr #6	8	Evans Cr Tributary	Upstream of Culvert on Redmond-Fall City Rd E of 218th Av NE
0434	Thornton Cr	9	Thornton Cr Mouth	1 Block S of Mathews Beach at Mouth
K434	Thornton Cr	9	Maple Leaf Cr	S of NE 108th St between 11th & 12th Av NE
T434	Thornton Cr	9	Thornton Cr N	Near 13038 10th Av NE
0442	Coal Cr #1	10	Coal Cr East	USGS gage near Coal Cr Pkwy & 119th Av SE
C442	Coal Cr #2	10	Coal Cr East	Coal Cr Pkwy bridge 1.2 miles from mouth
U442	Coal Cr #3	10	Coal Cr East	On Newcastle-Coal Cr Rd near Lakemont Blvd
0440	May Cr #1	11	May Creek mouth	Deactivated gaging station on L Wash Blvd near SE 80th St
K440	May Cr #2	11	May Creek	Bridge on 136th Av SE near SE May Valley Rd
X440	May Cr #3	11	May Creek	Bridge on 164th Av SE N of Renton-Issaquah Rd
0444	Mercer Slough #1	12	Mercer Slough	USGS gaging station under trestle near I405 & Richards Rd Exit
C444	Mercer Slough #2	12	Kelsey Cr W Branch	Footbridge near cabin in S end Kelsey Cr Park
D444	Mercer Slough #3	12	Kelsey Cr	Footbridge in NE qtr Kelsey Cr Park behind barns
0631	Issaquah Cr #1	13	Issaquah Cr Mouth	Bridge on SE 56th St
A631	Issaquah Cr #2[b]	13	Issaquah Cr	Upstream from bridge on W Underwood Blvd above fish hatchery
A632	Issaquah Cr #2[b]	13	Issaquah Cr N Fork	Behind bldgs on E Lk Sammamish Pkwy SE across from Reid Sand & Gravel
0633	Issaquah Cr #3	13	Issaquah Cr E Fork	Near confluence with Issaquah Cr at abandoned sewage treatment plant
0634	Issaquah Cr #4	13	McDonald Cr (Mason Cr)	Bridge on 216th Av SE near May Valley Rd
A660	Issaquah Cr #5	13	15 Mile Cr	Bridge on May Valley Rd 1/4 mile S of Issaquah-Hobart Rd
H631	Issaquah Cr #6	13	Issaquah Cr	2nd bridge on new rd W of SE May Valley Rd
A640	Issaquah Cr #7	13	Holder Cr	Bridge on access Rd to Hwy 18 from Issaquah-Hobart Rd
A650	Issaquah Cr #8	13	Carey Cr	W side of Hwy 18 1 mile S of Issaquah-Hobart Rd
3106	Lower Green R[b]	14	Green River	Bridge in Ft Denton Park
0311	Lower Green R[b]	14	Green River	Renton Junction bridge on W Valley Rd at Hwy 1

0315	Lower Green R[b]	14	Green River	Kent-Des Moines Rd bridge at Frager Rd
A315	Lower Green R[b]	14	Hill Cr	Bridge at 68th Av S & S 261st St
0317	Black River	15	Springbrook Cr	Bridge at N end Longacres Race Track
0438	Lower Cedar R[b]	16	Cedar River	Bridge on Bronson Wy in Renton
A438	Lower Cedar R[b]	16	Cedar River	Bridge on Jones Rd at 196th Av SE
H438	Upper Cedar R[b]	17	Cedar R at Landsburg	Between dams in Landsburg Park
F320	Big Soos Cr #1	18	Big Soos Cr	Bridge on Hwy 516 W of 156th Pl SE
G320	Big Soos Cr #2	18	Little Soos Cr	Covington Way SE, W of intersection W Hwy 516
D320	Big Soos Cr #4	18	Jenkins Cr	Bridge on Kent-Black Diamond Rd near 157th Av SE
B320	Big Soos Cr #5	18	W Fork Big Soos Cr	Upstream from bridge 1 mi N of hatchery
0320	Big Soos Cr #6	18	Big Soos Cr	Footbridge at hatchery near mouth of stream
C320	Big Soos Cr #7	18	Covington Cr	Bridge on Kent-Black Diamond Rd at SE Green Valley Rd
A319	Middle Green R[b]	19	Green River	Bridge on Auburn-Black Diamond Rd at SE Green Valley Rd
B319	Middle Green R[b]	19	Green River	Bridge on SE Green Valley Rd at 212th Pl SE
0321	Middle Green R[b]	19	Crisp Cr	Bridge on SE Green Valley Rd W of 212th Pl SE
0322	Newaukum Cr #1[b]	20	Newaukum Cr Mouth	USGS gage downstream from 219th Av SE
F322	Newaukum Cr #2[b]	20	Newaukum Cr	On SE 416th St Bridge near cemetery
T322	Newaukum Cr #2[b]	20	Newaukum Cr N Fork	N/A

[a]includes only stations in 1981 Metro routine monitoring program for which Puget Sound Council of Governments (PSCOG) subbasins designations are available. Some stations may currently be inactive

[b]multiple stations within PSCOG subbasin

APPENDIX B. Trend Program Documentation and Listing

DATA DECK SETUP

The first 8 record groups are always required, subsequent cards depend on the channel options desired and the sequence in which they are called. These optional cards are described in the following table.

Record Group	No. of Records	Variables	Columns[1]	Default[2]	Description
1	1	NCHAN N IPLOT	1-5(R) 6-10(R) 11-15(R)	- - 0	NCHAN= number of parameters; N= length of data record; IPLOT= plot option (0= no plots, 1 = low quality printer plot, 2= ink plot, 3= high quality printer plot)
2	NCHAN	NAME(1) . . NAME(NCHAN)	1-80(L)	- -	Identifier for each parameter (1 card per parameter, all 80 columns may be used)
3	1	FMT2	1-40(L)	-	Variable read format for missing data code (XMDAT); use first 40 columns only, must include parentheses
4	1	FMT3	1-40(L)	-	Variable write format for echo print data - use first 40 columns only, must include parentheses. First 3 fields must print year, month, day, i.e., ('',3I5, ...)
5	1	XMDAT	Use FMT2	-	Missing data code
6	1	IUNIF RINT IOPT IFILE	1-5(R) 6-10(R) 11-15(R) 16-20(R)	0 - 0 -	IUNIF= 0; analyze all data as is, any number records/observations, no error checks, must be uniform time series for most options = 1; convert data to uniform time series with uniform interval RINT (four 80 column records/sample date). Accepts numbers and decimal points only - all other characters set to blank RINT= 0; if IUNIF= 0 > 0; sampling interval in months

					i.e., 0.5, 1.0, 2.0 IOPT= 0; convert to uniform series by averaging values within the interval RINT. = 1; convert to uniform series by taking value closest to center of interval RINT. IFILE= number of file to read data from (6 or 7 is recommended); otherwise, PROGRAM card (1st card of program) must be revised.
7	1 or 2	NVAR1	1-5(R)	0	NVAR1= number of variables to be read by FMT1 (FMT1 reads first 140 characters of data for each sample date).
		FMT1	6-75(L)	-	if IUNIF= 0: NVAR1 is ignored. FMT1 reads year, month, day, parameters, must include parentheses. FMT is not read - do not include second record in the data deck. Maximum value of NVAR1 is NCHAN. if IUNIF= 1; NVAR1 is the number of parameters which fall within the first 140 columns of the 4-card record for each observation FMT1 reads year, month, day and values of the first NVAR1 parameters; standard Fortran format - use "/" to skip records
		FMT	1-80(L)	-	FMT reads values of the remaining parameters; these parameters fall within columns 141-280; FMT should not be used if there are no parameters in columns 141-280

Note: See Figure B-1 for example use of FMT1 and FMT

8	N	Data on file IFILE	Use FMT1 FMT4	-	See description of data input above - if IFILE = 6, data go here; if IFILE / 6, data are on separate
9[3]	1	IAR1(1)	1-2(R)	-	Channel option input and output channels, if less than 16 used leave remainder blank
		IAR2(1)	3-4(R)	-	
		. . .			
		IAR1(16)	6-7(R)	-	
		IAR2(16)	8-9(R)	-	
10[3]	1	ICOMP(1)	1-5(R)	-	Channel options - if less than 16 options leave remainder blank
		. . .			
		ICOMP(16)	76-80(R)	-	
11[3]	variable	see channel option descriptions			

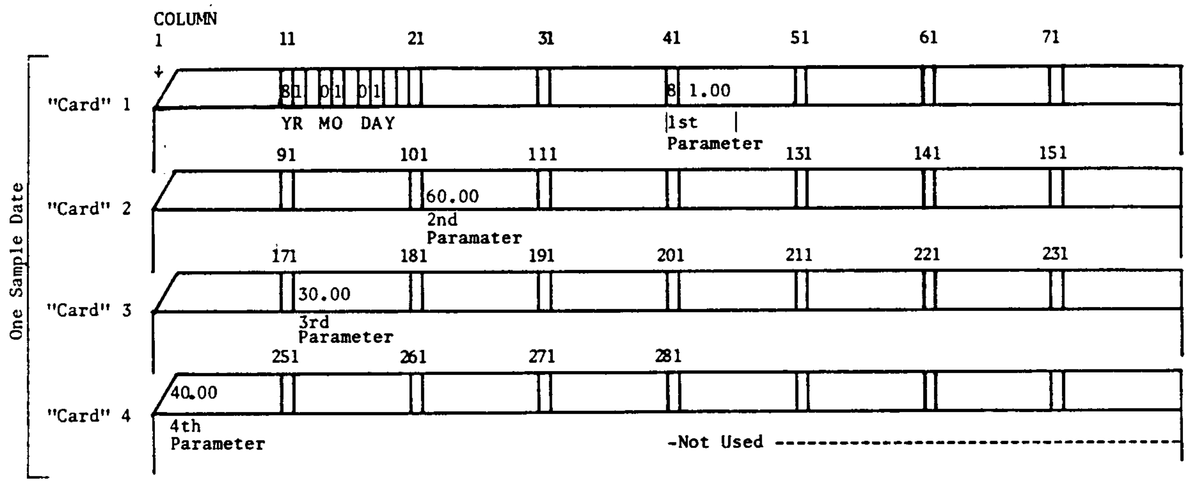
[1]L = left adjust; R = right adjust

[2]"-" indicates no default value; data <u>must</u> be entered

[3]repeat groups 9-11 for each variable (i.e., NCHAN times)

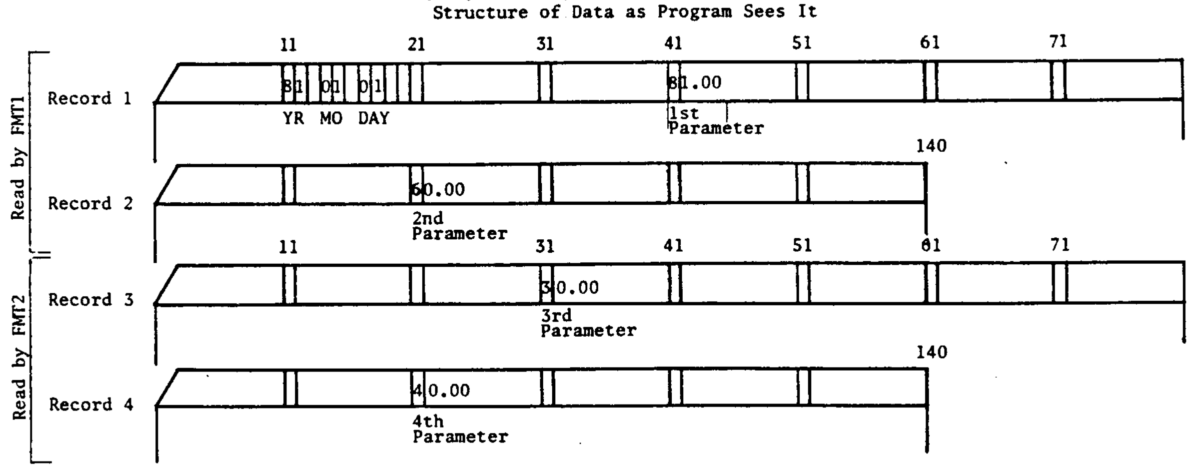
EXAMPLE OF USE OF NVAR1, FMT1, FMT2

Actual Structure of Data



NCHAN = 4 FMT1 = (10X,I2,X,I2,X,I2,22X,F5.2/20X,F5.2)
NVAR1 = 2 FMT2 = (30X,F5.2/20X,F5.2)

Structure of Data as Program Sees It



Note: FMT2 reads columns 141-220 as the 1st record then uses a "/" to skip to columns 221-280 if necessary (see example above).

Figure B-1. Metro Raw Water Quality Data Format Detail.

DATA CHANNEL OPTION DESCRIPTIONS

(Corresponding to record group 11 of preceeding table)

OPTION 1: Data transformation. This option performs either a natural logarithmic or a power transformation on the data, e.g., $Y_j = \ln(X_j)$ or $Y_j = (X_j)^{POW}$. Missing data are left as missing.

Data Read: ITRANS, POW (transformation option, 1 = natural log, 2 = power; and power POW if ITRANS = 2, leave blank otherwise).

Columns: 1-10(R), 11-20(R)

Defaults: -;0

Input Channel: data

Output Channel: transformed data

OPTION 2: Seasonal mean removal. If IOPT = 0, this option subtracts from the data the corresponding seasonal mean and adds the grand mean. For instance, if monthly seasons are used, each January datum is computed as the difference between the original value and the mean of all January data available, plus the mean of all data. If IOPT = 1, the seasonal mean is subtracted from the data and this difference is divided by the seasonal standard deviation. Missing data are left as missing in the output channel.

Data Read: NGP,NYR,IOPT - if IOPT = 0 NEW DATA = OLD DATA - SEASONAL MEAN + GRAND MEAN
if IOPT = 0 NGP is the number of data points grouped for seasonal mean; NYR is the number of data points per year
if IOPT = 1 NEW DATA = (OLD DATA - SEASONAL MEAN)/SEASONAL STANDARD DEVIATION
if IOPT = 1 NGR is the number of data points per season; NYR = 0

Columns: 1-5(R), 6-10(R), 11-15(R)

Defaults: - ; - ; 0

Input Channel: data

Output Channel: deseasonalized data

OPTION 3: Data Differencing. This option computes a new data set as the differences of the input data, e.g., $Y_j = X_j - X_{j-NDIF}$. If X_j or X_{j-NDIF} is missing, Y_j is set to missing in output channel.

Data Read: NDIF (number of data points lagged in differencing).

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: differenced data

OPTION 4: Quantile-Quantile plot. Data are ordered without respect to time. Sample quantiles are computed and plotted against theoretical quantiles of the normal distribution. A lineprinter plot is given, no CalComp plot is available. The output data channel is the same as the input channel, no manipulation on data is performed, hence the specified output channel is ignored. Missing data are not included in the plot.

Data Read: None

Input Channel: data

Output Channel: not used

OPTION 5: Time series plot of data. Non-missing data in the input channel are plotted versus time (missing data are left as blank in plot). CalComp (IPLOT = 2,3) and lineprinter plots (IPLOT = 1) are available.

Lineprinter plots are easy and inexpensive but not very good quality. If IPLOT = 3 CalComp lineprinter plots (relatively inexpensive and good quality) are produced. If IPLOT = 2, a CalComp ink plot file is prepared. Several devices, including the Gould electrostatic plotter and the CalComp ink plotter (excellent quality) are available with IPLOT = 2.

Data Read (Do not use cards 1-7 for IPLOT = 0 or 1):

Record No.	Variables Read	Column	Default	Description
1	NBP	1-5(R)	0	Bypass option: NBP = 0 reads cards 2-7 (must set NBP = 0 on first parameter run). NBP = 1 eliminates need for cards 2-5, uses previously supplied values; therefore if NBP = 0, do not supply cards 2-5.
2	NPER	1-5(R)	-	NPER = Number of data collected per year;
	IPER	6-10(R)	-	IPER = initial period for first data (i.e., IPER = 12 if first month is December)
	IYR	11-15(R)	-	IYR = initial year number
3	XMIN XMAX YMIN YMAX	1-10(R) 11-20(R) 21-30(R) 31-40(R)	- - - -	Location in inches of X-axis, end of X-axis, Y-axis, end of Y-axis from arbitrarily defined plotter origin. Suggested values are 1.0, 9.0, 1.5, 7.0.
4	XLSZ1 XLSZ2 XLSZ3	1-10(R) 11-20(R) 21-30(R)	- - -	Lettering size for axis increments, axis plots and labels, plot title. Suggested values are .098, .114, .140
5	TEXTB	1-80	-	X-axis label, any alphameric information up to 80 characters (center in field)
6	TEXTL	1-80	-	Y-axis label, any alphameric information up to 80 characters (center in field)
7	XTIT	1-80	-	Plot label, any alphameric information up to 80 characters (center in field)

Input Channel: data

Output Channel: not used

OPTION 6: Data transfer. Transfers data from input to output channel.

Data Read: None

OPTION 7: Time series model identification. Computes summary statistics, correlation (ACF) and partial autocorrelation (PACF) functions. ACF and PACF are plotted (lineprinter only). The suggested procedure is to use output from data option 10 as input to remove nonstationarity. Missing data not included in computations.

Data Read: NLAG (maximum number of lags for which autocorrelation is computed).

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: not used

OPTION 8: CUSUM plot. Cumulative sum of data is plotted. The plot is lineprinter only. Missing data are plotted as 0.

Data Read: NDP, final point from which pre-intervention mean computed. Some non-missing data must exist prior to t = NDP. If there is no effect of the intervention at time NDP, the plot will show no trend.

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: not used

OPTION 9: Data censoring. Censors given data, treating it as if given point(s) were missing. Maximum of 16 points per pass.

Data Read: (N1(J), J=1, 16) (sequence numbers of data censored, if less than 16, leave remainder blank). Note: sequence number is based on the uniform intervals created by record group 6, not on the sequence number of the original data.

Input and Output Channels: Are the same - if the original data are to be saved, they must first be stored in an alternate channel using OPTION 6.

Columns: 1-5(R); 6-10(R); 11-15(R); etc.

Defaults: None

OPTION 10: Residuals from moving average. Computes new time series as residuals of input channel data from moving average of data in specified channel. At each time, average of NAV points surrounding J (J is central point if NAV is odd; if NAV is even, NAV/2 of points to be averaged precede J) is computed. Output time series is computed as difference between raw data and moving average at each time. This option is particularly useful for removing trends prior to estimating correlation and autocorrelation functions via Option 7. Missing values are excluded from averages. The residual of a missing value is treated as missing.

Data Read: NAV, KCHAN (number of data averaged, channel from which moving average is computed - need not be same as input channel).

Columns: 1-5(R); 6-10(R)

Defaults: - ; -

Input Channel: data

Output Channel: residuals

OPTION 11: Nonparametric tests. Given necessary beginning and ending data indices, Mann-Whitney's or Spearman's rho test statistic is computed from data. Number of data in first (and, for Mann-Whitney's test, second) partition of the data are computed and written, ignoring missing data, for use in computing critical levels. No allowance is made for ties.

Data Read: NTEST, IS1, IF1, IS2, IF2 (NTEST = test option, 1 for Mann-Whitney's, 2 for Spearman's rho; IS1, IF1 = initial and final points of first data partition, IS2, IF2 = initial and final points of second data participation. Leave IS2, IF2 blank for Spearman's rho).

Columns: 1-5(R); 6-10(R); 11-15(R); 16-20(R); 21-25(R)

Defaults: 1 ; - ; - ; - ; -

Input Channel: data

Output Channel: data used in test (i.e., IS1 to IF1 and IS2 to IF2).

OPTION 12: Computes step or linear changes in estimated mean level via least squares and estimated standard deviation of change. Estimated step and linear trends are also plotted if desired using OPTION 5.

Data Read: KSL, KPL, IS1, IF1, IS2, IF2, ILOOP, RO, KGAP. KSL is trend type, 1 for step, 2 for linear; KPL is plot option - 0 gives no plot, 1 gives lineprinter (high quality), 2 gives CalComp. IS1, IF1, IS2, IF2 are same as for OPTION 11. ILOOP is multiple loop parameter when it is desired to plot more than one estimated trend on same time series plot - use 1 for start of multiple loop, 0 for single iteration only, -1 for continuation of multiple loop, -2 for end of multiple loop. If KPL = 2, plot data must be read in exactly as for OPTION 5, but plot data are read in only when ILOOP = 0 or 1. RO is daily lag one correlation coefficient, KGAP is sampling interval in days (e.g., for monthly data KGAP = 30). Suggested value for RO is 0.85 in absence of data-based estimate.

Columns: 1-5(R); 6-10(R); 11-15(R); 16-20(R); 21-25(R); 26-30(R); 31-35(R); 36-40(R); 41-45(R)

Defaults: 1 ; 0 ; - ; - ; - ; - ; 0 ; 0 ; -

Input Channel: data

Output Channel: not used

OPTION 13: Flow adjustment computes flow. Adjusted concentrations using best model, no model, linear, log-linear, hyperbolic or inverse; see Hirsch, et al. (1982) for explanation. Output is model selected and model parameters. Flows are read from unit NUNIT using variable format FMT5. Date from original datum is matched with flow date. Missing values are not included in computations, and remain missing in output data.

Data Read: (First call to OPTION 13 only; no data are read on subsequent calls) Record 1 - NUNIT, IDEF. NUNIT is the Fortran unit number for flow data; must be 8 or 6 to avoid changing program. IDEF is format choice: IDEF = 0 reads standard USGS flow data format, no further information required; IDEF = 1 causes program to read record 2 (below).

Columns: 1-5(R); 6-10(R)

Default: - ; 0

Record 2 - (FMT5(J),J=1,8). FMT5 is the variable format which must read year, month, day, flow in that order; use only if IDEF = 1. Note: the flow record must be continuous from the first sampling date to the last;

fill with zeroes if necessary.

Columns: 1-80

Default: -

Input Channel: concentration data

Output Channel: flow-adjusted concentrations

OPTION 14: Kendall's tau test (Hollander and Wolfe, 1973) for trend is computed using all data. Ties are allowed, and missing data are not included in analyses. The p-value of tau is computed using a normal approximation.

Data Read: none

Input Channel: data

Output Channel: not used

OPTION 15: The seasonal Kendall's tau test for trend (no slope estimator) is computed using all data. Computes tau for each season and adds statistics (assumes independence of seasons). Ties are allowed and missing data are not included in the analyses. The significance of tau is computed using a normal approximation.

Data Read: NSEAS (number of seasons per year)

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: not used

OPTION 16: The seasonal Kendall's tau test for trend with the slope estimator (Hirsch, et al., 1982) is performed. The test is otherwise similar to Option 15. Ties are allowed.

Data Read: NSEAS (as in OPTION 15)

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: not used

OPTION 17: The first 4 (central) moments of non-missing data are computed. This option may be used in conjunction with OPTION 2 to obtain moments of the deseasonalized data.

Data Read: none

Input Channel: data

Output Channel: not used

OPTION 18: Seasonal regression is performed using model $y_{ij} = a_i + b_i X_{ij}$ time where i is season. Missing data are not included in the regression. This option returns a, b, r (correlation coefficient) and significance of r (as in OPTION 15).

Data Read: NSEAS

Columns: 1-5(R)

Default: -

Input Channel: data

Output Channel: not used

OPTION 19: This option performs the usual linear regression (y = a + bt) on non-missing data in the input channel; it is not recommended for seasonal data. Output values are a, b, r (correlation coefficient) and significance of r.

Data Read: none

Input Channel: data

Output Channel: data with missing values removed

OPTION 20: A seasonal rank sum test for a step difference between two periods (Bradley, 1968, p. 115-117) is performed where the first period is IS1, IS1 + NX1 - 1 and second period is IS2, IS2 + NX2 - 1. Note that ABS (NX1 - NX2) must be an even multiple of NSEAS. Missing data are not included in the analysis. Output is the test statistic and p-value using normal approximation.

Data Read: IS1, IS2, NX1, NX2 (see definition above)

Columns: 1-5(R); 6-10(R); 11-15(R); 16-20(R)

Defaults: - ; - ; - ; -

Input Channel: data

Output Channel: not used

```
      PROGRAM MAIN(INPUT,OUTPUT,DATA,FLOWD,TAPE5=INPUT,TAPE6=OUTPUT,
     $TAPE7=DATA,TAPE8=FLOWD,TAPE9)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM5/T(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),  NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
     $,XAR(2), YAR(2)   ,N1(16)    , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
      REAL FMT2(4),FMT5(8),FIT(5),S(4),LABEL(5)
      DATA LABEL/4*10H          ,8H        /
      READ(5,1) NCHAN, N , IPLOT
      WRITE(6,191) NCHAN,N,IPLOT
191   FORMAT('1','  NUMBER OF PARAMETERS (NCHAN) = ',I5,10X,
     $'NUMBER OF DATA TO READ (N) =',I5,10X,'PLOT OPTION (IPLOT) ='
     $,I5)
      IF(IPLOT .EQ. 3) CALL PRNTON
      IF (IPLOT.EQ.2) CALL STCCON(LABEL)
      READ(5,2) ((NAME(J,K), K= 1,8), J= 1, NCHAN)
      READ(5,2) (FMT2(J), J= 1,4)
      READ(5,2) (FMT3(J), J= 1,4)
      READ(5,FMT2) XMDAT
1     FORMAT(16I5)
2     FORMAT(8A10)
      WRITE(6,192) (FMT2(J),J=1,4),XMDAT
192   FORMAT('0','FORMAT TO READ MISSING DATA INDICATOR -'/' ',4A10
     $,10X,'MISSING DATA INDICATOR = ',E14.5)
      WRITE(6,193) (FMT3(J),J=1,4)
193   FORMAT('0FORMAT TO ECHO PRINT DATA -'/' ',4A10)
      WRITE(6,100)
100   FORMAT(1H1, 40X, 'ECHO PRINT OF INPUT DATA',//)
      CALL DATIN(NCHAN,N,XMDAT)
      DO 106 J = 1, 6
106   LCHAN(J) = N
C --  DOE/METRO WATER QUALITY TREND ANALYSIS PROGRAM AS MODIFIED
C --  12/81
C --  PROGRAM OPERATES ON A CHANNEL-OPTION CONCEPT, USER SPECIFIES
C --  ANALYSIS OPTION ALONG WITH INPUT AND OUTPUT CHANNELS AND
C --  ANY INPUT DATA NEEDED FOR SPECIFIC OPTIONS
C -- ICOMP(J) HOLDS DATA COMPUTATION OPTIONS
C -- IAR1 HOLDS THE INPUT ARRAY, IAR2 HOLDS THE OUTPUT ARRAY
C -- DATA COMPUTATION OPTIONS ARE
C --      1 -- TRANSFORMS  DATA (MUST READ IN TRANSFORMATION OPTION,
C --      1 = NATURAL LOG, 2 = POWER (READ IN POWER ON SAME CARD)
C --      2 -- REMOVE SEASONAL MEAN (MUST READ IN NUMBER OF DATA POINTS
C --      IN EACH SEASON, NUMBER OF DATA POINTS PER YEAR)
C --      3 -- DIFFERENCES DATA (READ IN NUMBER OF LAGS)
C --      4 -- DRAWS Q-Q PLOT
C --      5 -- PLOTS DATA (READ IN PLOT OPTION, 1 = LINEPRINTER, 2 =
C --      CALCOMP. IF CALCOMP, ADDITIONAL INPUT PARAMETERS REQ,D (SEE
C --      DOCUMENTATION))
C -- NPER IS NUMBER OF SEASONS/YR
C -- NYR IS NUMBER OF YEARS OF RECORD (NOT USED)
C -- IPER IS INDEX OF INITIAL SEASON
C -- IYR IS INITIAL YEAR
C --      6 -- PLACES DATA IN INPUT CHANNEL INTO OUTPUT CHANNEL
C --      7 -- COMPUTES CORRELATION, PARTIAL AUTOCORRELATION AND PLOTS
```

```
C --      (MUST READ IN MAXIMUM NUMBER OF LAGS)
C --      8 -- PLOTS CUSUM OF GIVEN CHANNEL (MUST READ IN NUMBER OF
C --      DATA POINTS FROM WHICH MEAN IS CALCULATED)
C --      9 -- IGNORES GIVEN DATA POINTS (READ IN SEQUENCE NUMBERS OF
C --      POINTS, UP TO 16)
C --      10 -- TAKES RESIDUALS FROM MOVING AVERAGE (MUST READ IN NUMBER
C --      OF DATA POINTS TO BE AVERAGED, CHANNEL FROM WHICH DATA IS AV-
C --      ERAGED
C --      11 -- CALCULATES MANN-WHITNEY"S OR SPEARMAN"S RHO TEST STAT-
C --      ISTIC ON DATA. READ IN TEST OPTION (1=MW, 2=SR), INITIAL AND
C --      FINAL DATA POINT OF FIRST DATA SEGMENT (COMPLETE RECORD FOR SR)
C --      AND INITIAL AND FINAL POINTS FOR SECOND DATA SEGMENT
C --      12 -- CALCULATES STEP HEIGHT OR LINEAR SLOPE HEIGHT VIA LEAST
C --      SQUARES. READ IN STEP OR LINEAR OPTION, PLOT OPTION (NONE, LINE
C --      PRINTER, OR CALCOMP. FOR CALCOMP, MUST READ IN NORMAL CAL-
C --      COMP PLOT PARAMETERS (SEE DOCUMENTATION). BASE LAG ONE CORRELA-
C --      TION COEFFICIENT, SAMPLING INTERVAL IN DAYS ALSO REQUIRED
C --      ILOOP = 1, START MULTIPLE LOOP, 0, SINGLE ITERATION ONLY,
C --      -1, CONTINUE MULTIPLE LOOP, -2, END MULTIPLE LOOP
C  TABLE OF CONTENTS  (HIRSCH PROGRAMS)
C
C  CDFN  -  THE STANDARD NORMAL CUMULATIVE DISTRIBUTION FUNCTION
C
C  FAC = OPT13  -  ESTIMATE THE FLOW-CONCENTRATION RELATIONSHIP AND
C  COMPUTE THE RESIDUALS
C
C  KEN = OPT14  -  THE MANN - KENDALL TEST FOR TREND
C
C   MOM4 = OPT17 -  COMPUTE THE MEAN, STANDARD DEVIATION, SKEWNESS COEFFICIENT
C          AND KURTOSIS COEFFICIENT (MULTIPLE ENTRY POINTS MOM2 AND MOM3)
C          CAN NOT HANDLE MISSING DATA.
C
C
C  PACKER - TAKES AN ARRAY OF MONTHLY DATA WITH POSSIBLE MISSING VALUES
C          AND PACKS IT INTO VECTORS OF Y(DATA) AND T(TIME IN MONTHS).
C          USED TO PREPARE DATA FOR PASSING TO REGRES.
C
C  REGSEA  - USED IN SEASONAL REGRESSION (CALLED BY SEAREG)
C
C  REGRES = OPT19 - STANDARD ALL PURPOSE LINEAR REGRESSION.
C           CAN BE USED AS A TREND TEST.
C           MISSING DATA ARE NOT ALLOWED.
C
C  SEAKEN = OPT15 - SEASONAL KENDALL TEST WITHOUT THE SLOPE ESTIMATOR.
C
C  SEAREG = OPT18 - SEASONAL REGRESSION TEST FOR TREND.
C
C  SEARS = OPT20 - MANN-WHITNEY-WILCOXON RANK SUM TEST, FOR GROUPED DATA
C          (GROUPS ARE MONTHS)
C
C  SKND = OPT16 - SEASONAL KENDALL TEST WITH SLOPE ESTIMATOR.
C
C
C  FOOTNOTE:             UNLESS OTHERWISE INDICATED ALL PROGRAMS CAN HANDLE
C                         MISSING DATA.  THE MISSING VALUE INDICATOR IS
C                         0.0
C -- XMDAT IS THE MISSING DATA CODE
      IFC = 0
```

```
            DO 1000 KJ = 1, NCHAN
            DO 21 J= 1,6
            DC 21 K= 1,200
21          Y(J,K) = 0.
           READ(5,4) (IAR1(J), IAR2(J), J= 1,16)
              READ(5,1) (ICOMP(J), J= 1,16)
4            FORMAT(16(2I2,1X))
           DO 11 J= 1,16
             IF(ICOMP(J) .EQ. 0) GO TO 12
11       JMAX = J
12       CONTINUE
            WRITE(6,35)  (NAME(KJ,J), J= 1,8)
35          FORMAT(/////,    10X, 8A10)
            WRITE(6,36) (ICOMP(J), J= 1,JMAX)
36          FORMAT(//, 10X, 'ARRAY OPTIONS ARE', 3X, 16I5)
             WRITE(6,37) (IAR1(J), IAR2(J), J= 1,JMAX)
37          FORMAT(//, 10X, 'CHANNEL OPTIONS ARE', 1X, 16(2I2, 1X))
            DO 45 J = 1,N
            Y(1,J) = X(KJ,J)
45         IF(Y(1,J) .EQ. XMDAT) Y(1,J) = 0.
              KSL = ILOOP = 0
            DO 50 JJ = 1, JMAX
         WRITE(6,848)
848      FORMAT('0',100('-'))
            IC = ICOMP(JJ)
            JAR1 = IAR1(JJ)
          JAR2=IAR2(JJ)
            GO TO (51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68
        *,69,70) , IC
51         READ(5,110) ITRANS, POW
         WRITE(6,810) ITRANS,POW
810      FORMAT('OOPTION 1, ITRANS = ',I10/11X,'POW = ',F10.4)
C --     ITRANS IS TRANSFORMATION OPTION, POW IS EXPONENT FOR ITRANS
C --     = 2
           LL = LCHAN(JAR1)
110         FORMAT(I10, F10.0)
         CALL OPT1(ITRANS,POW,LL,JAR1,JAR2)
           GO TO 50
52         READ(5,1) NGP, NYR ,IOPT
         WRITE(6,811)NGP,NYR,IOPT
811      FORMAT('OOPTION 2, NGP = ',I5/11X,'NYR = ',I5/11X,'IOPT = ',
        +I5)
C        IF IOPT = 0 NEWDATA = OLDDATA - SEAS MEAN + GRAND MEAN
C                = 1 NEWDATA = (OLDDATA - SEAS MEAN)/SEAS SD
           LL = LCHAN(JAR1)
C IF IOPT = 0 -- NGP IS THE NUMBER OF DATA POINTS GROUPED FOR SEASONAL MEANS,
C              -- NYR IS THE NUMBER OF DATA POINTS PER YEAR
C IF IOPT = 1 -- NGP IS THE NUMBER OF DATA POINTS PER SEASON
C              -- NYR = 0
         IF (IOPT.EQ.0) CALL OPT2(NGP,NYR,LL,JAR1,JAR2)
         IF (IOPT.EQ.1) CALL DSEAS(JAR1,JAR2,NGP,LL)
           GO TO 50
53         READ(5,1) NDIF
         WRITE(6,812) NDIF
812      FORMAT('OOPTION 3, NDIF = ',I5)
C --     NDIF IS NUMBER OF LAGS FOR DIFFERENCING
         CALL OPT3(NDIF,LL,JAR1,JAR2)
           GO TO 50
```

```
54        LL = LCHAN(JAR1)
          CALL QQPLOT(LL, JAR1)
          GO TO 50
55        LL = LCHAN(JAR1)
      CALL OPT5(LL,IPLOT,JAR1,ILOOP,JPOINTS,IFLAG,KSL)
      IF(IFLAG .EQ. 1) GO TO 62
      GO TO 50
56        LL = LCHAN(JAR1)
          DO 150 J= 1,LL
150       Y(JAR2,J) = Y(JAR1,J)
          LCHAN(JAR2) = LCHAN(JAR1)
           GO TO 50
57    LL = LCHAN(JAR1)
      READ(5,1) NLAG
      WRITE(6,813) NLAG
813   FORMAT('0OPTION 7,  NLAG = ',I5)
C --  NLAG IS NUMBER OF LAGS FOR AUTOCORRELATION AND PARTIAL AUTO-
C --  CORRELATION ANALYSIS
      CALL OPT7(NLAG,LL,JAR1,N,IPLOT)
        GO TO 50
58        LL = LCHAN(JAR1)
          READ(5,1) NDP
      WRITE(6,814) NDP
814   FORMAT('0OPTION 8,  NDP = ',I5)
C --  NDP IS ASSUMED INTERVENTION POINT FOR CUMULATIVE SUM PLOTS
      CALL OPT8(LL,JAR1,NDP)
          GO TO 50
59        READ(5,1) (N1(J), J= 1,16)
      WRITE(6,815) (N1(J),J=1,16)
815   FORMAT('0OPTION 9, INDEX NUMBERS OF DATA POINTS TO BE CENSORED-'
     +/' ',16I5)
C --  N1(J) IS INDEX NUMBER OF J TH SAMPLE TO BE CENSORED
          DO 180 J= 1,16
          LL = N1(J)
          IF(LL .EQ. 0) GO TO 50
180        Y(JAR1,LL) = 0.
           GO TO 50
60        READ(5,1) NAV, KCHAN
      WRITE(6,816) NAV,KCHAN
816   FORMAT('0OPTION 10,  NAV = ',I5,'   KCHAN = ',I5)
C --  NAV IS NUMBER OF POINTS IS MOVING AVERAGE, KCHAN IS INPUT
C --  DATA CHANNEL FOR MOVING AVERAGE COMPUTATION
          IF(KCHAN .EQ. 0) KCHAN = 1
      LL = LCHAN(KCHAN)
      CALL OPT10(NAV,KCHAN,LL,JAR1,JAR2)
          GO TO 50
61        READ(5,1) NTEST, IS1, IF1, IS2, IF2
      WRITE(6,817) NTEST,IS1,IF1,IS2,IF2
817   FORMAT('0OPTION 11,  NTEST = ',I5,'    IS1 = ',I5,'    IF1 = '
     +,I5,'   IS2 = ',I5,'   IS3 = ',I5)
C --  NTEST, IS1,IF1,IS2,IF2 ARE TEST INDEX NUMBER (MANN-WHITNEY
C --  OR SPEARMAN S RHO) AND INITIAL AND ENDING INDEX OF DATA
C --  SEGMENTS FOR TESTS (IS2,IF2 IGNORED FOR SPEARMAN S RHO)
      CALL OPT11(NTEST,IS1,IF1,IS2,IF2,JAR1,JAR2)
           GO TO 50
62        READ(5,250) KSL, KPL, IS1, IF1, IS2, IF2, ILOOP, RO, KGAP
      WRITE(6,818) KSL,KPL,IS1,IF1,IS2,IF2,ILOOP,RO,KGAP
818   FORMAT('0OPTION 12, KSL,KPL,IS1,IF1,IS2,IF2,ILOOP,RO,KGAP -'/
```

```
     +' ',7I5,F5.3,8I5)
C --  KSL,KPL,IS1,IF1,IS2,IF2,ILOOP,RO,KGAP ARE PLOT PARAMETERS,
C --  START AND END PARAMETERS, DAILY CORRELATION COEFFICIENT,
C --  AND AVERAGE SAMPLE INTERVAL FOR COMPUTATION OF REGRESSION
C --  BASED TRENDS
250      FORMAT(7I5, F5.0, 8I5)
      LL=LCHAN(JAR1)
      CALL OPT12(LL,KSL,KPL,IS1,IF1,IS2,IF2,ILOOP,RO,KGAP,JAR1)
      GO TO 50
63    LL=LCHAN(JAR1)
       IF (IFC .GE. 1) GOTO 634
        READ(5,1) NUNIT,IDEF
      FMT5(1)=10H(18X,I2,I2
      FMT5(2)=10H,I2,8F7.0)
      DO 633 IJ=3,8
633   FMT5(IJ)=10H
        IF (IDEF.EQ.1) READ(5,2)(FMT5(IJ),IJ=1,8)
      WRITE(6,819) NUNIT,(FMT5(IJ),IJ=1,8)
819   FORMAT('0OPTION 13,  READ FLOW DATA FROM UNIT ',I3,
     +' ACCORDING TO FORMAT '/' ',8A10)
       CALL FLOWIN(NUNIT,IDEF,FMT5,LL,JAR1)
      IFC = 1
C -- READ FLOWS ON UNIT NUNIT ACCORDING TO FORMAT FMT5
634   CALL FAC(LL,FIT,MODEL,JAR1,JAR2,XMDAT)
      GO TO 50
64    LL=LCHAN(JAR1)
      CALL KEN(LL,TAU,ALPHA,JAR1)
      GO TO 50
65    LL=LCHAN(JAR1)
      READ(5,1) NSEAS
      WRITE(6,820) IC,NSEAS
820   FORMAT('0OPTION ',I2,',  NSEAS = ',I5)
C -- NSEAS = NUMBER OF SEASONS(=DATA POINTS) PER CYCLE(IE YEAR)
      CALL SEAKEN(LL,TAU,ALPHA,NSEAS,JAR1)
      GO TO 50
66    LL=LCHAN(JAR1)
      READ(5,1)NSEAS
      WRITE(6,820)IC,NSEAS
C -- NSEAS = NUMBER OF SEASONS(=DATA POINTS) PER CYCLE(IE YEAR)
      CALL SKND(LL,TAU,ALPHA,SLOPE,NSEAS,JAR1)
      GO TO 50
67    LL=LCHAN(JAR1)
      DO 670 JI=1,LL
670   T(JI)=Y(JAR1,JI)
      CALL MOM4(T,LL,S)
      WRITE(6,666) JAR1,(S(I9),I9=1,4)
666   FORMAT('0DATA IN CHANNEL ',I2/'0     MEAN      ',
     *'    STD. DEV.         SKEW         KURTOSIS'/1X,4E14.5)
      GO TO 50
68    LL=LCHAN(JAR1)
      READ(5,1) NSEAS
      WRITE(6,820) IC,NSEAS
C -- NSEAS = NUMBER OF SEASONS(=DATA POINTS) PER CYCLE(IE YEAR)
      CALL SEAREG(LL,A,B,ALPHA,R,NSEAS,JAR1)
      GO TO 50
69    LL=LCHAN(JAR1)
      CALL PACKER(LL,NN,LENGTH,ISTART,JAR1,JAR2)
      LCHAN(JAR2)=NN
```

```
      CALL REGRES(NN,A,B,ALPHA,R,JAR2)
      WRITE(6,667) A,B,R,ALPHA
667   FORMAT('0 LINEAR REGRESSION -'/'  INTERCEPT = ',E14.6,
     '7X,'SLOPE = ',E14.6,7X,'ABS(R) = ',F7.5,7X
     *,'SIGNIF(R) (ASSUMING NORMAL ERRORS) =',F7.5)
      GO TO 50
70    READ(5,1) IS1,IS2,NX1,NX2,NSEAS
      WRITE(6,821) IS1,IS2,NX1,NX2,NSEAS
821   FORMAT('0OPTION 20,  IS1 , IS2 , NX1 , NX2 , NSEAS -'/' ',5I5)
      CALL SEARS(IS1,IS2,NX1,NX2,Z,ALPHA,NSEAS,JAR1)
C
C       SEASONAL RANK SUM TEST, SEE BRADLEY P 115-117
C        THE TWO PERIODS OF RECORD MUST START WITH THE SAME SEASON
C        MISSING DATA CODE XMIS MUST BE NONPOSITIVE
C        PERIODS OF RECORD COMPARED ARE INTERVALS IS1, IS1 + NX1
C        - 1, IS2, IS2 + NX2 - 1
C        ABS(NX1 - NX2) MUST BE EVEN MULTIPLE OF NSEAS
C
50         KSL = ILOOP = 0
1000       CONTINUE
          IF(IPLOT .GE. 2) CALL EXITPL
            END
      SUBROUTINE DATIN(NCHAN,N,XMDAT)
      COMMON/FLBLK/ FYR,FMO,FDAY
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),  NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)   , YR(15)  , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
      INTEGER YY(20),MO(20),DA(20),IMO(12),CD(260)
      INTEGER FYR(250),FMO(250),FDAY(250)
      REAL S1(20),XX(6,20),MDPT,FMT1(7),CARD(28),FMT2(7)
      LOGICAL DONE
      DATA IMO/32,30,32,31,32,31,32,32,31,32,31,32/
      DONE=.FALSE.
      READ(5,1) IUNIF,RINT,IOPT,IFILE
1     FORMAT(I5,F5.1,2I5)
      WRITE(6,191) IUNIF,RINT,IOPT,IFILE
191   FORMAT('0DATA READ OPTIONS - IUNIF = ',I5,5X,'RINT = ',F5.1,
     $5X,'IOPT = ',I5,5X,'IFILE = ',I5)
C
C--   IUNIF = 0    ANALYZE ALL DATA AS IS
C--         = 1    CONVERT DATA TO UNIFORM TIME SERIES WITH
C--                UNIFORM INTERVAL RINT
C--   RINT = 0     IF IUNIF=C
C--        > 0     SAMPLING INTERVAL IN MONTHS IE. .5,1,2
C--                MAX # INTERVALS ALLOWED IS 250
C--   IOPT = 0 CONVERT TO UNIFORM SERIES BY AVERAGING VALUES
C--          WITHIN THE INTERVAL
C--        = 1 TAKE VALUE CLOSEST TO CENTER OF INTERVAL
C
      READ(5,2) NVAR1,(FMT1(J),J=1,7)
2     FORMAT(I5,7A10)
      WRITE(6,192) NVAR1,(FMT1(J),J=1,7)
192   FORMAT(' ',20X,'NVAR1 = ',I5,5X,'FMT1 = ',7A10)
      IF (NVAR1.LT.NCHAN) READ(5,22)(FMT2(J),J=1,7)
22    FORMAT(8A10)
      IF (NVAR1.LT.NCHAN) WRITE(6,193) (FMT2(J),J=1,7)
```

```
193    FORMAT(' ',38X,'FMT2 = ',7A10)
C
C--     FMT1 READS YR,MO,DAY,VAR1,...,VAR6
C
       IF (IUNIF.EQ.0) GO TO 2000
       READ(IFILE,221) (CD(I),I=1,280)
221    FORMAT(80R1)
       DO 110 I=1,140
110    IF ((CD(I).LT.27 .OR. CD(I).GT.36) .AND. CD(I).NE.47) CD(I)=45
       ENCODE(140,221,CARD) (CD(I),I=1,140)
       DECODE(140,FMT1,CARD) YY(1),MO(1),DA(1),(XX(J,1),J=1,NVAR1)
       IF (NVAR1.GE.NCHAN) GO TO 112
       DO 111 I=141,280
111    IF ((CD(I).LT.27 .OR. CD(I).GT.36) .AND. CD(I).NE.47) CD(I)=45
       ENCODE(140,221,CARD(15)) (CD(I),I=141,280)
       DECODE(140,FMT2,CARD(15)) (XX(J,1),J=NVAR1+1,NCHAN)
112    K=1
       WRITE(6,FMT3) YY(K),MO(K),DA(K),(XX(J,1),J=1,NCHAN)
       S1(K)=YY(K)*100 + MO(K) + FLOAT(DA(K))/IMO(MO(K))
       CINT=YY(1)*100 + MO(1)
       IF (RINT.LT.1.0) CINT=CINT+(DA(1)/16)*.5
       DO 1000 I=1,250
       CINT=CINT+RINT
       TT1=CINT-INT(CINT)/100*100
       IF (TT1.GE.13.) CINT=CINT+88.
3      K=K+1
       IF (K.EQ.1) GO TO 4
       READ(IFILE,221,END=3000) (CD(L),L=1,280)
       IF (EOF(IFILE).NE.0) GO TO 3000
4      DO 210 L=1,140
210    IF ((CD(L).LT.27 .OR. CD(L).GT.36) .AND. CD(L).NE.47) CD(L)=45
       ENCODE(140,221,CARD) (CD(L),L=1,140)
       DECODE(140,FMT1,CARD) YY(K),MO(K),DA(K),(XX(J,K),J=1,NVAR1)
       IF (NVAR1.GE.NCHAN) GO TO 212
       DO 211 L=141,280
211    IF ((CD(L).LT.27 .OR. CD(L).GT.36) .AND. CD(L).NE.47) CD(L)=45
       ENCODE(140,221,CARD(15)) (CD(L),L=141,280)
        DECODE(140,FMT2,CARD(15)) (XX(J,K),J=NVAR1+1,NCHAN)
212    S1(K)=YY(K)*100 + MO(K) + FLOAT(DA(K))/IMO(MO(K))
       IF (K.GT.1) WRITE(6,FMT3) YY(K),MO(K),DA(K),(XX(J,K),J=1,NCHAN)
       IF (S1(K).LE.CINT) GO TO 3
       GO TO 5
3000   DONE=.TRUE.
       N=I
5      K=K-1
       IF (K.GT.0) GO TO 20
       DO 10 J=1,NCHAN
       FYR(I)=0
       FMO(I)=0
       FDAY(I)=0
10     X(J,I)=0.0
       GO TO 999
20     IF (IOPT.EQ.1) GO TO 40
       DO 30 J=1,NCHAN
       X(J,I)=0.0
       NNN=0
       DO 35 IJ=1,K
       IF (XX(J,IJ).EQ.XMDAT) GO TO 35
```

```
      NNN=NNN+1
      X(J,I)=X(J,I) + XX(J,IJ)
35    CONTINUE
      IF (NNN.EQ.0) GO TO 30
      X(J,I) = X(J,I)/NNN
30    CONTINUE
      GO TO 999
40    MDPT=CINT-RINT/2.
      TT1=MDPT-INT(MDPT)/100*100
      IF (TT1.LT.1 .OR. TT1.GT.90.) MDPT=MDPT-88
      RMIN=RINT*2.
      DO 50 IJ=1,K
      IF (ABS(S1(IJ)-MDPT).GE.RMIN) GO TO 50
      MINK=IJ
      RMIN=ABS(S1(IJ)-MDPT)
50    CONTINUE
      DO 60 J=1,NCHAN
60    X(J,I)=XX(J,MINK)
      FYR(I)=YY(MINK)
       FMO(I)=MO(MINK)
      FDAY(I)=DA(MINK)
999    K=0
       IF (DONE) RETURN
1000  CONTINUE
      WRITE(6,900) RINT
900   FORMAT('0USING AN INTERVAL OF',F5.2,' MONTH(S), DATA SPANS'/
     *' MORE THAN 250 INTERVALS - EXTRA DATA NOT USED IN ANALYSES')
      RETURN
2000  READ(IFILE,FMT1)(FYR(I),FMO(I),FDAY(I),(X(J,I),J=1,NCHAN),I=1,N)
      WRITE(6,FMT3) (FYR(I),FMO(I),FDAY(I),(X(J,I),J=1,NCHAN),I=1,N)
      RETURN
      END
      SUBROUTINE FLOWIN(NUNIT,IDEF,FMT5,LL,JAR1)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),  NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)   , YR(15)  , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
      COMMON /FLBLK/ FYR,FMO,FDAY
      COMMON/COM1/ Y(6,250),FLOW(250)
      INTEGER FYR(250),FMO(250),FDAY(250),DAY
      REAL FL(3),FMT5(8)
      WRITE(6,201)
201   FORMAT(' ECHO PRINT OF FLOW DATA')
      IF (IDEF.EQ.1) GO TO 100
      K=1
5     READ(NUNIT,FMT5,END=999) IYR,MO,MUL,(FL(J),J=1,8)
6     IF (FYR(K).NE.0) GO TO 7
      FLOW(K)=0
      WRITE(6,FMT3) FYR(K),FMO(K),FDAY(K),FLOW(K)
      K=K+1
      IF (K.GT.LL) RETURN
      GO TO 6
7     DO 20 I=1,8
      DAY=(MUL-1)*8 + I
      IF (IYR.NE.FYR(K).OR.MO.NE.FMO(K).OR.DAY.NE.FDAY(K)) GO TO 20
      FLOW(K)=FL(I)
      WRITE(6,FMT3) IYR,MO,DAY,FLOW(K)
```

```
      K=K+1
      IF (K.GT.LL) RETURN
20    CONTINUE
      GOTO 5
999   WRITE(6,222) K - 1
222   FORMAT(' NOTE - ONLY FOUND FLOWS FOR FIRST ',I3,' OBSERVATIONS',
     $'; REST OF FLOWS SET TO MISSING')
      DO 998 IJ=K,LL
998   FLOW(IJ)=0
      RETURN
100   K=1
10    READ(NUNIT,FMT5,END=999) IYR,MO,DAY,FLW
16    IF (FYR(K).NE.0) GOTO 17
      FLOW(K)=0
      WRITE(3,FMT3) FYR(K),FMO(K),FDAY(K),FLOW(K)
      K=K+1
      IF (K.GT.LL) RETURN
      GO TO 16
17    IF (IYR.NE.FYR(K).OR.MO.NE.FMO(K).OR.DAY.NE.FDAY(K)) GO TO 10
      FLOW(K)=FLW
      WRITE(6,FMT3) FLOW(K)
      K=K+1
      IF (K.GT.LL) RETURN
      GOTO 10
       END
      SUBROUTINE OPT1(ITRANS,POW,LL,JAR1,JAR2)
      COMMON/COM1/Y(6,250),FLOW(250)
C --  SUBROUTINE TO TRANSFORM DATA VIA LOGARITHMIC OR
C --  POWER FUNCTION
         GO TO (210,211), ITRANS
210      DO 212 J = 1,LL
         Y(JAR2,J) = Y(JAR1,J)
212      IF(Y(JAR1,J) .NE. 0.) Y(JAR2,J) = ALOG(Y(JAR1,J))
          RETURN
211      DO 213 J = 1,LL
213       Y(JAR2,J) = Y(JAR1,J)**POW
      RETURN
      END
       SUBROUTINE AUTCOR(L,RM,V,N)
       COMMON/COM4/R(401), RR(401), SC(401),DUD(401)
         COMMON/COM3/X(500)
C --  SUBROUTINE TO COMPUTE AUTOCORRELATION FUNCTION
       DO 1 J= 1,L
         IC1 = 0
       KK = N-J
       DUM = 0.
       DO 2 I= 1,KK
        IND1 = X(I)/(X(I) + 1.E-06) + 1.E-04
         IND2 = X(I+J)/(X(I+J)+1.E-06) + 1.E-04
           IC1 = IC1 + IND1*IND2
2       DUM = DUM + (X(I)-RM)*(X(I+J)-RM)  *IND1*IND2
         R(J) = 0.
         IF(IC1 .EQ. 0)GO TO 1
          R(J) = DUM/IC1/V
1        CONTINUE
       RETURN
        END
      SUBROUTINE OPT2(NGP,NYR,LL,JAR1,JAR2)
```

```
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
C --  SUBROUTINE TO DESEASONALIZE DATA BY REMOVING SEASONAL MEAN
         NN = NYR/NGP
       NNN=LL/NYR+1
         NDATT = 0
          DO 120 J= 1, NN
         NSTART = (J-1)*NGP
         SUM = 0.
       NDAT=0
         DO 121 K = 1, NNN
         DO 121 L = 1, NGP
         KK = NSTART + (K-1)*NYR + L
         IF(KK .GT.LL) GO TO 122
         XXX = ABS(Y(JAR1,KK))/(ABS(Y(JAR1,KK)) + 1.E-06)  + 1.E-04
           IND = XXX
         SUM = SUM + Y(JAR1,KK)*IND
121      NDAT = NDAT + IND
122      XBAR = SUM/NDAT
         XHOLD(J) = XBAR
           XT(J) = NDAT
         NDATT = NDATT  + NDAT
         DO 123 K = 1, NNN
         DO 123 L= 1,NGP
        KK = NSTART + (K-1)*NYR + L
         IF(KK .GT.LL) GO TO 120
         Y(JAR2,KK) = Y(JAR1,KK)
        IF(Y(JAR1,KK) .NE. 0.)
     $   Y(JAR2,KK) = Y(JAR1,KK) - XBAR + 1.E-06
123      CONTINUE
120      CONTINUE
          XBAR = 0.
         DO 1200 J = 1, NN
1200      XBAR = XBAR + XT(J)/NDATT*XHOLD(J)
         DO 1201 J= 1, LL
1201      IF(Y(JAR2,J) .NE. 0.) Y(JAR2,J) = Y(JAR2,J) + XBAR - 1.E-06
      RETURN
      END
      SUBROUTINE DSEAS(JAR1,JAR2,NSEAS,N)
C      DESEASONALIZES THE DATA SET OF N VALUES OF SEASON LENGTH NSEAS
C      SUBTRACTS SEASONAL MEAN AND DIVIDES BY SEASONAL STANDARD DEVIATION
C        ACCEPTS MISSING VALUES, MISSING DATA CODE XMIS MUST BE
C       NONPOSITIVE
      REAL S(2)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      DO 10 IM=1,NSEAS
      K=0
      DO 5 I=IM,N,NSEAS
      IF(Y(JAR1,I).EQ.0.0) GO TO 5
      K=K+1
      XT(K) = Y(JAR1,I)
    5 CONTINUE
      CALL MOM2(XT,K,S)
      AVE = S(1)
      SD = S(2)
      IF(K.LE.1) SD = 1.0
      IF(SD.LE.0.0) SD = 1.0
```

```
      DO 15 I = IM,N,NSEAS
      XX = Y(JAR1,I)
      Y(JAR2,I) = (XX - AVE)/SD + 1.E-6
      IF(XX.EQ.0.0) Y(JAR2,I)=0.0
   15 CONTINUE
   10 CONTINUE
      RETURN
      END
      SUBROUTINE OPT3(NDIF,LL,JAR1,JAR2)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)     , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)     , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
C --  SUBROUTINE TO DIFFERENCE DATA
         LL = LCHAN(JAR1)
       NM = LL- NDIF
         DO 130 J = 1, NM
         Y(JAR2,J) = 0.
         IF(Y(JAR1,J+NDIF) .NE. 0. .AND. Y(JAR1,J) .NE. 0.)
     $   Y(JAR2,J) = Y(JAR1,J+NDIF) - Y(JAR1,J)
  130    CONTINUE
         LCHAN(JAR2) = LCHAN(JAR1)- NDIF
      RETURN
      END
      SUBROUTINE OPT5(LL,IPLOT,JAR1,ILOOP,JPOINTS,IFLAG,KSL)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/COM5/T(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)     , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)     , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
      REAL TDUM(2), XDUM(2)
C --  SUBROUTINE TO PLOT DATA
      IFLAG = 0
         IF(IPLOT .EQ. 1) GO TO 555
        IF(ILOOP .LT. 0) GO TO 179
         READ(5,1) NBP
  555     IF(ILOOP .LT. 0) GO TO 271
  700    DO 140 J= 1, LL
         T(J) = J
  140     XHOLD(J) = Y(JAR1,J)
          CALL QKRSRT(LL)
         XAR(1) = LL
      XAR(2)=0
      YAR(1)=XHOLD(LL)
      YAR(2)=XHOLD(1)
         DO 142 J= 1, LL
  142    XHOLD(J) = Y(JAR1,J)
         IF(IPLOT .EQ. 1) GO TO 143
          IF(NBP .NE. 0) GO TO 147
         READ(5,1) NPER,  IPER , IYR
         READ(5,201) XMIN,XMAX,YMIN,YMAX
         READ(5,201) XLSZ1, XLSZ2, XLSZ3
      WRITE(6,601) NPER,IPER,IYR,XMIN,XMAX,YMIN,YMAX,XLSZ1,XLSZ2,XLSZ3
```

```
801    FORMAT('0OPTION 5 (MAY BE CALLED FROM OPTION 12) INPUT PARAMETERS'
      +/' NPER = ',I5,'   IPER = ',I5,'   IYR = ',I5/' XMIN = ',F10.3,
      +'     XMAX = ',F10.3,'   YMIN = ',F10.3,'   YMAX = ',F10.3/
      +' XLSZ1 = ',F10.3,'    XLSZ2 = ',F10.3,'    XLSZ3 = ',F10.3)
1      FORMAT(16I5)
2      FORMAT(8A10)
201       FORMAT(8F10.0)
          READ(5,2) (TEXTB(J), J=1,8)
147       READ(5,2) (TEXTL(J), J=1,8)
            READ(5,2) (XTIT(J), J= 1,8)
           CALL STS2OB(XMIN,XMAX,YMIN,YMAX)
       CALL STSYMB(11)
          GY(1) = YAR(1)
        GY(2) = YAR(2)
        GY(3) = 10
          MAX = (LL-1)/NPER + 1
           XPLT = MAX*NPER
           CALL STNDIV(MAX,1)
           CALL STSUBJ(0.,XPLT,0.,GY(1))
          CALL FABLIY(GY)
           CALL AXLILI
         CALL STCHSZ(XLSZ1)
            CALL STNDEC(0)
         CALL NODLIB
         CALL STNDEC(2)
        CALL NODLIL
        XINT = NPER*(XMAX-XMIN)/XPLT
         XI = (NPER/2+1 - IPER)*XINT/NPER - XINT/NPER/2.
           IP = 0
          IF(XI .GT. 0.) GO TO 243
          IP = 1
          XI = XI + XINT
        IYR =IYR+1
243     DO 144 J= 1,15
144       YR(J) = IYR+ J - 1
          NMAX = 10*MAX
          IF(NMAX .LT. 150) GO TO 240
          MMAX = NMAX-150
         MMAX1 = MMAX/10
          NMAX = 150
          DO 241 J= 1, MMAX1
241       YR1(J) = YR(15) + J
        ENCODE(50,145,YYR) YR1
          DO 242 J= 1, MMAX1
242       XYR(J+15) = YYR(J)
240      ENCODE(150,145,XYR) YR
145       FORMAT(15(3H    , F4.0, 3H     ))
            XSTART = XMIN + XI - 4.*XLSZ2
           IYR = IYR - IP
           CALL STCHSZ(XLSZ2)
           YSTART = YMIN - 4.*XLSZ1
          MMAX = MAX-1
           CALL STNCHR(10)
           DO 146 J= 1, MMAX + 1
          CALL OBLNST(XSTART, YSTART)
          TEXT = XYR(J)
          CALL TITLEG(TEXT)
146        XSTART = XSTART + XINT
```

```
         CALL STNCHR(80)
        CALL TITLEL(TEXTL)
          XSTART = XMIN + (XMAX-XMIN)/2. - 25.*XLSZ3
        YSTART = YMIN - 4.*XLSZ1 - 4.*XLSZ2
        CALL OBLNST(XSTART,YSTART)
        CALL TITLEG(TEXTB)
        YSTART = YMAX
        CALL OBLNST(XSTART,YSTART)
        CALL STCHSZ(XLSZ3)
          CALL TITLEG(XTIT)
       CALL STTXTR(1)
      JK=0
      DO 900 JI=1,LL
      IF (XHOLD(JI).EQ.0.0) GO TO 910
      JK=JK+1
      XHOLD(JK)=XHOLD(JI)
      T(JK)=T(JI)
      GO TO 900
910   IF (JK.EQ.0) GO TO 900
      CALL STNPTS(JK)
      CALL SLLILI(T,XHOLD)
      KJ = 2
      IF(JK .EQ. 1) KJ = 1
      CALL STNPTS(KJ)
      TDUM(1) = T(1)
      TDUM(2) = T(JK)
      XDUM(1) = XHOLD(1)
      XDUM(2) = XHOLD(JK)
      CALL PSLILI(TDUM,XDUM)
      JK=0
900   CONTINUE
      IF (JK.EQ.0) GO TO 179
      CALL STNPTS(JK)
      CALL SLLILI(T,XHOLD)
      KJ = 2
      IF(JK .EQ. 1) KJ = 1
      CALL STNPTS(KJ)
      TDUM(1) = T(1)
      TDUM(2) = T(JK)
      XDUM(1) = XHOLD(1)
      XDUM(2) = XHOLD(JK)
      CALL PSLIL1(TDUM,XDUM)
179    IF (KSL.EQ.0) GO TO 554
        CALL STTXTR(2)
      CALL STNPTS(JPOINTS)
      CALL SLLILI(T1,XJ1)
        IF(IABS(ILOOP) .EQ. 1) IFLAG = 1
554      CALL ADVANC(999.,999.)
        RETURN
143      IF(ILOOP .LT. 0) GO TO 271
        WRITE(6,141) JAK1
141      FORMAT(1H1, 40X, 'PLOT OF DATA IN CHANNEL', I5, //)
        CALL PLOTA(XAR,2,YAR,2)
        CALL PLOTB(D,D,D,D)
        CALL PLOT3(1H*, T, XHOLD,LL)
        IF(KSL .EQ. 0) GO TO 273
271      CALL PLOT3(1H+, T1, XJ1, LL)
        IF(IABS(ILOOP) .EQ. 1) GO TO 62
```

```
      GO TO 273
62    IFLAG = 1
      RETURN
273      CALL PLOT4(0,0)
      RETURN
      END
      SUBROUTINE OPT7(NLAG,LL,JAR1,N,IPLOT)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM5/T(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)    , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
C --  SUBROUTINE TO COMPUTE AUTOCORRELATION AND PARTIAL AUTO-
C --  CORRELATION FUNCTIONS
          DO 160 J= 1,LL
160       XHOLD(J) = Y(JAR1,J)
          SUM = 0.
        JSUM=0
         L = JAR1
         IF(L .EQ. 0) L = 1
          DO 161 J = 1, N
         IF(Y(L,J) .EQ. 0.) GO TO 161
          SUM = SUM + Y(L,J)
          JSUM = JSUM + 1
161        CONTINUE
          XBAR = SUM/JSUM
         CALL PCOR(NLAG, LL, 1, XBAR,IPLOT)
      RETURN
      END
      SUBROUTINE OPT8(LL,JAR1,NDP)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/COM5/T(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)    , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
C --  SUBROUTINE TO COMPUTE AND PLOT CUMULATIVE SUM FUNCTION
      SUM = 0.
      JSUM = 0
         DO 170 J = 1, NDP
          IF(Y(JAR1,J) .EQ. 0) GO TO 170
         JSUM = JSUM + 1
          SUM = SUM + Y(JAR1,J)
170      CONTINUE
         XBAR = SUM/JSUM
         SUM = 0.
        JSUM=0
          DO 171 J = 1,LL
         XHOLD(J) = 0.
         IF(Y(JAR1,J) .EQ. 0.) GO TO 171
         SUM = SUM + Y(JAR1,J)
          JSUM = JSUM + 1
          XHOLD(J) = SUM-XBAR*JSUM
```

```
171     CONTINUE
        XAR(1) = LL
      XAR(2)=1
         DO 172 J = 1,LL
172      T(J) = XHOLD(J)
        CALL QKRSRT(LL)
        YAR(1) = XHOLD(LL)
         YAR(2) = XHOLD(1)
       DO 173 J = 1,LL
        XHOLD(J) = T(J)
173      T(J) = J
        NNDP = NDP + 1
        WRITE(6,174) JAR1, NNDP
174     FORMAT(1H1, 20X, 'CUSUM PLOT OF DATA IN CHANNEL', I3, ' WITH IN
     *TERVENTION AVERAGE AT DATA POINT NUMBER', I3, //)
       CALL PLOTA(XAR,2,YAR,2)
        CALL PLOTB(D,D,D,D)
        CALL PLOT3(1H*, T, XHOLD, LL)
         CALL PLOT4(0,0)
      RETURN
      END
      SUBROUTINE OPT10(NAV,KCHAN,LL,JAR1,JAR2)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)     , FMT3(4)
     $,XAR(2), YAR(2)  ,N1(16)    , YR(15)   , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(8), XTIT(8)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/COM5/T(250)
C --  SUBROUTINE TO COMPUTE RESIDUALS FROM MOVING AVERAGE
      LLL = LL - NAV
          DO 191 J = 1, LLL
        JJJ = J + NAV/2
        XHOLD(JJJ) = 0.
       JSUM=0
        DO 192 K = 1, NAV
        IF(Y(KCHAN, J+K-1) .EQ. 0.) GO TO 192
       XHOLD(JJJ) = XHOLD(JJJ) + Y(KCHAN, J+K-1)
        JSUM = JSUM + 1
192     CONTINUE
        IF(XHOLD(JJJ) .NE. 0.) XHOLD(JJJ) = XHOLD(JJJ)/JSUM
191      IF(XHOLD(JJJ) .EQ. 0.) XHOLD(JJJ) = XHOLD(JJJ-1)
        JJ1 = NAV/2
       DO 193 J = 1, JJ1
193     XHOLD(J) = XHOLD(JJ1 + 1)
        JJ2 = LLL + NAV/2 + 1
        DO 194 J = JJ2, LL
194    XHOLD(J) = XHOLD(JJ2-1)
        LL = LCHAN(JAR1)
        DO 195 J= 1,LL
       Y(JAR2,J) = 0.
195     IF(Y(JAR1,J) .NE. 0.) Y(JAR2,J) = Y(JAR1,J) - XHOLD(J)
      RETURN
      END
      SUBROUTINE OPT11(NTEST,IS1,IF1,IS2,IF2,JAR1,JAR2)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
```

```
      COMMON/COM5/T(250)
C --  SUBROUTINE TO COMPUTE MANN-WHITNEY S OR SPEARMAN S RHO
C --  TEST STATISTIC
      GO TO (220,221), NTEST
220   M1 = IF1 - IS1 + 1
      DO 222 J = 1, M1
222   Y(JAR2,J) = Y(JAR1, IS1+J-1)
      N2 = IF2 - IS2 + 1
      N1P1 = M1 + 1
      NNN=M1+N2
      DO 223 J = N1P1, NNN
223   Y(JAR2,J) = Y(JAR1, J-N1P1 + IS2)
      ICC = 0
      DO 224 J= 1, M1
      IF(Y(JAR2,J) .EQ. 0.) GO TO 224
      ICC = ICC + 1
      XHOLD(ICC)=Y(JAR2,J)
224   CONTINUE
      M1 = ICC
      DO 225 J = N1P1, NNN
      IF(Y(JAR2,J) .EQ. 0.) GO TO 225
      ICC = ICC + 1
      XHOLD(ICC)=Y(JAR2,J)
225   CONTINUE
      NNN = ICC
      CALL MNWHIT(NNN,M1,TSTAT,W,WP)
      WRITE(6,226) NNN, M1, TSTAT, IS1, IF1, IS2, IF2
226   FORMAT(//, 20X, 'MANN-WHITNEY"S TEST STATISTIC FOR DATA WITH N
     $= ', I4, ', N1 = ', I4, ', IS', F7.0, /, 20X, 'INITIAL AND FINAL P
     $OINTS IN FIRST AND SECOND DATA SEGMENTS ARE', I4, ',', I4, ',', I4
     $,',', I4, ',', ' RESPECTIVELY')
      RETURN
221   M1 = IF1-IS1+1
      DO 230 J= 1, M1
230   Y(JAR2,J) = Y(JAR1,IS1+J-1)
      ICC = 0
      DO 231 J= 1, M1
      IF(Y(JAR2,J) .EQ. 0.) GO TO 231
      ICC = ICC + 1
      XHOLD(ICC)=Y(JAR2,J)
      GO TO 231
231   CONTINUE
      NNN = ICC
      CALL SPEARRO(NNN, TSTAT)
      WRITE(6,232) NNN, TSTAT, IS1, IF1
232   FORMAT(//, 20X, 'SPEARMAN"S RHO TEST STATISTIC FOR DATA WITH N
     $= ', I5, ' IS', F6.3,/, 20X, 'INITIAL AND FINAL DATA POINTS ARE',
     $I4, ',', I4, ', RESPECTIVELY',//)
      RETURN
      END
      SUBROUTINE OPT12(LL,KSL,KPL,IS1,IF1,IS2,IF2,ILOOP,RO,KGAP,
     $JAR1)
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM5/T(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/BLOCK/ T1(250), XJ1(250),LCHAN(6)
     $, IAR2(16),    NAME(6,8)
     $, IAR1(16), X(6,250), ICOMP(16)    , FMT3(4)
```

```
     $,XAR(2), YAR(2)  ,N1(16)   , YR(15)  , YYR(5), YR1(5)
     $,GY(3), XYR(20), TEXTB(8), TEXTL(6), XTIT(6)
C --  SUBROUTINE TO FIT AND PLOT LEAST SQUARES STEP OR LINEAR
C --  TREND TO DATA
        XRAT = (1. + RO**KGAP)/(1.-RO**KGAP)
        GO TO (251, 252), KSL
251     SUM1 = SUM2 = 0.
       SUMV1 = SUMV2 = 0.
        LC1 = LC2 = 0
      DO 257 J = IS1, IF1
        LC = ABS(Y(JAR1,J))/(ABS(Y(JAR1,J))+ 1.E-06) + 1.E-04
        SUMV1 = SUMV1 + Y(JAR1,J)*Y(JAR1,J)
       SUM1 = SUM1 + Y(JAR1,J)
257    LC1 = LC1 + LC
         XBAR1 = SUM1/LC1
        DO 253 J= IS2, IF2
        LC = ABS(Y(JAR1,J))/(ABS(Y(JAR1,J))+ 1.E-06) + 1.E-04
        SUM2 = SUM2 + Y(JAR1,J)
       SUMV2 = SUMV2 + Y(JAR1,J)*Y(JAR1,J)
253      LC2 = LC2  + LC
         XBAR2 = SUM2/LC2
        XJUMP = XBAR2 - XBAR1
        SSQ1 = SUMV1/LC1 - XBAR1*XBAR1
         SSQ2 = SUMV2/LC2 - XBAR2*XBAR2
        XVAR = (SSQ1/LC1 + SSQ2/LC2)*XRAT
        XSD = SQRT(XVAR)
         WRITE(6,254) IS1, IF1, IS2, IF2, LC1, LC2, XJUMP, XSD
254     FORMAT(//, 20X, 'ESTIMATED STEP TREND MAGNITUDE FOR START AND E
     $ND POINTS', I5, ',', I5, ',', I5, ',',' AND', I5, ',',' WITH NUMBE
     $R OF DATA', /, 20X, I5,' AND', I5, ', IS', F10.3, ' WITH STANDARD
     $DEVIATION', F10.2, //)
        IPLOT = KPL
         IF(IPLOT .EQ. 0) RETURN
       DO 255 J= IS1, IF1
         T1(J-IS1 + 1) = J
255     XJ1(J-IS1 + 1) = XBAR1
       JSTAG = IF1-IS1 + 1
       DO 256 J= IS2, IF2
         T1(J-IS2 + 1 + JSTAG) = J
256     XJ1(J-IS2+ 1 + JSTAG) = XBAR2
        JPOINTS = IF1-IS1 + 1 + IF2-IS2 + 1
        CALL OPT5(LL,IPLOT,JAR1,ILOOP,JPOINTS,IFLAG,KSL)
      RETURN
252     SUM1 = SUM2 = SUM3 = SUM4 = 0.
        LC1 = 0
       DO 260 J= IS1, IF1
        LC =ABS(Y(JAR1,J))/(ABS(Y(JAR1,J))+ 1.E-06) + 1.E-04
       LC1 = LC1 + LC
        SUM1 = SUM1 + Y(JAR1,J)
        SUM2 = SUM2 + LC*J
        SUM3 = SUM3 + Y(JAR1,J)*J
260       SUM4 = SUM4 + LC*J*J
        BETA = (SUM1*SUM2 - LC1*SUM3)/(SUM2*SUM2 - LC1*SUM4)
        ALPHA = 1./LC1*(SUM1-BETA*SUM2)
        SUMV = 0.
        SUMX1 = SUMX2 = 0.
         DO 261 J= IS1, IF1
        LC = ABS(Y(JAR1,J))/(ABS(Y(JAR1,J)) + 1.E-06) + 1.E-04
```

```
          SUMX1 = SUMX1 + J
           SUMX2 = SUMX2 + J*J
           UX = (ALPHA + BETA*J - Y(JAR1,J))*LC
261        SUMV = SUMV + UX*UX
            SQ = SUMV/(LC1-2)
           VARB = SQ/(SUMX2-SUMX1*SUMX1/(IF1-IS1+1)/(IF1-IS1+1))
             SDB = SQRT(VARB)*(IF1-IS1)
            XJUMP = BETA*(IF1-IS1)
            WRITE(6,265) IS1, IF1, LC1, XJUMP, SDB
265        FORMAT(//, 20X, 'ESTIMATED LINEAR TREND MAGNITUDE FOR START AND
     $ END POINTS', I5, ',', I5, ' WITH NUMBER OF DATA', I5,  /, 20X,
     $'IS', F10.2, ' WITH STANDARD DEVIATION', F10.3, //)
           IPLOT = KPL
           IF(IPLOT .EQ. 0) RETURN
             DO 262 J= IS1, IF1
              T1(J-IS1+1) = J
262         XJ1(J-IS1+1) = ALPHA + BETA*J
           JPOINTS = IF1-IS1 + 1
       CALL OPT5(LL,IPLOT,JAR1,ILOOP,JPOINTS,IFLAG,KSL)
       RETURN
       END
          SUBROUTINE CPLOT(L)
        COMMON/COM4/R(401), RR(401), X(401),DUD(401)
C --   NPS PLOT SETUP AUXILIARY SUBROUTINE
          XL = L
           CALL STS2OB(.5,6.5,.5,3.5)
          CALL STSUBJ(0.,XL,-1.,1.)
        DO 1 J = 1,L
        X(J) = J-1
           JJ = L-J + 1
           R(JJ + 1) = R(JJ)
1         RR(JJ+1) =RR(JJ)
           R(1) = RR(1) = 1.
           LL = L-1 + 2
           X(LL) = LL-1
          CALL STNDEC(2)
          CALL STNPTS(LL)
        DO 10 J = 1,2
           CALL STNDIV(1,2)
           CALL GDLILI
          CALL STNDIV(10,10)
          CALL AXLILI
          CALL NODLIB
          CALL NODLIL
          IF(J .EQ. 2) GO TO 11
         CALL SLLILI(X,R)
         CALL ADVANC(999.,999.)
          GO TO 10
11          CALL SLLILI(X,RR)
10           CONTINUE
            CALL EXITPL
          RETURN
          END
          SUBROUTINE PCOR(L,N,INDIC, XXBAR,NPLOT)
         COMMON/COM4/R(401), RR(401), SC(401),DUD(401)
           COMMON/COM3/X(250)  , DUM(250)
          DIMENSION IMAGE(700), RJ(100)
C --    SUBROUTINE TO COMPUTE AUTOCORRELATIONS AND PARTIAL AUTO-
```

```
C --   CORRELATIONS
         SUM1 = SUM2 = 0.
           IC = 0
        DO 1 J= 1,N
        IND = X(J)/(X(J) + 1.E-06) + 1.E-04
          IC = IC + IND
        SUM1 = SUM1 + X(J)*IND
1       SUM2 = SUM2 + X(J)*X(J)  *IND
         XBAR = SUM1/IC
        VAR = SUM2/IC  -XBAR*XBAR
         CALL AUTCOR(L,XBAR,VAR,N)
        RR(1) = SC(1) = R(1)
        DO 12 K= 2,L
        KK = K-1
        SUM1 = SUM2 = 0.
        DO 8 J= 1,KK
        SUM1 = SUM1 + SC(J)*R(K-J)
8       SUM2 = SUM2 + SC(J)*R(J)
        RR(K) = (R(K)-SUM1)/(1.-SUM2)
        DO 9 J= 1,KK
9       DUD(J) = SC(J)-RR(K)*SC(K-J)
        DO 10 J= 1,KK
10       SC(J) = DUD(J)
12       SC(K) = RR(K)
         RL = L
        IF(INDIC .NE. 1) RETURN
        WRITE(6,20)
20       FORMAT(1H1, 40X, 'PLOT OF AUTOCORRELATION FUNCTION OF INPUT DATA
     $')
        DO 2 J= 1,L
2        RJ(J) = J
         CALL PLOT2(IMAGE,RL,0.,1.,-1.)
         CALL PLOT3(1H*, RJ,R,L)
         RX = 0.
        RY=1.
         CALL PLOT3(1H*, RX,RY,1)
        CALL PLOT4(0,0)
         WRITE(6,3)
3       FORMAT(1H1, 'CORRELATIONS ARE', //, 25X, 'LAG', 7X, 'COR',///
     $/)
        WRITE(6,4) (J, R (J), J = 1,L)
4        FORMAT(18X, I10, F10.3)
          SDD = SQRT(VAR)
           CVV = SDD/XXBAR
          WRITE(6,706)XXBAR, SDD    , CVV
706       FORMAT(///, 40X, 'SUMMARY STATISTICS ARE         ', //,
     $ 46X, 'MEAN', 13X, 'STD DEV', 18X, 'CV', //, 30X, 2E20.3, F20.3)
          WRITE(6,21)
21       FORMAT(1H1, 40X, 'PLOT OF PARTIAL AUTOCORRELATION FUNCTION OF IN
     $PUT DATA')
         CALL PLOT2(IMAGE,RL,0.,1.,-1.)
         CALL PLOT3(1H*, RJ,RR,L)
         CALL PLOT3(1H*, RX,RY,1)
         CALL PLOT4(0,0)
          WRITE(6,5)
5         FORMAT(1H1, 'PARTIAL CORRELATIONS ARE',//, 25X, 'LAG', 5X,
     $'P COR', ////)
          WRITE(6,4) (J, RR(J), J= 1,L)
```

```
          IF(NPLOT .EQ. 1) CALL CPLOT(L)
        RETURN
         END
          SUBROUTINE QQPLOT(LL,JAR1)
          COMMON/COM3/XHOLD(250)  ,XXP(250)
          COMMON/COM5/XP(250)
          COMMON/COM1/Y(6,250),FLOW(250)
          COMMON/COM2/IMAGE(600)
       DIMENSION XAR(2),YAR(2)
C --   SUBROUTINE TO EXECUTE Q-Q PLOTS
          JJ = 0
          DO 1 J= 1,LL
          IF(Y(JAR1,J) .EQ. 0.) GO TO 1
          JJ = JJ + 1
          XHOLD(JJ) = Y(JAR1,J)
1          CONTINUE
          DO 81 I= 1,JJ
          PP = (I-.5)/JJ
        IF = PP/.5 + 1
         IFF = (IF-1)*2 - 1
         GO TO (82,83), IF
82       TT = SQRT(ALOG(1./PP/PP))
         GO TO 84
83        TT = SQRT(ALOG(1./(1.-PP)/(1.-PP)))
84      XP(I) =          IFF*(TT-(2.30753 + .27061*TT)/(1. + .99229*TT +
      $ .04481*TT*TT))
81     CONTINUE
          CALL QKRSRT(JJ)
        XAR(1) = 3.
        XAR(2)=-3.
          YAR(1) = XHOLD(JJ)
          YAR(2)=XHOLD(1)
         CALL PLOTA(XAR,2,YAR,2)
         CALL PLOTB(0,0,0,0)
          WRITE(6,2) JAR1
2          FORMAT(1H1, 40X, 'Q-Q PLOT OF DATA IN CHANNEL', I3, ' AGAINST
      $A NORMAL DISTRIBUTION',/)
            CALL PLOT3(1H*, XP, XHOLD,JJ)
         CALL PLOT4(0,0)
          RETURN
          END
        SUBROUTINE QKRSRT(JJ)
          COMMON/COM3/NA(250), IA(250)
        DIMENSION NUT(20), NLT(20)
       LOGICAL LE2,GE2
        REAL NA, NT, NX
       J=JJ
        DO 99 I= 1,J
99       IA(I) = I
       I=1
       M=1
    10 I1=I+1
       IF(J.LE.I1) GO TO 90
       NP=(J+I)/2
       NT=NA(NP)
        IT = IA(NP)
       NA(NP)=NA(I)
         IA(NP) = IA(I)
```

```
      NQ = J
      K=I
   15 K=K+1
      IF(K.GT.NQ) GO TO 50
      IF(NA(K).LE.NT) GO TO 15
      NQ=NQ+1
   20 NQ=NQ-1
      IF(NQ.LT.K) GO TO 30
      IF(NA(NQ).GE.NT) GO TO 20
      NX=NA(K)
      NA(K) = NA(NQ)
      NA(NQ)=NX
       IX = IA(K)
       IA(K) = IA(NQ)
       IA(NQ) = IX
      NQ=NQ-1
      GO TO 15
   30 NQ=K-1
   50 NA(I)=NA(NQ)
      NA(NQ)=NT
        IA(I) = IA(NQ)
        IA(NQ) = IT
      IF(2*NQ-I-J) 70,70,60
   60 NLT(M)=I
      NUT(M)=NQ-1
      I=NQ+1
      GO TO 80
   70 NLT(M)=NQ+1
      NUT(M)=J
      J=NQ-1
   80 M=M+1
      GO TO 10
   90 IF(I.GE.J) GO TO 100
      IF(NA(I).LE.NA(J)) GO TO 100
      NX=NA(I)
      NA(I)=NA(J)
      NA(J)=NX
       IX = IA(I)
        IA(I) = IA(J)
        IA(J) = IX
  100 M=M-1
       IF(M .EQ. 0) RETURN
      I=NLT(M)
      J=NUT(M)
      GO TO 10
      END
       SUBROUTINE PDQSRT(JJ)
      COMMON /COM4/ NA(1604)
       DIMENSION NUT(20), NLT(20)
      LOGICAL LE2,GE2
       REAL NA, NT, NX
      J=JJ
      I=1
      M=1
   10 I1=I+1
      IF(J.LE.I1) GO TO 90
      NP=(J+I)/2
      NT=NA(NP)
```

```
      NA(NP)=NA(I)
      NQ=J
      K=I
   15 K=K+1
      IF(K.GT.NQ) GO TO 50
      IF(NA(K).LE.NT) GO TO 15
      NQ=NQ+1
   20 NQ=NQ-1
      IF(NQ.LT.K) GO TO 30
      IF(NA(NQ).GE.NT) GO TO 20
      NX=NA(K)
      NA(K) = NA(NQ)
      NA(NQ)=NX
      NQ=NQ-1
      GO TO 15
   30 NQ=K-1
   50 NA(I)=NA(NQ)
      NA(NQ)=NT
      IF(2*NQ-I-J) 70,70,60
   60 NLT(M)=I
      NUT(M)=NQ-1
      I=NQ+1
      GO TO 80
   70 NLT(M)=NQ+1
      NUT(M)=J
      J=NQ-1
   80 M=M+1
      GO TO 10
   90 IF(I.GE.J) GO TO 100
      IF(NA(I).LE.NA(J)) GO TO 100
      NX=NA(I)
      NA(I)=NA(J)
      NA(J)=NX
  100 M=M-1
       IF(M .EQ. 0) RETURN
      I=NLT(M)
      J=NUT(M)
      GO TO 10
      END
        SUBROUTINE SPEARRO(L,SUM)
        COMMON/COM3/Y(250), NR(250)
C --  SUBROUTINE TO COMPUTE SPEARMAN S RHO TEST STATISTIC
        CALL QKRSRT(L)
       NSUM = 0
       DO 10 J= 1,L
10     NSUM = NSUM + (J-NR(J))*(J-NR(J))
       SUM = NSUM
      SUM=1-(6.*SUM)/(L**3-L)
        RETURN
        END
        SUBROUTINE MNWHIT(N,N1, T,W,WP)
         COMMON/COM3/Y(250), NR(250)
C --  SUBROUTINE TO COMPUTE MANN WHITNEY S TEST STATISTIC
          L = N
        CALL QKRSRT(L)
        RN = N1
        RM = N - N1
       XP =-1.96
```

```
       WP= (RN*RM)/2. + XP*SQRT(RN*RM*(RN + RM + 1.)/12.)
       W  = N1*(N-N1)
      W = W - WP
      NSUM = 0
      DO 20 J= 1,N
      IF(NR(J) .LE. N1) NSUM = NSUM + J
20    CONTINUE
      SUM = NSUM
      T = SUM - FLOAT(N1*(N1 + 1))/2.
      RETURN
      END
      FUNCTION CDFN(X)
C CDFN
C     CUMULATIVE DISTRIBUTION FUNCTION FOR THE
C     '          '             '
C        NORMAL ZERO-ONE DISTRIBUTION.
C        '
C     PRIMARY REFERENCE IS: ABRAMOWITZ & STEGUN,
C        NBS HANDBOOK OF MATHEMATICAL FUNCTIONS, EQUATION 26.2.19
      IF (X) 10,20,30
   10 CONTINUE
      IF (X.LT.-6.0) GO TO 40
      T=-X
      CDFN=      0.5/(1.0+0.0498673470*T+0.0211410061*T**2
     &   +0.0032776263*T**3+0.380036E-4*T**4+0.488906E-4*T**5
     &   +0.53830E-5*T**6)**16
      RETURN
   20 CONTINUE
      CDFN=0.5
      RETURN
   30 CONTINUE
      IF (X.GT.6.0) GO TO 50
      CDFN=1.0-0.5/(1.0+0.0498673470*X+0.0211410061*X**2
     &   +0.0032776263*X**3+0.380036E-4*X**4+0.488906E-4*X**5
     &   +0.53830E-5*X**6)**16
      RETURN
C     OUTSIDE THE RANGE +-6 THE APPROXIMATION IS USELESS.
   40 CONTINUE
      CDFN=0.0
      RETURN
   50 CONTINUE
      CDFN=1.0
      RETURN
      END
      SUBROUTINE FAC(NM,FIT,MODEL,JAR1,JAR2,XMIS)
C     SUBROUTINE TO CREATE FLOW ADJUSTED CONCENTRATIONS
C     Y(JAR1,250) = ARRAY CONTAINING CONCENTRATIONS
C     XFLOW(250) = ARRAY CONTAINING FLOWS
C     Y(JAR2,250)= VECTOR OF FLOW ADJUSTED CONCENTRATION VALUES
C      NM IS THE NUMBER OF DATA IN THE RECORD
C
C     MODEL IS THE INDEX OF MODEL NUMBER
C              0 = NO MODEL WAS FIT
C              1 = LINEAR
C              2 = LOG - LINEAR
C              3-10 = HYPERBOLIC MODELS
C              11 = INVERSE
C     FIT(1) = INTERCEPT
```

```
C       FIT(2) = SLOPE
C       FIT(3) = ALPHA
C       FIT(4) = R SQUARED
C       FIT(5) = BETA (FOR THE HYPERBOLIC MODELS)
C                       SET TO -1.0 FOR MODELS 1,2,11
C
        COMMON/COM1/Y(6,250),XFLOW(250)
        COMMON/COM3/FQ(250),Q(250)
        COMMON/COM5/C(250)
        DIMENSION BETA(11)
         LOGICAL BETMOD
         REAL STAT(4), FIT(5),MOD(5)
         REAL AR(11), BR(11), ALPR(11), RR(11)
        DATA MOD/10HNO MODEL  ,10HLINEAR    ,10HLOG-LINEAR,
       *10HHYPERBOLIC,10HINVERSE   /
        DO 1 J = 1,11
1       BETA(J) = 0.
         IF (NM.LE.250) GO TO 5
         WRITE(6,1000)
1000     FORMAT(1X,"LENGTH OF DATA VECTOR EXCEEDS 250, PROGRAM MUST",
       $" BE REDIMENSIONED FOR NM")
         RETURN
5        CONTINUE
        J = 0
        DO 10 I = 1, NM
        FLOW = XFLOW(I)
        CONC = Y(JAR1,I)
        IF(FLOW.LE.0.0 .OR. CONC .LE. 0.) GO TO 10
        J = J + 1
        Y(JAR2,J)=Q(J) = FLOW
        C(J) = CONC
   10 CONTINUE
        CALL REGRES(J,AR(1),BR(1),ALPR(1),RR(1),JAR2)
        DO 20 I = 1, J
        Y(JAR2,I)=FQ(I) = ALOG(Q(I))
   20 CONTINUE
        CALL REGRES(J,AR(2),BR(2),ALPR(2),RR(2),JAR2)
        CALL MOM3(Q,J,STAT)
        IBETA = ALOG10(STAT(1))
        DO 40 K = 3, 10
        BETAEXP = 0.5 * K - 4.0 - IBETA
        BETA(K) = 10.0 ** BETAEXP
        BET = BETA(K)
        DO 30 I = 1, J
        Y(JAR2,I)=FQ(I) = 1.0 / (1.0 + BET * Q(I))
   30 CONTINUE
        CALL MOM2(FQ,J,STAT)
        IF(STAT(2)/STAT(1).GT.0.0001) GO TO 435
        AR(K) = 0.0
        BR(K) = 0.0
        ALPR(K) = 1.0
        RR(K) = 0.0
        GO TO 40
  435 CALL REGRES(J,AR(K),BR(K),ALPR(K),RR(K),JAR2)
   40 CONTINUE
        DO 50 I = 1,J
        Y(JAR2,I) =FQ(I) = 1.0 / Q(I)
   50 CONTINUE
```

```
      CALL REGRES(J,AR(11),BR(11),ALPR(11),RR(11),JAR2)
      RMAX = XMIS
      DO 60 K = 1, 11
      RR(K) = RR(K)**2
      IF(RR(K).LT.RMAX) GO TO 60
      RMAX = RR(K)
      KBEST = K
   60 CONTINUE
      A = AR(KBEST)
      B = BR(KBEST)
      BET = BETA(KBEST)
      IF(KBEST.GE.3) BETMOD = .TRUE.
      IF(KBEST.LT.3.OR.KBEST.GT.10) BETMOD = .FALSE.
      DO 70 I = 1, NM
      FLOW = XFLOW(I)
      CONC = Y(JAR1,I)
      IF (FLOW.GT.0.0 .AND. CONC .GT. 0.) GO TO 65
      Y(JAR2,I) = 0.0
      GO TO 70
   65 IF(BETMOD) GO TO 475
      IF(KBEST.EQ.1) CHAT = A + B * FLOW
      IF(KBEST.EQ.2) CHAT = A + B * ALOG(FLOW)
      IF(KBEST.EQ.11) CHAT = A + (B/FLOW)
      GO TO 476
  475 CHAT = A + B * (1.0/(1.0 + BET * FLOW))
  476 Y(JAR2,I) = Y(JAR1,I) - CHAT
   70 CONTINUE
      MODEL = KBEST
      FIT(1) = A
      FIT(2) = B
      FIT(3) = ALPR(KBEST)
      FIT(4) = RR(KBEST)
      FIT(5) = BETA(KBEST)
      IF (MODEL.GE.3.AND. MODEL .LE.10) MODEL=3
      IF (MODEL.EQ.11) MODEL=4
      WRITE(6,666) J,MODEL,MOD(MODEL+1),(FIT(KK),KK=1,5)
666   FORMAT('0 NUMBER OF DATA POINTS USED IN FITTING - ',I3/
     *'0 MODEL FITTED -',I2,' = ',A10/'0 PARAMETERS -       INTERCEPT',
     *'        SLOPE           ALPHA      R SQUARED          BETA'/
     *15X,5E14.5)
      RETURN
      END
       SUBROUTINE KEN(N,TAU,ALPHA,JAR1)
C           KENDALL'S TAU TEST FOR TREND .
C          VECTOR Y(JAR1,250) SHOULD CONTAIN THE N OBSERVATIONS.
C          TAU IS THE RESULTANT STATISTIC EQUIVALENT TO KENDALL'S TAU.
C          ALPHA IS THE SIGNIFICANCE LEVEL OF TAU.
       LOGICAL ODD
      LOGICAL WASTIE
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/COM5/WASTIE(250)
C       PUT ALL NON-MISSING DATA INTO ARRAY Y AND COUNT THE NUMBER OF
C       ACTUAL OBSERVATIONS
      J = 0
      DO 10 I =1, N
      XX = Y(JAR1,I)
      IF(XX.LE.0.0) GO TO 10
```

```
         J = J + 1
         XT(J) = XX
      10 CONTINUE
         NN = J
         IF (NN.GT.250) STOP 'ERROR IN KEN -- REDIMENSION PROGRAM FOR N'
   C         ZERO OUT THE COUNTERS.
         DO 100 I=1,NN
         WASTIE(I)=.FALSE.
     100 CONTINUE
         NPLUS = 0
         NMINUS = 0
         FIXVAR=0.0
         NCOMP = 0
   C         PICK AN OBSERVATION.
         DO 20 ISTART = 1, NN-1
   C          VALUE IS ALWAYS TIED WITH ITSELF.
         NTIE=1
   C         TRY EACH LATER MONTH.
         DO 30 IEND = ISTART+1, NN
   C         COMPARE.
         YY = XT(IEND) - XT(ISTART)
         IF (YY.GT.0.0) NPLUS = NPLUS + 1
         IF (YY.LT.0.0) NMINUS = NMINUS + 1
         IF (YY.EQ.0.0) NTIE=NTIE+1
   C        MARK VALUES THAT ARE TIED.
         IF (YY.EQ.0.0) WASTIE(IEND)=.TRUE.
      30 CONTINUE
   C        UPDATE VARIANCE CORRECTION IF TIES OCCURED AND TIES WERE NOT
   C           COUNTED BEFORE.
         IF (NTIE.NE.1.AND..NOT.WASTIE(ISTART)) FIXVAR=FIXVAR+
       &    NTIE*(NTIE-1.0)*(2.0*NTIE+5.0)/18.0
      20 CONTINUE
   C         ACCUMULATE THIS MONTH'S RESULTS.
   C         DONE COMPARING.
         S = NPLUS - NMINUS
   C         WERE THERE ANY VALID COMPARISONS?
         IF (NPLUS+NMINUS.GT.0) GO TO 40
   C         NO VALID COMPARISONS -- GO HOME EMTPY.
         TAU = 0.0
         ALPHA = 1.0
         GO TO 70
   C         CALCULATE THE STATISTICS.
      40 CONTINUE
         NCOMP = NN * (NN - 1.0) / 2.0
         VAR = (1.0/18.0) * NN * (NN-1.0) * (2.0*NN+5.0)
          VAR = VAR - FIXVAR
         TAU = S / NCOMP
   C         CONTINUITY CORRECTION.
         IF (S.GT.0.0) S = S - 1.
         IF (S.LT.0.0) S = S + 1.
   C         COMPARE TO THE STANDARD NORMAL DISTRIBUTION. THE FUNCTION
   C         CDFN RETURNS THE CUMULATIVE PROBABILITY AT DEVIATION Z IN THE
   C         STANDARD NORMAL DISTRIBUTION.
         Z = S / SQRT(VAR)
         IF (Z.LE.0.0) ALPHA = 2.0 * CDFN(Z)
         IF (Z.GT.0.0) ALPHA = 2.0 * (1.0 - CDFN(Z))
   70    WRITE(6,666) TAU,ALPHA
   666   FORMAT('0 KENDALL"S TAU STATISTIC (TEST FOR TREND) = ',F8.4/
```

```
     *'     SIGNIFICANCE (NORMAL APPROX. ASSUMING INDEP. DATA)= ',F7.4)
      RETURN
      END
      SUBROUTINE MOM4(X,N,S)
      REAL X(N),S(4)
      LOGICAL THREE,FOUR
      THREE=.TRUE.
      FOUR=.TRUE.
   10 CONTINUE
      S(1)=X(1)
      S(2)=0.0
      IF (THREE) S(3)=0.0
      IF (FOUR) S(4)=0.0
      IF (N.LT.2) RETURN
      FN=N
      SUM=0.0
      SSQ=0.0
      IF (THREE) SCU=0.0
      IF (FOUR) SFO=0.0
      DO 20 I=1,N
      IF (X(I).EQ.0.0) GO TO 20
      W=X(I)
      SUM=SUM+W
      SSQ=SSQ+W**2
      IF (THREE) SCU=SCU+W**3
      IF (FOUR) SFU=SFO+W**4
   20 CONTINUE
      SUM=SUM/FN
      SSQ=SSQ/FN-SUM**2
      STD=SQRT(SSQ)
      S(1)=SUM
      S(2)=STD
      IF (.NOT.THREE.OR.S(2).LE.0.0) RETURN
      SCU=SCU/FN-3.0*SUM*SSQ-SUM**3
      S(3)=SCU/(STD**3)
      IF (FOUR)
     &   S(4)=(SFO/FN-4.0*SUM*SCU-6.0*SSQ*SUM**2-SUM**4)/(SSQ**2)
      RETURN
      ENTRY MOM3
      THREE=.TRUE.
      FOUR=.FALSE.
      GO TO 10
      ENTRY MOM2
      THREE=.FALSE.
      FOUR=.FALSE.
      GO TO 10
      END
      SUBROUTINE PACKER(NMAX,N,LENGTH,ISTART,JAR1,JAR2)
      COMMON /COM1/Y(6,250),FLOW(250)
      COMMON /COM5/ T(250)
C       Y(JAR1,250) IS THE INPUT VECTOR OF LENGTH NMAX.
C       Y(JAR2,250) IS THE PACKED OUTPUT VECTOR, LENGTH N.
C       T IS THE TIME (IN YEARS) INDEX VECTOR OF VALUES IN Y, LENGTH N.
C       LENGTH IS TIME IN MONTHS FROM FIRST TO LAST OBSERVATION
C         (INCLUSIVE)
C       ISTART IS THE TIME INDEX OF FIRST OBSERVATION.
      DO 5 K = 1, NMAX
      IF(Y(JAR1,K).GT.0.0) GO TO 6
```

```
      5 CONTINUE
        N = 0
        LENGTH = 0
        ISTART = NMAX + 1
        RETURN
      6 J = 1
         Y(JAR2,1)=Y(JAR1,K)
        ISTART = K
        IEND = K
        T(1) = K/12.0
        IF(K.LT.NMAX) GO TO 7
        N = 1
        LENGTH = 1
        ISTART = NMAX
        RETURN
      7 DO 10 I = K+1, NMAX
        IF(Y(JAR1,I).EQ.0.0) GO TO 10
        J = J + 1
        Y(JAR2,J) = Y(JAR1,I)
        T(J) = I/12.0
        IEND = I
     10 CONTINUE
        N = J
        LENGTH = IEND - ISTART + 1
        RETURN
        END
         SUBROUTINE REGSEA(X,Y,N,A,B,ALPHA,R,VAR)
C           THIS SUBROUTINE IS CALLED BY SEAREG
C            IT DOES THE REGRESSION OF THE DESEASONALIZED
C            DATA AND COMPUTES THE SIGNIFICANCE USING THE STUDENT-T
C            WHERE THE DEGREES OF FREEDOM IS COMPUTED FROM THE
C             VARIANCE
C           THE VARIANCE IS EXACT,    BUT THE DISTRIBUTION IS NOT
C         A = INTERCEPT, B= SLOPE    Y = A +BX
         REAL X(N),Y(N),NN
        IF(N.LE.2) STOP  'REGRESSION SAMPLE SIZE TOO SMALL IN REGRES.'
         NN= N
         XSUM=0.0
         YSUM=0.0
         DO 10 I=1,N
        XSUM = XSUM + X(I)
         YSUM = YSUM + Y(I)
     10 CONTINUE
         XBAR = XSUM / NN
        YBAR = YSUM / NN
         XX = 0.0
        YY = 0.0
        XY = 0.0
         DO 100 I = 1,N
        XD = X(I) - XBAR
        YD = Y(I) - YBAR
        XY = XY + XD*YD
        XX = XX + XD**2
        YY = YY + YD**2
  100    CONTINUE
        B = XY / XX
        R = B * SQRT(XX) / SQRT(YY)
        T = B * SQRT(A)
```

```
      DF = 2 * VAR / (VAR - 1.0)
      CALL MOTD(T,DF,ALPHA,IER)
      A =  YBAR - B * XBAR
       RETURN
       END
       SUBROUTINE REGRES(N,A,B,ALPHA,R,JAR1)
      COMMON/COM1/ Y(6,250),FLOW(250)
      COMMON/COM5/ X(250)
C          STANDARD ALL PURPOSE SIMPLE LINEAR REGRESSION
C            NO MISSING VALUES ALLOWED
C        A = INTERCEPT, B= SLOPE    Y = A +BX
       REAL NN
      IF(N.LE.2) STOP  'REGRESSION SAMPLE SIZE TOO SMALL IN REGRES.'
       NN= N
       XSUM=0.0
       YSUM=0.0
       DO 10 I=1,N
      XSUM = XSUM + X(I)
       YSUM = YSUM + Y(JAR1,I)
   10 CONTINUE
       XBAR = XSUM / NN
      YBAR = YSUM / NN
       XX = 0.0
      YY = 0.0
      XY = 0.0
       DO 100 I = 1,N
      XD = X(I) - XBAR
      YD = Y(JAR1,I) - YBAR
      XY = XY + XD*YD
      XX = XX + XD**2
      YY = YY + YD**2
100     CONTINUE
      B = XY / XX
      R = B * SQRT(XX) / SQRT(YY)
      T = R * SQRT(NN-2.0) / SQRT(1.0 - R**2)
      DF = N - 2
      CALL MOTD(T,DF,ALPHA,IER)
       A = YBAR - B *XBAR
       RETURN
       END
       SUBROUTINE SEAKEN(N,TAU,ALPHA,NSEAS,JAR1)
C         THIS IS AMODIFIED VERSION OF SKND...IT LACKS THE SLOPE ESTIMATOR
C          MODIFIED KENDALL'S TAU TEST FOR TREND IN SEASONAL DATA.
C          VECTOR Y(JAR1,250) SHOULD CONTAIN THE N SEASONS OF DATA.
C          TAU IS THE RESULTANT STATISTIC EQUIVALENT TO KENDALL'S TAU.
C          ALPHA IS THE SIGNIFICANCE LEVEL OF TAU.
       LOGICAL ODD
       LOGICAL WASTIE
       COMMON/COM1/Y(6,250),FLOW(250)
       COMMON/COM5/WASTIE(250)
C         CHECK WASTIE
       IF (N.GT.250) WRITE(6,4)
4       FORMAT (' ERROR IN SUBROUTINE SEAKEN, PROGRAM ',
     *'MUST BE REDIMENSIONED FOR NM')
       IF (N.GT.250) STOP
C          ZERO OUT THE COUNTERS.
       DO 100 I=1,N
       WASTIE(I)=.FALSE.
```

```
  100 CONTINUE
      NPLUS = 0
      NMINUS = 0
      NCMPT = 0
      VARTOT = 0.0
      INDEX = 0
      FIXVAR=0.0
C         DO EACH SEASON.
      DO 10 MONTH = 1,NSEAS
      NCOMP = 0
C         PICK AN OBSERVATION.
      DO 20 ISTART = MONTH, N-NSEAS, NSEAS
C         VALID VALUE?
      IF (Y(JAR1,ISTART).EQ.0.0) GO TO 20
C          VALUE IS ALWAYS TIED WITH ITSELF.
      NTIE=1
C         TRY EACH LATER SEASON.
      DO 30 IEND = ISTART+NSEAS, N, NSEAS
C         VALID VALUE?
      IF (Y(JAR1,IEND).EQ.0.0) GO TO 30
C         COMPARE.
      NCOMP = NCOMP + 1
      INDEX = INDEX + 1
      YY = Y(JAR1,IEND) - Y(JAR1,ISTART)
      IF (YY.GT.0.0) NPLUS = NPLUS + 1
      IF (YY.LT.0.0) NMINUS = NMINUS + 1
      IF (YY.EQ.0.0) NTIE=NTIE+1
C        MARK VALUES THAT ARE TIED.
      IF (YY.EQ.0.0) WASTIE(IEND)=.TRUE.
C         SAVE ADJUSTED DIFFERENCES.
   30 CONTINUE
C        UPDATE VARIANCE CORRECTION IF TIES OCCURED AND TIES WERE
C            NOT COUNTED BEFORE.
      IF (NTIE.NE.1.AND..NOT.WASTIE(ISTART)) FIXVAR=FIXVAR+
     &   NTIE*(NTIE-1.0)*(2.0*NTIE+5.0)/18.0
   20 CONTINUE
C         ACCUMULATE THIS SEASON'S RESULTS.
      NCMPT = NCMPT + NCOMP
      NMONTH = (1.0 + SQRT(1.0 + 8.0 * NCOMP))/2.0
      VARTOT = VARTOT + (1./18.)*NMONTH*(NMONTH-1.0)*(2.0*NMONTH+5.0)
   10 CONTINUE
C         DONE COMPARING.
      S = NPLUS - NMINUS
C         WERE THERE ANY VALID COMPARISONS?
      IF (NCMPT.GT.0) GO TO 40
C         NO VALID COMPARISONS -- GO HOME EMTPY.
      TAU = 0.0
      ALPHA = 1.0
      GO TO 70
C         CALCULATE THE STATISTICS.
   40 CONTINUE
      VARTOT=VARTOT-FIXVAR
      TAU = S / NCMPT
C         CONTINUITY CORRECTION.
      IF (S.GT.0.0) S = S - 1.
      IF (S.LT.0.0) S = S + 1.
C         COMPARE TO THE STANDARD NORMAL DISTRIBUTION. THE FUNCTION
C         CDFN RETURNS THE CUMULATIVE PROBABILITY AT DEVIATION Z IN THE
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```
C         STANDARD NORMAL DISTRIBUTION.
      Z = S / SQRT(VARTOT)
      IF (Z.LE.0.0) ALPHA = 2.0 * CDFN(Z)
      IF (Z.GT.0.0) ALPHA = 2.0 * (1.0 - CDFN(Z))
70    WRITE(6,666) TAU,ALPHA
666   FORMAT('0SEASONAL KENDALL"S TAU TEST FOR TREND '/' TAU = ',
     *E14.6,10X,'SIGNIF (NORMAL APPROX.; ASSUMES INDEP. DATA) = ',
     *F7.5)
      RETURN
      END
      SUBROUTINE SEAREG(N,A,B,ALPHA,R,NSEAS,JAR1)
C         THIS SUBROUTINE DOES THE DESEASONALIZING FOR
C         SEASONAL REGRESSION
      REAL XBAR(12), XSTD(12),S(2)
      COMMON/COM1/Y(5,250),FLOW(250)
      COMMON/COM3/XHOLD(250),XT(250)
      COMMON/COM5/T(250)
      DATA VNUM,VDENOM/0.,0./
      IF(N.GT.1000) STOP 'DIMENSIONS TOO SMALL IN SEAREG.'
      SUMAVE=0.0
      SUMSD=0.0
      DO 10 IM=1,NSEAS
      NI=0
      J = 0
      DO 5 I=IM,N,NSEAS
      J = J + 1
      IF (Y(JAR1,I).EQ.0.0) GO TO 5
      NI=NI+1
      XT(NI) = Y(JAR1,I)
      T(NI) = J
    5 CONTINUE
      CALL MOM2(XT,NI,S)
      XBAR(IM) = S(1)
      XSTD(IM) = S(2)
      IF(S(2).EQ.0.0) XSTD(IM) = 1.0
      CALL MOM2(T,NI,S)
      VDENOM = VDENOM + NI * (S(2)**2)
      SJSQ = 0.0
      SJK = 0.0
      DO 6 J = 1, NI
      TJ = T(J)
      SJSQ = SJSQ + TJ * TJ
      DO 7 K = 1, NI
    7 SJK = SJK + TJ * T(K)
    6 CONTINUE
      SJK = SJK - SJSQ
      IF (NI.GT.1) GO TO 8
      RN1 = 0.0
      GO TO 9
    8 RN1 = 1.0/(NI - 1.0)
    9 VNUM = VNUM + SJSQ - RN1 * SJK
   10 CONTINUE
      K = 0
      DO 20 IM=1,12
      AVE = XBAR(IM)
      SD = XSTD(IM)
      SUMAVE = SUMAVE + AVE
      SUMSD = SUMSD + SD
```

```
      DO 15 I = IM,N,12
      IF(Y(JAR1,I).EQ.0.0) GO TO 15
      K = K + 1
      XT(K) = (Y(JAR1,I) - AVE)/SD
      IY = (I-1)/12
      T(K) = IY + 0.5
   15 CONTINUE
   20 CONTINUE
      IF(VDENOM.GT.0.0) GO TO 100
      R = 0.0
      ALPHA = 1.0
      A = 0.0
      B = 0.0
      GO TO 90
  100 VAR = VNUM / VDENOM
      A = VDENOM
      CALL REGSEA(T,XT,K,A,B,ALPHA,R,VAR)
   90 B = (1./12.) * B * SUMSD
      A = (1./12.) * (SUMAVE + A * SUMSD)
      WRITE(6,666) A,B,R,ALPHA
  666 FORMAT('OSEASONAL LINEAR REGRESSION -'/'  INTERCEPT = ',E14.6,
     *7X,'SLOPE = ',E14.6,7X,'ABS(R) = ',F7.5,7X,
     *'SIGNIF(R) (ASSUMES NORMAL ERROR) = ',F7.5)
      RETURN
      END
      SUBROUTINE SEARS(IS1,IS2,NX1,NX2,Z,ALPHA,NSEAS,JAR1)
C
C       SEASONAL RANK SUM TEST, SEE BRADLEY P 115-117
C        THE TWO PERIODS OF RECORD MUST START WITH THE SAME SEASON
C        INPUT ARRAY IS Y(JAR1,250)
C        PERIODS OF RECORD COMPARED ARE INTERVALS IS1, IS1 + NX1
C        - 1, IS2, IS2 + NX2 - 1
C        ABS(NX1 - NX2) MUST BE EVEN MULTIPLE OF NSEAS
C
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM3/X1(250),X2(250)
      COMMON/COM4/Y1(250),Y2(250),YP(250),IR(250),EXTRA(604)
      DIMENSION M(52),N(52),W(52)
      DO 10 I = 1,NX1
   10 X1(I) = Y(JAR1,I+IS1-1)
      DO 11 I = 1,NX2
   11 X2(I) = Y(JAR1,I+IS2-1)
      IF(NSEAS .GT. 52) STOP 'NSEAS EXCEEDS 52, REDIMENSION SUBROUTINE S
     $EARS'
      DO 1 I = 1,NSEAS
      M(I) = 0
      N(I) = 0
    1 W(I) = 0.
C      LOOP THROUGH THE SEASONS
      DO 500 IM = 1, NSEAS
C        LOOP THROUGH YEARS FOR VALUES IN SEASON IM
C       FIRST PERIOD
      NI = 0
      DO 60 I = IM,NX1,NSEAS
      XX = X1(I)
      IF(XX.EQ.0.0) GO TO 60
      NI = NI + 1
      Y1(NI) = XX
```

```
   60 CONTINUE
C        SKIP THE SEASON IF NO VALUES
      IF(NI.EQ.0) GO TO 500
C        SECOND PERIOD
      MI = 0
      DO 70 I = IM,NX2,NSEAS
      XX = X2(I)
      IF(XX.EQ.0.0) GO TO 70
      MI = MI + 1
      Y2(MI) = XX
   70 CONTINUE
C        SKIP THE SEASON IF NO VALUES
      IF(MI.EQ.0) NI = 0
      IF(NI.EQ.0) GO TO 500
      M(IM) = MI
      N(IM) = NI
      NN = MI + NI
      IF(NN.GT.250) STOP 'DIMENSIONS TOO SMALL IN SEARS'
C        REASON FOR TWO PASSES OF THE RANKING IS TO DEAL WITH TIES
C        FIRST PASS AT RANKING AND SUMMING RANKS
      DO 110 I = 1, NI
      YP(I) = Y1(I)
      IR(I) = 1
  110 CONTINUE
      DO 120 I = NI+1, NN
      YP(I) = Y2(I-NI)
      IR(I) = 0
  120 CONTINUE
      CALL VSRTR(YP,NN,IR)
      IW1 = 0
      DO 130 I = 1, NN
      IW1 = IW1 + I * IR(I)
  130 CONTINUE
C        SECOND PASS AT RANKING AND SUMMING RANKS
      DO 210 I = 1, MI
      YP(I) = Y2(I)
      IR(I) = 0
  210 CONTINUE
      DO 220 I = MI+1, NN
      YP(I) = Y1(I-MI)
      IR(I) = 1
  220 CONTINUE
      CALL VSRTR(YP,NN,IR)
      IW2 = 0
      DO 230 I = 1, NN
      IW2 = IW2 + I * IR(I)
  230 CONTINUE
      W(IM) = (IW1 + IW2)/2.0
  500 CONTINUE
C        SUMMING THE W VALUES AND COMPUTING THE MEAN AND VARIANCE OF T
C        THE TEST STATISTIC IS T, THE SUM OF THE W
      T = 0.0
      ET = 0.0
      VT = 0.0
      DO 600 IM = 1, NSEAS
      T = T + W(IM)
      F = N(IM) * (N(IM) + M(IM) + 1)
      ET = ET + (F/2.0)
```

```
      VT = VT + (M(IM) * F / 12)
  600 CONTINUE
      IF(VT.LE.0.0) GO TO 700
      Z = (T - ET) / SQRT(VT)
C       THE SIGN CHANGE IS SO POSITIVE Z WILL INDICATE UP-TREND
      Z = -Z
      IF(Z.LE.0.0) ALPHA = 2.0 * CDFN(Z)
      IF(Z.GT.0.0) ALPHA = 2.0 * (1.0 - CDFN(Z))
      GO TO 999
  700 Z = 0.0
      ALPHA = 1.0
999   WRITE(6,666) IS1,(IS1+NX1-1),IS2,(IS2+NX2-1),Z,ALPHA
666   FORMAT('0SEASONAL WILCOXAN TEST FOR DIFFERENCE BETWEEN PERIODS'
     *,I3,' - ',I3,' AND ',I3,' - ',I3/' GIVES Z STATISTIC = ',F8.4,
     *10X,'SIGNIFICANCE (NORMAL APPROX.;ASSUMES INDEP. DATA) = ',F7.5)
      RETURN
      END
       SUBROUTINE SKND(N,TAU,ALPHA,SLOPE,NSEAS,JAR1)
C          MODIFIED KENDALL'S TAU TEST FOR TREND IN SEASONAL DATA.
C          VECTOR Y(JAR1,250) SHOULD CONTAIN THE N SEASONS OF DATA.
C          MISSING DATA CODE MUST BE NONPOSITIVE
C          TAU IS THE RESULTANT STATISTIC EQUIVALENT TO KENDALL'S TAU.
C          ALPHA IS THE SIGNIFICANCE LEVEL OF TAU.
C          SLOPE IS THE ESTIMATE OF THE SLOPE OF THE TREND.
      COMMON/COM1/Y(6,250),FLOW(250)
      COMMON/COM5/WASTIE(250)
      COMMON/COM4/YP(1604)
      LOGICAL ODD
      LOGICAL WASTIE
C          CHECK FOR ENOUGH WORK STORAGE IN ARRAY YP TO HOLD THE DIFFERENCES.
      M = 6 * ((N/NSEAS) + 1) * (N/NSEAS)
      IF (M.GT.1604) PRINT 4,M
4      FORMAT(' IN SUBROUTINE SKND, THE DIMENSION OF THE ARRAY YP',
     *' MUST BE INCREASED TO ',I5,' FROM 1604.')
      IF (M.GT.1604) STOP
C         CHECK WASTIE
      IF (N.GT.250) PRINT 5,N
5      FORMAT(' IN SUBROUTINE SKND, THE DIMENSION OF THE ARRAY WASTIE',
     *' MUST BE INCREASED TO ',I4,' FROM 250.')
      IF (N.GT.250) STOP
C          ZERO OUT THE COUNTERS.
      DO 100 I=1,N
      WASTIE(I)=.FALSE.
  100 CONTINUE
      NPLUS = 0
      NMINUS = 0
      NCMPT = 0
      VARTOT = 0.0
      INDEX = 0
      FIXVAR=0.0
C          DO EACH MONTH.
      DO 10 MONTH = 1,NSEAS
      NCOMP = 0
C          PICK AN OBSERVATION.
      DO 20 ISTART = MONTH, N-NSEAS, NSEAS
C          VALID VALUE?
      IF (Y(JAR1,ISTART).EQ.0.0) GO TO 20
C            VALUE IS ALWAYS TIED WITH ITSELF.
```

```
      NTIE=1
C          TRY EACH LATER MONTH.
      DO 30 IEND = ISTART+NSEAS, N, NSEAS
C          VALID VALUE?
      IF (Y(JAR1,IEND).EQ.0.0) GO TO 30
C          COMPARE.
      NCOMP = NCOMP + 1
      INDEX = INDEX + 1
      YY = (Y(JAR1,IEND) - Y(JAR1,ISTART))/((IEND-ISTART)/FLOAT(NSEAS))
      IF (YY.GT.0.0) NPLUS = NPLUS + 1
      IF (YY.LT.0.0) NMINUS = NMINUS + 1
      IF (YY.EQ.0.0) NTIE=NTIE+1
C         MARK VALUES THAT ARE TIED.
      IF (YY.EQ.0.0) WASTIE(IEND)=.TRUE.
C          SAVE ADJUSTED DIFFERENCES.
      YP(INDEX) = YY
   30 CONTINUE
C         UPDATE VARIANCE CORRECTION IF TIES OCCURED AND TIES WERE NOT COUNTED
C             BEFORE.
      IF (NTIE.NE.1.AND..NOT.WASTIE(ISTART)) FIXVAR=FIXVAR+
     &   NTIE*(NTIE-1.0)*(2.0*NTIE+5.0)/18.0
   20 CONTINUE
C          ACCUMULATE THIS MONTH'S RESULTS.
      NCMPT = NCMPT + NCOMP
      NMONTH = (1.0 + SQRT(1.0 + 8.0 * NCOMP))/2.0
      VARTOT = VARTOT + (1./18.)*NMONTH*(NMONTH-1.0)*(2.0*NMONTH+5.0)
   10 CONTINUE
C          DONE COMPARING.
      S = NPLUS - NMINUS
C          WERE THERE ANY VALID COMPARISONS?
      IF (NCMPT.GT.0) GO TO 40
C          NO VALID COMPARISONS -- GO HOME EMTPY.
      TAU = 0.0
      ALPHA = 1.0
      SLOPE = 0.0
       GO TO 665
C          CALCULATE THE STATISTICS.
   40 CONTINUE
      VARTOT=VARTOT-FIXVAR
      TAU = S / NCMPT
C          CONTINUITY CORRECTION.
      IF (S.GT.0.0) S = S - 1.
      IF (S.LT.0.0) S = S + 1.
C          COMPARE TO THE STANDARD NORMAL DISTRIBUTION. THE FUNCTION
C          CDFN RETURNS THE CUMULATIVE PROBABILITY AT DEVIATION Z IN THE
C          STANDARD NORMAL DISTRIBUTION.
      Z = S / SQRT(VARTOT)
      IF (Z.LE.0.0) ALPHA = 2.0 * CDFN(Z)
      IF (Z.GT.0.0) ALPHA = 2.0 * (1.0 - CDFN(Z))
C          SUBROUTINE PDQSRT SORTS THE VECTOR YP OF LENGTH INDEX IN
C          ASCENDING ORDER IN PLACE.
      CALL PDQSRT(INDEX)
C          PICK MEDIAN.
      ODD = MOD(INDEX,2).EQ.1
      IF (ODD) YMED = YP((INDEX+1)/2)
      IF (.NOT.ODD) YMED = 0.5 * (YP(INDEX/2) + YP((INDEX/2)+1))
      SLOPE = YMED
      IF (SLOPE.NE.0.0) GOTO 665
```

```
C         ADJUST FOR THE FACT THAT TAU AND ALPHA MAY SAY THERE IS A
C         SIGNIFICANT TREND BUT THE ESTIMATE OF THE SLOPE IS ZERO
C         DUE TO A TIE
      IF (NMINUS.GT.NPLUS) SLOPE = -1.0E-30
      IF (NMINUS.LT.NPLUS) SLOPE = 1.0E-30
665   WRITE(6,666) TAU,ALPHA,SLOPE
666   FORMAT('0 KENDALL"S TREND TEST WITH SLOPE ESTIMATOR'/
     *' TAU = ',E14.6,'     SIGNIF = ',F7.5,7X,'SLOPE = ',E14.5)
      RETURN
      END
```

APPENDIX C. Impervious Area Estimates Derived From Puget Sound Council of Governments Data

The estimates of impervious area given below were calculated using the same method as described by Harper and Owes (1981), i.e., attributing a fractional impervious area to each land use type (ASCE, 1969), then summing the products of acreage in each land use and fractional impervious area. In most cases, subbasins correspond to existing Metro stations, however in some cases one PSCOG subbasin includes multiple Metro water quality stations; in these cases the areas were disaggregated to arrive at the values given in Appendix D-2.

Primary Basin No.	PSCOG Descriptor	Metro Station(s)	1980 Per cent Impervious	1980 Equiv. Imprv. Acres	2000 Per cent Impervious	2000 Equiv. Imprv. Acres
1	Swamp Cr 1	0470	18.3	302	26.8	443
1	Swamp Cr 2	B470	23.0	3017	33.9	4436
2	North Cr 1	0474	17.3	175	26.1	264
2	North Cr 2	D474	13.9	2479	22.6	4051
3	Bear Cr 1	0478	14.4	283	19.0	373
3	Bear Cr 2	B478	5.6	456	9.7	793
4	McAleer Cr 1	A432	35.5	671	38.6	731
4	McAleer Cr 2	E432	46.6	1773	47.8	1820
5	Lyon Cr 1	0430	30.8	335	36.7	399
5	Lyon Cr 2	E430	33.6	519	39.3	608
-	Lake Washington	none	38.4	14701	42.3	16201
6	Juanita Cr 1	C446	21.6	443	25.5	525
6	Juanita Cr 2	0446	18.9	172	22.8	207
6	Juanita Cr 3	D446	23.2	245	27.6	292
7	Sammamish R	0450, 0480, 0486	17.3	2764	23.2	3718
8	Evans Cr 1	N484	9.1	937	13.8	1427
8	Evans Cr 2	J484	7.1	447	10.1	637
8	Evans Cr 3	G484, C484	8.7	515	11.7	690
8	Evans Cr 4	0484	13.1	238	16.1	293
8	Evans Cr 5	B484	7.9	435	10.8	592
8	Evans Cr 6	R484	6.4	137	10.3	220
9	Thornton Cr	0434, K434, T434	43.7	3562	43.8	3569
--	Lake Union	none	61.1	5553	60.3	5482
10	Coal Cr 1	0442	38.3	476	41.7	517
10	Coal Cr 2	C442	8.7	180	21.0	432
10	Coal Cr 3	U442	4.9	113	7.3	166
11	May Cr 1	0440	13.2	290	16.3	359
11	May Cr 2	K440	11.3	338	15.6	469
11	May Cr 3	X440	6.6	198	9.4	281
12	Mercer Slough 1	0444	45.4	958	46.9	991
12	Mercer Slough 2	C444	32.6	904	38.8	1078
12	Mercer Slough 3	D444	33.9	1488	41.6	1824
--	Lk Sammamish 1	none	14.7	3484	17.6	4153
--	Lk Sammamish 2	none	14.0	123	15.0	132

13	Issaquah Cr 1	0631, A631	10.4	123	15.0	132
13	Issaquah Cr 2	A632	4.5	144	5.5	174
13	Issaquah Cr 3	0633	6.0	346	6.8	390
13	Issaquah Cr 4	0634	5.2	174	7.5	252
13	Issaquah Cr 5	A660	2.2	77	2.7	93
13	Issaquah Cr 6	H631	3.8	229	5.1	306
13	Issaquah Cr 7	A640	1.8	78	2.2	97
13	Issaquah Cr 8	A650	4.3	203	5.4	257
14	Lower Green R	3106,0311,0315,A315	29.4	7056	35.2	8440
15	Black R	0317	22.5	3352	29.5	4393
16	Lower Cedar R	0438, A438	11.3	4780	13.4	5678
17	Upper Cedar R	H438	3.5	217	4.5	276
18	Big Soos Cr 1	F320	19.5	563	26.6	767
18	Big Soos Cr 2	G320	14.2	842	18.7	1108
18	Big Soos Cr 3	none	9.5	298	12.5	394
18	Big Soos Cr 4	D320	8.7	840	10.1	974
18	Big Soos Cr 5	B320	13.0	491	17.3	651
18	Big Soos Cr 6	0320	14.3	306	15.3	327
18	Big Soos Cr 7	C320	9.1	1317	10.2	1479
19	Middle Green R	A319, B319, 0321	4.2	1898	4.8	2181
20	Newaukum Cr 1	0322	4.6	170	5.2	191
20	Newaukum Cr 2	F322, T322	5.1	709	5.8	810
--	Puget Sound 1	none	17.4	1906	26.4	2892
--	Puget Sound 2	none	34.5	1888	39.3	2151
--	Puget Sound 3	none	38.4	1887	39.3	1933
--	Puget Sound 4	none	50.4	2028	49.0	1971
--	Puget Sound 5	none	42.1	4055	43.7	4210
--	Puget Sound 6	none	26.5	6619	35.8	8937
--	Puget Sound 7	none	11.3	2618	15.0	3465

APPENDIX D. Routine Monitoring Network Review Data

Appendices D-1 - D-4 contain the data used in the network review reported in Chapter III. Included are both the raw data for the existing network, and estimated values corresponding to sequential reductions in the number of stations within each basin. In all cases, the final row for each basin (maximum number of stations, p) corresponds to the existing network. The upper entry is the station number and the lower entry is the value of the particular variable (drainage area, impervious area change, summer geometric mean coliform count, or stream walk index). For smaller values of p, the stations listed are those that would be retained, and the value listed under each is the estimated variable value. In the case of drainage area and impervious area change, areas are simply aggregated according to the particular monitoring configuration. For coliform counts, the recorded average at each station is used (no weighting is given to values for stations eliminated). For the stream walk index, a stream length weighted average, described in Chapter III, is used. As an example, consider the drainage area hierarchy for Evans Creek (Appendix D-1). Evans Creek is basin number 8. Currently, there are p = 7 stations in Evans Creek, including numbers 0484, B484, N484, J484, R484, G484, and C484. Drainage areas for these stations are 1816, 5471, 10351, 6327, 2138, 3000, and 2897 acres, respectively. For option p = 4 (which is the allocation of stations to Evans Creek in the revised, 30-station network given in Table 2) the stations retained would be 0484, B484, N484, and J484, with 7713, 7609, 10351, and 6327 acres, respectively, drained by each. It should be noted that while areas are listed to the nearest acre, the accuracy of the subbasin areas is probably not much greater than ±100 acres. The total area for the primary basins (sum over the subbasins) is considerably more accurate, however.

Appendix D-1. Drainage Area (acres)

Basin/Name	p =	1	2	3	4	5	6	7	8	9
1 Swamp Creek		0470 / 14748								
		0470 / 1650	B470 / 13098							
2 North Creek		0474 / 18905								
		0474 / 1012	D474 / 17893							
3 Bear Creek		0478 / 10175								
		0478 / 1966	B478 / 8209							
4 McAleer Creek		A432 / 5695								
		A432 / 1891	E432 / 3804							
5 Lyon Creek		0430 / 2633								
		0430 / 1087	E430 / 1546							
6 Juanita Creek		0446 / 4019								
		0446 / 1964	C446 / 2055							
		0446 / 909	C446 / 2055	D446 / 1055						
7 Sammamish Cr		0450 / 16008								
		0450 / 5337	0480 / 10671							
		0450 / 5337	0480 / 9000	0486 / 1671						

8 Evans Creek

$\frac{0484}{32000}$

$\frac{0484}{21649}$ $\frac{N484}{10351}$

$\frac{0484}{14040}$ $\frac{B484}{7609}$ $\frac{N484}{10351}$

$\frac{0484}{7713}$ $\frac{B484}{7609}$ $\frac{N484}{10351}$ $\frac{J484}{6327}$

$\frac{0484}{7713}$ $\frac{B484}{5471}$ $\frac{N484}{10351}$ $\frac{J484}{6327}$ $\frac{R484}{2138}$

$\frac{0484}{4713}$ $\frac{B484}{5471}$ $\frac{N484}{10351}$ $\frac{J484}{6327}$ $\frac{R484}{2138}$ $\frac{G484}{3000}$

$\frac{0484}{1816}$ $\frac{B484}{5471}$ $\frac{N484}{10351}$ $\frac{J484}{6327}$ $\frac{R484}{2138}$ $\frac{G484}{3000}$ $\frac{C484}{2897}$

9 Thornton Creek

$\frac{0434}{8145}$

$\frac{0434}{7345}$ $\frac{K434}{800}$

$\frac{0434}{6545}$ $\frac{K434}{800}$ $\frac{T434}{800}$

10 Coal Creek

$\frac{0442}{5585}$

$\frac{0442}{3305}$ $\frac{U442}{2280}$

$\frac{0442}{1242}$ $\frac{U442}{2280}$ $\frac{C442}{2063}$

11 May Creek

$\frac{0440}{8205}$

$\frac{0440}{5206}$ $\frac{X440}{2999}$

$\frac{0440}{2200}$ $\frac{X440}{2999}$ $\frac{K440}{3006}$

12 Mercer Slough

$\frac{0444}{9270}$

$\frac{0444}{4886}$ $\frac{D444}{4384}$

	$\frac{0444}{2111}$	$\frac{D444}{4384}$	$\frac{C444}{2775}$						
13 Issaquah Creek	$\frac{0631}{34721}$								
	$\frac{0631}{19633}$	$\frac{H631}{15088}$							
	$\frac{0631}{16287}$	$\frac{H631}{15088}$	$\frac{0634}{3346}$						
	$\frac{0631}{10536}$	$\frac{H631}{15088}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$					
	$\frac{0631}{7364}$	$\frac{H631}{15088}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$	$\frac{A632}{3172}$				
	$\frac{0631}{2000}$	$\frac{H631}{15088}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$	$\frac{A632}{3172}$	$\frac{A631}{5364}$			
	$\frac{0631}{2000}$	$\frac{H631}{10337}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$	$\frac{A632}{3172}$	$\frac{A631}{5364}$	$\frac{A650}{4751}$		
	$\frac{0631}{2000}$	$\frac{H631}{10337}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$	$\frac{A632}{3172}$	$\frac{A631}{1942}$	$\frac{A650}{4751}$	$\frac{A660}{3422}$	
	$\frac{0631}{2000}$	$\frac{H631}{5963}$	$\frac{0634}{3346}$	$\frac{0633}{5751}$	$\frac{A632}{3172}$	$\frac{A631}{1942}$	$\frac{A650}{4751}$	$\frac{A660}{3422}$	$\frac{A640}{4374}$
14 Lower Green R	$\frac{3106}{24005}$								
	$\frac{3106}{14406}$	$\frac{0315}{9600}$							
	$\frac{3106}{14406}$	$\frac{0315}{3600}$	$\frac{A315}{6000}$						
	$\frac{3106}{1200}$	$\frac{0315}{3600}$	$\frac{A315}{6000}$	$\frac{0311}{13205}$					
15 Black River	$\frac{0317}{14899}$								
16 Lower Cedar R	$\frac{0438}{42320}$								
	$\frac{0438}{21000}$	$\frac{A438}{21320}$							
17 Upper Cedar R	$\frac{H438}{6187}$								

18 Big Soos Creek	$\frac{0320}{42007}$					
	$\frac{0320}{32924}$	$\frac{G320}{9083}$				
	$\frac{0320}{30040}$	$\frac{G320}{9083}$	$\frac{F320}{2884}$			
	$\frac{0320}{26267}$	$\frac{G320}{9083}$	$\frac{F320}{2884}$	$\frac{B320}{3773}$		
	$\frac{0320}{11779}$	$\frac{G320}{9083}$	$\frac{F320}{2884}$	$\frac{B320}{3773}$	$\frac{C320}{14488}$	
	$\frac{0320}{2135}$	$\frac{G320}{9083}$	$\frac{F320}{2884}$	$\frac{B320}{3773}$	$\frac{C320}{14488}$	$\frac{D320}{9644}$
19 Middle Green R	$\frac{A319}{45120}$					
	$\frac{A319}{30120}$	$\frac{B319}{15000}$				
	$\frac{A319}{24120}$	$\frac{B319}{15000}$	$\frac{0321}{6000}$			
20 Newaukum Creek	$\frac{0322}{17606}$					
	$\frac{0322}{3692}$	$\frac{F322}{13914}$				
	$\frac{0322}{3692}$	$\frac{F322}{12414}$	$\frac{T322}{1500}$			

Appendix D-2. Projected Impervious Area Increase 1980-2000 (acres)

Basin/Name	p = 1	2	3	4	5	6	7	8	9
1 Swamp Creek	0470 / 1560								
	0470 / 141	B470 / 1419							
2 North Creek	0474 / 1661								
	0474 / 89	D474 / 1572							
3 Bear Creek	0478 / 427								
	0478 / 90	B478 / 337							
4 McAleer Creek	A432 / 107								
	A432 / 60	E432 / 47							
5 Lyon Creek	0430 / 153								
	0430 / 64	E430 / 89							
6 Juanita Creek	0446 / 164								
	0446 / 82	C446 / 82							
	0446 / 35	C446 / 82	D446 / 47						
7 Sammamish Cr	0450 / 954								
	0450 / 318	0480 / 636							

	0450/318	0480/600	0486/36				
8 Evans Creek	0484/1151						
	0484/661	N484/490					
	0484/421	B484/240	N484/490				
	0484/231	B484/240	N484/490	J484/190			
	0484/231	B484/157	N484/490	J484/190	R484/83		
	0484/143	B484/157	N484/490	J484/190	R484/83	G484/88	
	0484/55	B484/157	N484/490	J484/190	R484/83	G484/88	C484/88
9 Thornton Creek	0434/7						
	0434/3	K434/4					
	0434/2	K434/4	T434/1				
10 Coal Creek	0442/346						
	0442/293	U442/53					
	0442/41	U442/53	C442/252				
11 May Creek	0440/283						
	0440/200	X440/83					
	0440/69	X440/83	K440/131				
12 Mercer Slough	0444/543						

	0444/207	D444/336							
	0444/33	D444/336	C444/174						
13 Issaquah Creek	0631/354								
	0631/204	H631/150							
	0631/126	H631/150	0634/78						
	0631/82	H631/150	0634/78	0633/44					
	0631/52	H631/150	0634/78	0633/44	A632/30				
	0631/18	H631/150	0634/78	0633/44	A632/30	A631/34			
	0631/18	H631/96	0634/78	0633/44	A632/30	A631/34	A650/54		
	0631/18	H631/96	0634/78	0633/44	A632/30	A631/18	A650/54	A660/16	
	0631/18	H631/77	0634/78	0633/44	A632/30	A631/18	A650/54	A660/16	A640/19
14 Lower Green R	3106/1383								
	3106/851	0315/552							
	3106/831	0315/207	A315/345						
	3106/69	0315/207	A315/345	0311/762					
15 Black River	0317/1041								
16 Lower Cedar R	0438/898								
	0438/450	A438/448							

17 Upper Cedar R	H438/59					
18 Big Soos Creek	0320/1043					
	0320/681	G320/362				
	0320/477	G320/362	F320/204			
	0320/317	G320/362	F320/204	B320/160		
	0320/155	G320/362	F320/204	B320/160	C320/162	
	0320/21	G320/362	F320/204	B320/160	C320/162	D320/134
19 Middle Green R	A319/283					
	A319/198	B319/85				
	A319/156	B319/85	0321/42			
20 Newaukum Creek	0322/122					
	0322/21	F322/101				
	0322/21	F322/86	T322/15			

Appendix D-3. Geometric Mean Fecal Coliform Counts, 1979-81

Basin/Name	p =	1	2	3	4	5	6	7	8	9
1 Swamp Creek		0470 / 331.4								
		0470 / 331.4	B470 / 475.4							
2 North Creek		0474 / 922.3								
		0474 / 922.3	D474 / 435.4							
3 Bear Creek		0478 / 324.5	431.9							
		0478 / 324.5	431.9							
4 McAleer Creek		A432 / 339.7								
		A432 / 339.7	E432 / 123.5							
5 Lyon Creek		0430 / 687.3								
		0430 / 687.3	E430 / 1532.7							
6 Juanita Creek		0446 / 467.4								
		0446 / 467.4	C446 / 458.7							
		0446 / 467.4	C446 / 458.7	D446 / 200.6						
7 Sammamish Cr		0450 / 242.3								
		0450 / 242.3	0480 / 113.1							
		0450 / 242.3	0480 / 113.1	0486 / 23.7						

8 Evans Creek

$\frac{0484}{700.8}$

$\frac{0484}{700.8}$ $\frac{N484}{346.2}$

$\frac{0484}{700.8}$ $\frac{B484}{325.6}$ $\frac{N484}{346.2}$

$\frac{0484}{700.8}$ $\frac{B484}{325.6}$ $\frac{N484}{346.2}$ $\frac{J484}{113.2}$

$\frac{0484}{700.8}$ $\frac{B484}{325.6}$ $\frac{N484}{346.2}$ $\frac{J484}{113.2}$ $\frac{R484}{111.0}$

$\frac{0484}{700.8}$ $\frac{B484}{325.6}$ $\frac{N484}{346.2}$ $\frac{J484}{113.2}$ $\frac{R484}{111.0}$ $\frac{G484}{365.6}$

$\frac{0484}{700.8}$ $\frac{B484}{325.6}$ $\frac{N484}{346.2}$ $\frac{J484}{113.2}$ $\frac{R484}{111.0}$ $\frac{G484}{365.6}$ $\frac{C484}{413.4}$

9 Thornton Creek

$\frac{0434}{500.0}$

$\frac{0434}{500.0}$ $\frac{K434}{539.2}$

$\frac{0434}{500.0}$ $\frac{K434}{539.2}$ $\frac{T434}{122.3}$

10 Coal Creek

$\frac{0442}{116.5}$

$\frac{0442}{116.5}$ $\frac{U442}{10.6}$

$\frac{0442}{116.5}$ $\frac{U442}{10.6}$ $\frac{C442}{31.7}$

11 May Creek

$\frac{0440}{132.1}$

$\frac{0440}{132.1}$ $\frac{X440}{196.3}$

$\frac{0440}{132.1}$ $\frac{X440}{196.3}$ $\frac{K440}{292.2}$

12 Mercer Slough

$\frac{0444}{349.4}$

$\frac{0444}{349.4}$ $\frac{D444}{331.5}$

$\frac{0444}{349.4}$ $\frac{D444}{331.5}$ $\frac{C444}{474.4}$

13 Issaquah Creek

$\frac{0631}{165.7}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$ $\frac{A632}{231.9}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$ $\frac{A632}{231.9}$ $\frac{A631}{101.4}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$ $\frac{A632}{231.9}$ $\frac{A631}{101.4}$ $\frac{A650}{40.4}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$ $\frac{A632}{231.9}$ $\frac{A631}{101.4}$ $\frac{A650}{40.4}$ $\frac{A660}{28.9}$

$\frac{0631}{165.7}$ $\frac{H631}{220.9}$ $\frac{0634}{696.5}$ $\frac{0633}{154.4}$ $\frac{A632}{231.9}$ $\frac{A631}{101.4}$ $\frac{A650}{40.4}$ $\frac{A660}{28.9}$ $\frac{A640}{58.3}$

14 Lower Green R

$\frac{3106}{117.2}$

$\frac{3106}{117.2}$ $\frac{0315}{134.7}$

$\frac{3106}{117.2}$ $\frac{0315}{134.7}$ $\frac{A315}{954.0}$

$\frac{3106}{117.2}$ $\frac{0315}{134.7}$ $\frac{A315}{954.0}$ $\frac{0311}{133.2}$

15 Black River

$\frac{0317}{1201.9}$

16 Lower Cedar R

$\frac{0438}{52.8}$

$\frac{0438}{52.8}$ $\frac{A438}{28.6}$

17 Upper Cedar R

$\frac{H438}{12.7}$

18 Big Soos Creek	0320					
	126.6					
	0320	G320				
	126.6	861.4				
	0320	G320	F320			
	126.6	861.4	79.2			
	0320	G320	F320	B320		
	126.6	861.4	79.2	139.0		
	0320	G320	F320	B320	C320	
	126.6	861.4	79.2	139.0	46.7	
	0320	G320	F320	B320	C320	D320
	126.6	861.4	79.2	139.0	46.7	68.1
19 Middle Green R	A319					
	43.3					
	A319	B319				
	43.3	19.1				
	A319	B319	0321			
	43.3	19.1	50.5			
20 Newaukum Creek	0322					
	344.1					
	0322	F322				
	344.1	787.7				
	0322	F322	T322			
	344.1	787.7	34.7			

Appendix D-4. 1979 Streambed Evaluation

Basin/Name	p = 1	2	3	4	5	6	7	8	9
1 Swamp Creek	0470 / (64.7)								
	0470 / 64.7	B470 / (64.7)							
2 North Creek	0474 / (58.5)								
	0474 / 58.5	D474 / (58.5)							
3 Bear Creek	0478 / (70.4)								
	0478 / 70.4	B478 / (70.4)							
4 McAleer Creek	A432 / 79.6								
	A432 / 80.4	E432 / 79.0							
5 Lyon Creek	0430 / 77.5								
	0430 / 78.1	E430 / 77.0							
6 Juanita Creek	0446 / 89.2								
	0446 / 89.1	C446 / 89.4							
	0446 / 89.0	C446 / 89.4	D446 / (89.2)						
7 Sammamish Cr	0450								
	0450	0480							
	0450	0480	0486						

8	Evans Creek	0484						
		73.5						
		0484	N484					
		73.2	74.0					
		0484	B484	N484				
		70.2	77.2	74.0				
		0484	B484	N484	J484			
		73.9	77.2	74.0	66.1			
		0484	B484	N484	J484	R484		
		73.9	79.2	74.0	66.1	74.0		
		0484	B484	N484	J484	R484	G484	
		77.5	79.2	74.0	66.1	74.0	69.3	
		0484	B484	N484	J484	R484	G484	C484
		80.1	79.2	(74.0)	66.1	(74.0)	69.3	75.5
9	Thornton Creek	0434						
		78.4						
		0434	K434					
		74.8	89.4					
		0434	K434	T434				
		75.6	89.4	72.7				
10	Coal Creek	0442						
		68.4						
		0442	U442					
		68.4	68.4					
		0442	U442	C442				
		60.8	(68.4)	74.3				
11	May Creek	0440						
		69.8						
		0440	X440					
		71.1	68.0					
		0440	X440	K440				
		67.8	68.0	73.9				
12	Mercer Slough	0444						
		(82.0)						
		0444	D444					
		(82.0)	(82.0)					

	0444	D444	C444						
	(82.0)	82.0	(82.0)						
13 Issaquah Creek	0631								
	64.4								
	0631	H631							
	63.0	66.0							
	0631	H631	0634						
	62.4	66.0	64.2						
	0631	H631	0634	0633					
	64.3	66.0	64.2	59.9					
	0631	H631	0634	0633	A632				
	66.6	66.0	64.2	59.9	60.8				
	0631	H631	0634	0633	A632	A631			
	69.9	66.0	64.2	59.9	60.8	64.6			
	0631	H631	0634	0633	A632	A631	A650		
	69.9	62.4	64.2	59.9	60.8	64.6	71.2		
	0631	H631	0634	0633	A632	A631	A650	A660	
	69.9	62.4	64.2	59.9	60.8	65.1	71.2	64.2	
	0631	H631	0634	0633	A632	A631	A650	A660	A640
	69.9	(64.2)	(64.2)	59.9	60.8	65.1	71.2	(64.2)	60.2
14 Lower Green R	3106								
	3106	0315							
	3106	0315	A315						
	3106	0315	A315	0311					
			84.0						
15 Black River	0317								
	66.5								
16 Lower Cedar R	0438								
	0438	A438							
17 Upper Cedar R	H438								

18 Big Soos Creek	0320 / 63.6					
	0320 / 64.3	G320 / 62.4				
	0320 / 65.8	G320 / 62.4	F320 / 59.5			
	0320 / 64.3	G320 / 62.4	F320 / 59.5	B320 / 69.7		
	0320 / 61.4	G320 / 62.4	F320 / 59.5	B320 / 69.7	C320 / 66.9	
	0320 / 66.1	G320 / 62.4	F320 / 59.5	B320 / 69.7	C320 / 66.9	D320 / 59.2
19 Middle Green R	A319					
	A319	B319				
	A319	B319	0321 / 67.0			
20 Newaukum Creek	0322 / 64.9					
	0322 / 68.0	F322 / 63.3				
	0322 / 68.0	F322 / 62.0	T322 / 66.9			

APPENDIX E. Network Optimization Program Listing

The program listed in this appendix performs the dynamic programming optimization of station allocations using the scoring scheme discussed in Chapter III. Documentation is provided in the comment cards at the beginning of the listing. The input data used to derive the results summarized in Table 2 are also included. Copies of the program can be obtained from the first author.

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION XIND1(20,9,9),XIND2(20,9,9),XIND3(20,9,9),
     $XIND4(20,9,9),JSTA(20),XM(4),XSD(4),YIND(20,9,9)
C --  DYNAMIC PROGRAM TO DETERMINE OPTIMAL NMAX STATION
C --  NETWORKS CONSISTING OF SUBSETS OF METRO S EXISTING
C --  64 STATION RIVERS AND STREAMS TREND NETWORK.  THE
C --  20 EXISTING PRIMARY BASINS CONSIDERED AND EXISTING
C --  NUMBERS OF STATIONS PER BASIN ARE:
C     1  SWAMP CR (2: D470;B470)
C     2  NORTH CR (2: D474; D474)
C     3  BEAR CR (2:  D478; B478)
C     4  MCALEER CR (2: A432; E432)
C     5  LYON CR (2:  D430; E430)
C     6  JUANITA CK (3: C446; D446; D446)
C     6  SAMMAMISH R (3: D450; D450; D486)
C     8  EVANS CR (7: N484; J484; G484; C484; D484; B484; R484)
C     9  THORNTON CR (3: D434; K434; T434)
C     10 COAL CR (3: D442; C442; U442)
C     11 MAY CR (3: D440; U440; X440)
C     12 MERCER SLOUGH (3: D444; C444; D444)
C     13 ISSAQUAH CK (9: D631; A631; A632; D633; D634; A660; H631
C                        A640; A650)
C     14 LOWER GREEN R (4: 3106; D311; D315; A315)
C     15 BLACK R (1: D317)
C     16 LOWER CEDAR R (2: D438; A438)
C     17 UPPER CEDAR R (1: H438)
C     18 BIG SOOS CR (7: F320; G320; D320; B320; D320; C320)
C     19 MIDDLE GREEN R (3: A319; B319; D321)
C     20 NEWAUKUM CR (D322; F322; T322)
C --  DP TREATS BASINS AS STAGES: STATES AT STAGE K ARE NUMBER OF
C --  STATIONS ALLOCATED TO BASINS K - 20.  OBJECTIVE FUNCTION
C --  IS MAXIMIZATION OF NETWORK RATING, WHERE RATING AT EACH
C --  STATION IS AVERAGE OF FOUR INDICATORS:
C       100*LOG NORMAL CUMULATIVE PROBABILITY OF STATION DRAINAGE
C       AREA RELATIVE TO OTHER STATIONS IN SELECTED NETWORK
C       100*LOG NORMAL CUMULATIVE PROBABILITY OF PROJECTED CHANGE
C       IN IMPERVIOUS AREA FOR EACH STATION, 1980-200
C       100*LOG NORMAL CUMULATIVE PROBABILITY OF STATION AVERAGE
C       FECAL COLIFORM COUNT, 1977-81 (RELATIVE TO NETWORK SELECTED)
C       100*NORMAL CUMULATIVE PROBABILITY OF 1979 STREAM WALK
C       INDEX (NOT COUNTED FOR RIVER STATIONS)
C --  WITHIN EACH BASIN, OPTIONS WITH LESS THAN EXISTING NUMBER
C --  OF STATIONS ARE SPECIFIED AS INPUT, BASED ON AD HOC OP-
C --  TIMIZATION CONSIDERING STREAM ORDER NUMBERS AND PROJECTED
C --  IMPERVIOUS AREA CHANGES.  SINGLE STATION OPTION ALWAYS
C --  USES EXISTING STATION NEAREST MOUTH.  STREAM WALK INDICES
C --  ARE WEIGHTED BY SQUARE ROOT OF DRAINAGE SUBAREAS WHEN
C --  INDICES MUST BE AGGREGATED
C --
C --  NBASIN = NUMBER OF BASINS (20)
C --  NMAX = NUMBER OF STATIONS TO BE IN NETWORK
C --  JSTA(J),J = 1,NBASIN = NUMBER OF STATIONS CURRENTLY IN-
C --  CLUDED IN BASIN J
C --  (((XIND1(I,J,K), I = 1,NBASIN),J = 1,JSTA(I)), K = 1,J) =
C --  TOTAL AREA FOR STATION J, BASIN I, WHEN K STATIONS ARE
C --  ALLOCATED TO BASIN I
```

```
C      XIND2(I,J,K) = PROJECTED CHANGE IN IMPERVIOUS AREA, 1980-2000
C      XIND3(I,J,K) = GEOMETRIC MEAN SUMMER FECAL COLIFORM COUNT, 1977-81
C --   XIND4(I,J,K) = 1979 STREAM WALK INDEC
       READ(5,1) NBASIN, NMAX,IBUG
       READ(5,1) (JSTA(J),J=1,NBASIN)
       DO 10 I = 1,NBASIN
       MAX = JSTA(I)
       DO 10 J = 1,MAX
10     READ(5,2) (XIND1(I,J,K),XIND2(I,J,K),XIND3(I,J,K),
      $XIND4(I,J,K),K=1,J)
1      FORMAT(16I5)
2      FORMAT(8F10.0)
       IF(IBUG .NE. 0) GO TO 99
       WRITE(6,20)
20     FORMAT(1H1,10X,*RAW DATA, DRAINAGE AREA*,//)
       NAME = 7HSTATION
41     FORMAT(/)
40     FORMAT(//)
       DO 21 I =1,NBASIN
       WRITE(6,41)
       MAX = JSTA(I)
       WRITE(6,30) I, (J,J=1,MAX)
30     FORMAT(12X,*BASIN*,I3,9I10)
       WRITE(6,40)
       DO 21 J = 1,MAX
21     WRITE(6,22) J, NAME, (XIND1(I,J,K),K=1,J)
22     FORMAT(10X,I2,1X,A7,9F10.1)
       WRITE(6,31)
31     FORMAT(///,10X, *RAW DATA, IMPERVIOUS AREA CHANGE*,//)
       DO 23 I = 1,NBASIN
       WRITE(6,41)
       MAX = JSTA(I)
       WRITE(6,30) I, (J,J=1,MAX)
       WRITE(6,40)
       DO 23 J = 1,MAX
23     WRITE(6,22) J, NAME, (XIND2(I,J,K),K=1,J)
       WRITE(6,32)
32     FORMAT(///,10X, *RAW DATA, GEOMETRIC MEAN SUMMER FECAL*
      $,* COLIFORM COUNT*,//)
       DO 24 I = 1,NBASIN
       WRITE(6,41)
       MAX = JSTA(I)
       WRITE(6,30) I, (J,J=1,MAX)
       WRITE(6,40)
       DO 24 J = 1,MAX
24     WRITE(6,22) J, NAME, (XIND3(I,J,K),K=1,J)
       WRITE(6,33)
33     FORMAT(///,10X,*RAW DATA, STREAM WALK INDEX*,//)
       DO 25 I = 1,NBASIN
       WRITE(6,41)
       MAX = JSTA(I)
       WRITE(6,30) I, (J,J=1,MAX)
       WRITE(6,40)
       DO 25 J = 1,MAX
25     WRITE(6,22) J, NAME, (XIND4(I,J,K),K=1,J)
99     CALL STAT(JSTA,XIND1,XIND2,XIND3,XIND4,XM,XSD)
```

```
      CALL TRANS(JSTA,XIND1,XIND2,XIND3,XIND4,XM,XSD,YIND)
      IF(IBUG .NE. 0) GO TO 98
      WRITE(6,34)
34    FORMAT(///,10X,*SCORE, DRAINAGE AREA*,//)
      DO 26 I = 1,NBASIN
      WRITE(6,41)
      MAX = JSTA(I)
      WRITE(6,30) I, (J,J=1,MAX)
      WRITE(6,40)
      DO 26 J = 1,MAX
26    WRITE(6,22) J, NAME, (XIND1(I,J,K),K=1,J)
      WRITE(6,35)
35    FORMAT(///,10X,*SCORE, PROJECTED IMPERVIOUS AREA CHANGE*,//)
      DO 27 I = 1,NBASIN
      WRITE(6,41)
      MAX = JSTA(I)
      WRITE(6,30) I, (J,J=1,MAX)
      WRITE(6,40)
      DO 27 J = 1,MAX
27    WRITE(6,22) J, NAME, (XIND2(I,J,K),K=1,J)
      WRITE(6,36)
36    FORMAT(///,10X,*SCORE, GEOMETRIC MEAN SUMMER COLIFORM*,//)
      DO 28 I = 1,NBASIN
      WRITE(6,41)
      MAX = JSTA(I)
      WRITE(6,30) I, (J,J=1,MAX)
      WRITE(6,40)
      DO 28 J = 1,MAX
28    WRITE(6,22) J, NAME, (XIND3(I,J,K),K=1,J)
      WRITE(6,37)
37    FORMAT(///,10X,*SCORE, 1979 STREAM WALK INDEX*,//)
      DO 29 I = 1,NBASIN
      WRITE(6,41)
      MAX = JSTA(I)
      WRITE(6,30) I, (J,J=1,MAX)
      WRITE(6,40)
      DO 29 J = 1,MAX
29    WRITE(6,22) J, NAME, (XIND4(I,J,K),K=1,J)
      WRITE(6,38)
38    FORMAT(///,10X,*SCORE, OVERALL*,//)
      DO 39 I = 1,NBASIN
      WRITE(6,41)
      MAX = JSTA(I)
      WRITE(6,30) I, (J,J=1,MAX)
      WRITE(6,40)
      DO 39 J = 1,MAX
39    WRITE(6,22) J, NAME, (YIND(I,J,K),K=1,J)
98    CALL OPTSTA(YIND,NMAX,JSTA)
      WRITE(6,42)
42    FORMAT(1H1)
      END
      SUBROUTINE OPTSTA(YIND,NMAX,JSTA)
      DIMENSION YIND(20,9,9),JSTA(20),OLDOP(65,65),NEWOP(65,65),
     $ISTAK(20,65),LSTA(65),MSTA(20),MAXR(20)
      REAL NEWOP
      ISUM = 0
```

```
      DO 10 I = 1,20
      IR = 20 - I + 1
      ISUM = ISUM + JSTA(IR)
      MAXR(I) = ISUM
10    IF(MAXR(I) .GT. NMAX) MAXR(I) = NMAX
C     PRINT*,"MAXR", (MAXR(I),I=1,20)
      DO 20 I = 1,3
      ISTAK(1,I) = I
      DO 21 J = 1,I
21    OLDOP(I,J) = YIND(20,I,J)
C     PRINT*,"I,OLDOP(I,J)", I, (OLDOP(I,J),J=1,I)
20    CONTINUE
      DO 30 K = 2,20
      IMAX = MAXR(K)
      DO 35 I = 1,IMAX
C --  SUBROUTINE OPCOMB FINDS OPTIMAL STATION ALLOCATION AT STAGE
C --  K FOR I STATIONS REMAINING
      CALL OPCOMB(K,I,OLDOP,NK,NKM1,JSTA,YIND,MAXR)
C     PRINT*,"K,I,NK,NKM1"
C     PRINT*,K,I,NK,NKM1
      IF(NKM1 .EQ. 0) GO TO 40
      DO 41 J = 1,NKM1
41    NEWOP(I,J) = OLDOP(NKM1,J)
40    NM = NKM1 + 1
      IF(NK .EQ. 0) GO TO 42
      DO 43 J = NM,I
43    NEWOP(I,J) = YIND(20-K+1,NK,J-NM+1)
42    ISTAK(K,I) = NK
35    CONTINUE
C     PRINT*,"ISTAK", (ISTAK(K,I),I=1,IMAX)
      DO 44 I = 1,IMAX
      DO 44 J = 1,I
44    OLDOP(I,J) = NEWOP(I,J)
30    CONTINUE
      WRITE(6,101) (I,I=1,20)
101   FORMAT(1H1,//,30X,*OPTIMAL STATION ALLOCATIONS*,//,60X,
     $*BASIN*,/,*  NO. STNS*,20I5,*     SCORE*,/)
      DO 200 I = 1,NMAX
      SUM = 0.
      DO 201 J = 1,I
201   SUM = SUM + NEWOP(I,J)
      SUM = SUM/I
      ISUM = MSTA(1) = ISTAK(20,I)
      DO 202 K = 2,20
      IND = 20-K+1
      JIND = I - ISUM
C     PRINT*,"IND,JIND,ISTAK(IND,JIND)",IND,JIND,ISTAK(IND,JIND)
      IF(JIND .EQ. 0) GO TO 203
      MSTA(K) = ISTAK(IND,JIND)
      ISUM = ISUM + MSTA(K)
      GO TO 202
203   MSTA(K) = 0
202   CONTINUE
200   WRITE(6,102) I, (MSTA(K),K=1,20),SUM
102   FORMAT(1H ,I10,20I5,F10.1)
      RETURN
```

```
      END
      SUBROUTINE OPCOMB(K,I,OLDOP,NK,NKM1,JSTA,YIND,MAXCR)
      DIMENSION OLDOP(65,65),JSTA(20),YIND(20,9,9),MAXCR(20)
C --  K IS BASIN NUMBER
C --  I IS NUMBER OF STATIONS FROM BASIN K:20
C --  NK IS NUMBER IN OPTIMAL SET OF I AT BASIN K
C --  TRY ALL COMBINATIONS S.T. NK + NKM1 = I
C --  START WITH NK = 0
      KK = 20-K+1
      XSUM = 0.
      IMAX = I
      IF(IMAX .GT. MAXCR(K-1)) IMAX = MAXCR(K-1)
      DO 10 J = 1,IMAX
10    XSUM = XSUM + OLDOP(IMAX,J)
      IM = I - IMAX
      IF(IMAX .EQ. I) GO TO 15
      DO 18 J = 1,IM
18    XSUM = XSUM + YIND(KK,IM,J)
C     PRINT*,"XSUM",XSUM
15    NK = IM
      NKMAX = I
      IF(NKMAX .GT. JSTA(KK)) NKMAX = JSTA(KK)
      NKMIN = I - MAXCR(K-1)
      IF(NKMIN .LE. 1) NKMIN = 1
      DO 20 NK1 = NKMIN,NKMAX
      SUM = 0.
      DO 25 J = 1,NK1
25    SUM = SUM + YIND(KK,NK1,J)
      IF(NK1 .EQ. I) GO TO 29
      IMNK = I - NK1
      DO 28 J = 1,IMNK
28    SUM = SUM + OLDOP(IMNK,J)
29    IF(SUM .LT. XSUM) GO TO 21
      NK = NK1
      XSUM = SUM
21    CONTINUE
C     PRINT*,"NK,SUM,XSUM", NK,SUM,XSUM
20    CONTINUE
      NKM1 = I - NK
      RETURN
      END
      SUBROUTINE TRANS(JSTA,XIND1,XIND2,XIND3,XIND4,XM,XSD,YIND)
      DIMENSION XIND1(20,9,9),XIND2(20,9,9),XIND3(20,9,9),
     $XIND4(20,9,9),XM(4),XSD(4),YIND(20,9,9),JSTA(20)
      DO 20 I = 1,20
      JMAX = JSTA(I)
      DO 20 J = 1,JMAX
      DO 20 K = 1,J
      T1 = (ALOG(XIND1(I,J,K))-XM(1))/XSD(1)
      T1 = XIND1(I,J,K) = PTRANS(T1)*100.
      T2 = (ALOG(XIND2(I,J,K))-XM(2))/XSD(2)
      T2 = XIND2(I,J,K) = PTRANS(T2)*100.
      T3 = (ALOG(XIND3(I,J,K))-XM(3))/XSD(3)
      T3 = XIND3(I,J,K) = PTRANS(T3)*100.
      IF(XIND4(I,J,K) .EQ. 0.) GO TO 25
      T4 = (XIND4(I,J,K)-XM(4))/XSD(4)
```

```
      T4 = XIND4(I,J,K) = PTRANS(T4)*100.
      YIND(I,J,K) = (T1+T2+T3+T4)/4.
      GO TO 20
25    YIND(I,J,K) = (T1 + T2 + T3)/3.
20    CONTINUE
      RETURN
      END
      FUNCTION PTRANS(T)
      INTEGER FLAG
      FLAG = 1
      IF(T .LT. 0.) FLAG = -1
      T = ABS(T)
      TERM = 1. + .196854*T + .115194*T*T + .000344*T*T*T +
     $.019527*T*T*T*T
      PTRANS = 1.-.5/TERM/TERM/TERM/TERM
      IF(FLAG .EQ. -1) PTRANS = 1.-PTRANS
      RETURN
      END
      SUBROUTINE STAT(JSTA,XIND1,XIND2,XIND3,XIND4,XM,XSD)
      DIMENSION JSTA(20),XIND1(20,9,9),XIND2(20,9,9),XIND3(20,9,9)
     $,XIND4(20,9,9), XM(4),XSD(4),X(64)
      DO 100 KK = 1,4
      IC = 0
      DO 18 I = 1,20
      JMAX = JSTA(I)
      DO 10 J = 1,JMAX
      IC = IC + 1
      GO TO (1,2,3,4),KK
1     X(IC) = XIND1(I,JMAX,J)
      GO TO 10
2     X(IC) = XIND2(I,JMAX,J)
      GO TO 10
3     X(IC) = XIND3(I,JMAX,J)
      GO TO 10
4     IF(XIND4(I,JMAX,J) .EQ. 0.) GO TO 15
      X(IC) = XIND4(I,JMAX,J)
      GO TO 10
15    IC = IC  - 1
10    CONTINUE
18    CONTINUE
      IF(KK .EQ. 4) GO TO 20
      DO 21 I = 1,IC
21    X(I) = ALOG(X(I))
20    SUM = SUMV = 0.
      DO 22 I = 1,IC
      SUM = SUM + X(I)
22    SUMV = SUMV + X(I)*X(I)
      XM(KK) = SUM/IC
      XSD(KK) = SQRT(SUMV/IC-XM(KK)*XM(KK))
100   CONTINUE
      RETURN
      END
/EOS
   20   64    1
    2    2    2    2    2    3    3    7    3    3    3    3    9    4
    1    6    3    3
```

14748.	1560.	331.4	64.7				
1650.	141.	331.4	64.7	13098.	1419.	475.4	64.7
18905.	1661.	922.3	58.5				
1012.	89.	922.3	58.5	17993.	1572.	435.4	58.5
10175.	427.	324.5	70.4				
1966.	90.	324.5	70.4	8209.	337.	431.9	70.4
5695.	107.	339.7	79.6				
1891.	60.	339.7	80.4	3804.	47.	123.5	79.0
2633.	153.	687.3	77.5				
1087.	64.	687.3	78.1	1546.	89.	1532.7	77.0
4019.	164.	467.4	89.2				
1964.	82.	467.4	89.1	2055.	82.	458.7	89.4
909.	35.	467.4	69.0	2055.	82.	458.7	89.4
1055.	47.	200.6	89.2				
16008.	954.	242.3	0.				
5337.	318.	242.3	0.	10671.	636.	113.1	0.
5337.	318.	242.3	0.	9000.	600.	113.1	0.
1671.	36.	23.7	0.				
32000.	1151.	700.8	73.5				
21649.	661.	700.8	73.2	10351.	490.	346.2	74.0
14040.	421.	700.8	70.2	7609.	240.	325.6	77.2
10351.	490.	346.2	74.0				
7713.	231.	700.8	73.9	7609.	240.	325.6	77.2
10351.	490.	346.2	74.0	6327.	190.	113.2	66.1
7713.	231.	700.8	73.9	5471.	157.	325.6	79.2
10351.	490.	346.2	74.0	6327.	190.	113.2	66.1
2138.	83.	111.	74.0				
4713.	143.	700.8	77.5	5471.	157.	325.6	79.2
10351.	490.	346.2	74.0	6327.	190.	113.2	66.1
2138.	83.	111.	74.0	3000.	88.	365.6	69.3
1816.	55.	700.8	80.1	5471.	157.	325.6	79.2
10351.	490.	346.2	74.0	6327.	190.	113.2	66.1
2138.	83.	111.	74.0	3000.	88.	365.6	69.3
2897.	86.	413.4	75.5				
8145.	7.	500.	78.4				
7345.	3.	500.	74.8	800.	4.	539.2	89.4
6545.	2.	500.	75.6	800.	4.	539.2	89.4
800.	1.	122.3	72.7				
5585.	346.	116.5	68.4				
3305.	293.	116.5	68.4	2280.	53.	10.6	68.4
1242.	41.	116.5	60.8	2280.	53.	10.6	68.4
2063.	252.	31.7	74.3				
8205.	283.	132.1	69.8				
5206.	200.	132.1	71.1	2999.	83.	196.3	68.0
2200.	69.	132.1	67.8	2999.	83.	1996.3	68.0
3006.	131.	292.2	73.9				
9270.	543.	349.4	82.0				
4886.	207.	349.4	82.0	4384.	336.	331.5	82.0
2111.	33.	349.4	82.0	4384.	336.	331.5	82.0
2775.	174.	474.4	82.0				
34721.	354.	165.7	64.4				
19633.	204.	165.7	63.0	15088.	150.	220.9	66.0
16287.	126.	165.7	52.4	15088.	150.	220.9	66.0
3346.	78.	696.5	64.2				
10536.	82.	165.7	64.3	15088.	150.	220.9	66.0
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9

7364.	52.	165.7	66.6	15088.	150.	220.9	66.0
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9
3172.	30.	231.9	60.8				
2000.	18.	165.7	69.9	15088.	150.	220.9	66.0
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9
3172.	30.	231.9	60.8	5364.	34.	101.4	64.6
2000.	18.	165.7	69.9	10337.	96.	220.9	62.4
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9
3172.	30.	231.9	60.8	5364.	34.	101.4	64.6
4751.	54.	40.4	71.2				
2000.	18.	165.7	69.9	10337.	96.	220.9	62.4
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9
3172.	30.	231.9	60.8	1942.	18.	101.4	65.1
4751.	54.	40.4	71.2	3422.	16.	28.9	64.2
2000.	18.	165.7	69.9	5953.	77.	220.9	64.2
3346.	78.	696.5	64.2	5751.	44.	154.4	59.9
3172.	30.	231.9	60.8	1942.	18.	101.4	65.1
4751.	54.	40.4	71.2	3422.	16.	28.9	64.2
4374.	19.	58.3	60.2				
24005.	1383.	117.2	0.				
14406.	831.	117.2	0.	9600.	552.	134.7	0.
14406.	831.	117.2	0.	3600.	207.	134.7	0.
6000.	345.	954.0	0.				
1200.	69.	117.2	0.	3600.	207.	134.7	0.
6000.	345.	954.0	84.0	13205.	762.	133.2	0.
14899.	1041.	1201.9	66.5				
42320.	898.	52.8	0.				
21000.	450.	52.8	0.	21320.	448.	28.6	0.
6187.	59.	12.7	0.				
42007.	1043.	126.6	63.6				
32924.	681.	126.6	64.3	9083.	362.	861.4	62.4
30040.	477.	126.6	65.8	9083.	362.	861.4	62.4
2884.	204.	79.2	59.5				
26267.	317.	126.6	64.3	9083.	362.	861.4	62.4
2884.	204.	79.2	59.5	3773.	160.	139.0	69.7
11779.	155.	126.6	61.4	9083.	362.	861.4	62.4
2884.	204.	79.2	59.5	3773.	160.	139.	69.7
14488.	162.	46.7	66.9				
2135.	21.	126.6	66.1	9083.	362.	861.4	62.4
2884.	204.	79.2	59.5	3773.	160.	139.	69.7
14488.	162.	46.7	66.9	9044.	134.	68.1	59.2
45120.	283.	43.3	0.				
30120.	198.	43.3	0.	15000.	85.	19.1	0.
24120.	156.	43.3	0.	15000.	85.	19.1	0.
6000.	42.	50.5	67.0				
17606.	122.	344.1	64.9				
3692.	21.	344.1	68.0	13914.	101.	787.7	63.3
3692.	21.	344.1	68.0	13414.	86.	787.7	62.0
1500.	15.	34.7	66.9				

APPENDIX F. HYDROLOGIC DATA BASE FOR LOWLAND KING COUNTY STREAMS & RIVERS

Status[a]	Stream	USGS Gage No.	Type[b]	Rating Quality[c]	Period of Record[d]
I	Bear Creek	12-1225	continuous	good	May 1979 →
A	Big Soos Creek	12-1126	continuous	good	1961 →
A	Cedar R nr Landsburg	12-1175	continuous	excellent	1895 →
A	Cedar R at Renton	12-1190	continuous	good	August 1945 →
I	Coal Creek	12-1197	crest	--	1964-79
I	Evans Creek	12-2340	continuous	fair	June 1955-June 1973; Oct 1973-Apr 1974; 1975-76
A	Green R nr Auburn	12-1130	continuous	good	August 1936 →
A	Green R at Tukwila	12-11335	continuous	fair	1961 →
I	Honey Creek	12-11945	continuous	fair	Apr 1978-Apr 1979
A	Issaquah Creek	12-1216	continuous	good/poor[f]	1964 →
I	Issaquah Cr East Fork	12-12151	continuous	good	Mar 1975-July 1981
A	Juanita Creek	12-1205	continuous	poor	Sep 1963-June 1973; Oct 1973-Apr 1974; 1975 →
A	Kelsey (Mercer)	12-1200	continuous	good/poor[g]	June 1955 →
I	Kelsey (Mercer) N Brch	12-1198	crest	--	1949-1967; 1970-1976
I	Lyon Creek	12-1273	crest	--	1964-1975
I	May Creek	12-1196	continuous	good	Aug 1964-Sep 1971; 1973-1977 (crest); Jan 1978-Apr 1979
I	May Creek	12-119375	continuous	good	Jan 1978-Apr 1979
A	Newaukum Creek	12-1085	continuous	good	1952 →
I	McAleer	12-1276	crest	--	1963-1974
I	Newaukum Cr North Fork	12-10795	continuous	good/fair[h]	July 1977-July 1978
I	North Creek	12-1260	crest	--	1945-1974
I	Rock Creek	12-1185	crest	--	1945-1976
A	Sammamish River near Woodinville	12-1252	continuous	fair	Jan 1965 →
A	Swamp Creek	12-1271	continuous	fair	Oct 1963-June 1973; Oct 1973-Apr 1974; Oct 1974 →
I	Tibbets Creek	12-1217	continuous	good/fair[h]	Aug 1963-Sep 1968; Mar 1971-June 1973; Oct 1973-Apr 1974; Oct 1974-Sep 1976
I	Thornton	12-1280	continuous	good	May 1961-Sep 1968

[a] I = inactive; A = active

[b] continuous recorder provides instantaneous discharges (most easily retrievable as daily average); crest recorder provides annual instantaneous peaks only

[c] excellent: 95 percent of daily discharge estimates are within 5 percent of true value
good: 95 percent of daily discharge estimates are within 10 percent of true value
fair: 95 percent of daily discharge estimaets are within 15 percent of true value
poor: less accurate than fair by indeterminate amount

[d] months for which records were collected, inclusive; when month not noted, record is for entire water year (October of preceeding year through September)

[e] records for water years 1981 on are collected from June through October only

[f] poor for period December 1 - January 25

[g] records poor above 200 cfs discharge

[h] records fair for discharges less than 1.0 cfs

APPENDIX G. Metro Data Tape Format and File Index

To facilitate analysis of Metro's water quality data with the program TREND documented in Appendix A, it was necessary to create a magnetic tape of the data compatible with the program input structure. The essential element of this structure is that the data be sequential in time. A retrieval of all Metro's streams and river water quality data was made by Metro personnel. This tape was sequential by station and date, however, no file deleters were present between stations. As a result, retrieval of the data became a tedious and time consuming process. To streamline the data retrieval process, a new tape was created in University of Washington CDC Cyber internal format with the end of file markers between each of the stations. An index to the stations in the existing routine monitoring network is given in Table E-1. Within each file, the data are formatted in 284 column records, with 80 column card images (i.e., each record consists of four card images). The data fields include alphameric indicators as follows:

> greater than
< less than
E estimated
N

Because alphameric indicators are included throughout the record, it is best to read the data as alphameric fields, then to search for the various indicators. This is the approach used in the DATIN subroutine of TREND. The variable fields in each record, and units of the data, are given in Table F-2. The master copy of the tape is held by the first author.

Table G-1. Index to Active Routine Streams and Rivers Stations on Data Tape

Metro No.	PSCOG Description	Tape File No.	Primary Basin No.
0470	Swamp Cr #1	144	1
B470	Swamp Cr #2	132	1
0474	North Cr #1	160	2
D474	North Cr #2	148	2
0478	Bear Cr #1	174	3
B478	Bear Cr #2	162	3
A432	McAleer Cr #1	69	4
E432	McAleer Cr #2	72	4
0430	Lyon Cr #1	68	5
E430	Lyon Cr #2	65	5
C446	Juanita Cr #1	124	6
0446	Juanita Cr #2	127	6
D446	Juanita Cr #3	125	6
0450	Sammamish R	128	7
0480	Sammamish R	175	7
0486	Sammamish R	194	7
N484	Evans Cr #1	188	8
J484	Evans Cr #2	185	8
G484	Evans Cr #3	182	8
C484	Evans Cr #3	178	8
0484	Evans Cr #4	192	8
B484	Evans Cr #5	177	8
R484	Evans Cr #6	190	8
0434	Thornton Cr	97	9
K434	Thornton Cr	93	9
T434	Thornton Cr	99	9
0442	Coal Cr #1	119	10
C442	Coal Cr #2	117	10
U442	Coal Cr #3	118	10
0440	May Cr #1	116	11
K440	May Cr #2	112	11
X440	May Cr #3	114	11
0444	Mercer Sl #1	122	12
C444	Mercer Sl #2	120	12
D444	Mercer Sl #3	121	12
0631	Issaquah Cr #1	226	13
A631	Issaquah Cr #1	223	13
A632	Issaquah Cr #2	227	13
0633	Issaquah Cr #3	229	13
0634	Issaquah Cr #4	231	13
A660	Issaquah Cr #5	234	13
H631	Issaquah Cr #6	225	13
A640	Issaquah Cr #7	232	13
A650	Issaquah Cr #8	233	13
3106	Lower Green R	5	14
0311	Lower Green R	26	14
0315	Lower Green R	31	14
A315	Lower Green R	29	14

0317	Black R	36	15
0438	Lower Cedar R	110	16
A438	Lower Cedar R	102	16
H438	Upper Cedar R	109	17
F320	Big Soos Cr #1	46	18
6320	Big Soos Cr #2	47	18
D320	Big Soos Cr #4	44	18
B320	Big Soos Cr #5	42	18
0320	Big Soos Cr #6	52	18
C320	Big Soos Cr #7	43	18
A319	Middle Green R	37	19
B319	Middle Green R	38	19
0321	Middle Green R	53	19
0322	Newaukum Cr #1	59	20
F322	Newaukum Cr #2	56	20
T322	Newaukum Cr #2	58	20

Table G-2. Variable Fields for Data Type

Variable	Columns	Units	Comments
Stream number	1-3	--	ignore
Station number	4-8	--	Metro identifier used throughout this report
Date	9-14	--	year-month-day
Transverse distance	15-17	meters	not relevant for small streams
Depth	18-22	meters	not relevant for small streams
Temperature	23-26	^{o}C	
DO	27-31	mg/l	
BOD	32-36	mg/l	
pH	37-40	--	
Total Coliform	41-48	counts/100 ml	
Fecal coliform	49-56	counts/100 ml	
Fecal strep	57-64	counts/100 ml	
Flow	65-71	cfs	instantaneous - see Chapter III
Suspended solids	72-78	mg/l	
NH_3-N	79-84	mg/l	
NO_3-N	85-90	mg/l	
Orthophosphate-P	91-96	mg/l	
Total P	97-102	mg/l	
Total Kjeldahl N	103-107	mg/l	
Turbidity	108-114	JTU	
Time	115-118	minutes	24 hour - 0000 = midnight
Setteable solids	119-125	mg/l	
Conductivity	126-130		
Organic N	131-135	mg/l	
Oil & grease	136-140	mg/l	
Cd	141-148	mg/l	
Cr	149-156	mg/l	
Cu	157-164	mg/l	
Hg	165-172	mg/l	
Ni	173-180	mg/l	
Pb	181-188	mg/l	
Zn	189-196	mg/l	
Pesticides	197-201		
PCB's	202-206	mg/l	
Chlorophyll A	207-212	mg/l	
Fe	213-219	mg/l	
Transparency	220-223	meters	
Hydrolyzable P	224-228	mg/l	
Alkalinity	229-233	mg $CaCO_3$/l	
Periphyton C	234-238	mg/m^2	
Periphyton P	239-243	mg/m^2	
Cloud cover	244-246	per cent	
Wind direction	247-248	--	

Wind speed	249-253	MPH
Chlorine residual	254-257	mg/l
Salinity	258-263	parts per thousand
Solar radiation	264-269	langleys/day
DO per cent saturation	270-273	per cent
Chlorinity	274-280	mg/l