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Level III: Receiving Water Quality Modeling for Urban Stormwater Management

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August 1979

LEVEL III: RECEIVING WATER QUALITY MODELING FOR URBAN STORMWATER MANAGEMENT

by

Miguel A. Medina, Jr.
Department of Civil Engineering
Duke University
Durham, North Carolina 27706

Grant No. R-802411

Project Officers

Richard Field
Chi-Yuan Fan
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplied and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The deleterious effects of storm sewer discharges and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. Efforts to alleviate the problem depend in part upon the development of improved flow attenuation and treatment devices.

Assessment of the magnitude and frequency of occurrence of the aforementioned deleterious impacts derived from wet weather flows constitutes one of the goals of urban water management analysis. The mathematical model described hereafter is a user assistance tool for preliminary screening of areawide wastewater treatment strategies. It requires the availability of an electronic digital computer. The effectiveness of proposed control measures may be compared in terms of the number of water quality violations which may result from their implementation, or by more traditional methods.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

A simplified continuous receiving water quality model has been developed as a planning guide to permit preliminary screening of areawide wastewater treatment strategies. The model simulates the hypothetical response of the stream or tidal river system to the separate and combined effects of waste inputs from: 1) upstream sources, 2) dry weather urban sources, and 3) wet weather urban sources. The total hours of runoff-producing rainfall throughout a year are separated into storm events by defining a minimum interevent time. For a given storm event, the runoff and pollutant loads are summed and critical dissolved oxygen concentrations are estimated as a function of several hydrodynamic and biochemical parameters. Alternative control strategies are evaluated in terms of relative impacts by determining the probability of occurrence of water quality violations. Model output includes the downstream dissolved oxygen sag curves computed per each event, and the dissolved oxygen profile computed at a user-specified location downstream for all simulated events. An application to the Des Moines River at Des Moines, Iowa, is presented.

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ACKNOWLEDGMENTS

Wayne C. Huber and James P. Heaney at the University of Florida provided invaluable suggestions throughout the model development stages. W. Alan Peltz was responsible for several program improvements and made the necessary modifications to interface the model with the continuous version of the Storm Water Management Model's Runoff Block. Tony Arroyo allowed the author to modify a multiple-plot subroutine for use in Level III-Receiving.

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Numerous persons at Duke University contributed to this effort. Paul Spence was assigned the task of translating portions of the author's original program from PL/I to FORTRAN IV, and assisted with instructions for data preparation. Mark Flaherty and Barbara Ann Buzun tested the model at various stages of development. Ms. Buzun performed all programming tasks assigned to her extremely well, and also assisted with instructions for data preparation. The typing was performed with dedication by Judy Edwards and Kathy Worrell. Computations were performed at the Triangle Universities Computation Center, Research Triangle Park.

SECTION I

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A simplified continuous receiving water quality model has been developed to permit preliminary planning and screening of areawide urban wastewater treatment alternatives, in terms of frequency of water quality violations and more traditional approaches such as dissolved oxygen profiles. The model name is Level III-Receiving.

Model Capabilities

1. Level III-Receiving may be interfaced through peripheral storage devices with various hourly, continuous urban catchment hydrologic simulation models, notably the Hydrologic Engineering Center model STORM and the continuous version of the EPA Storm Water Management Model (SWMM).

2. A large number of wastewater inflow combinations to the receiving body of water, dry-weather flow and wet-weather flow treatment rates, and upstream flow conditions may be simulated. Thus, a comparative evaluation of many urban pollution control alternatives is possible in terms of their subsequent impact on receiving water quality.

3. Continuous analysis of receiving water quality allows representation of the impacts due to the random occurrence and probabilistic nature of hydrologic phenomena. Two methods of evaluation of alternatives are provided by comparing:

   (i) frequency histograms or normalized cumulative frequency curves of critical dissolved oxygen concentrations (or those at a specified location downstream); and

   (ii) classical dissolved oxygen sag curves per event and a composite dissolved oxygen profile for all events at a specified location downstream from the point of waste discharge.

4. Level III-Receiving computes a minimum interevent time to define statistically independent storm events. However, an

arbitrary or otherwise user-defined value may also be supplied directly to the model as input data.

Model Applications

1. Level III-Receiving has been developed on a general basis so that it may be applied to the surface drainage phase of most urban catchments by simply changing the input data to reflect the particular study area and hydrologic time series. There is virtually no limitation to the size of catchment modeled.

2. In theory, an unlimited number of storm events may be processed; however, practical considerations such as computer time and costs may be limiting to some users.

3. Data requirements are common to engineering analysis of non-point source problems and complete instructions on data preparation are provided.

4. Field measurements, quantitative and qualitative, are necessary to adequately calibrate model parameters and verify predicted values.

Model Limitations

1. The methodology is not applicable to stream and tidal river systems of such geometry and hydrodynamic behavior as to require multi-dimensional transient analysis.

2. Complex water quality conditions, such as eutrophication, non-linear kinetic interactions, sedimentation and sediment exchange are not accounted for by the mathematical representation of the physical system.

RECOMMENDATIONS

1. Because of the model's virginity, it should be tested on other urban watersheds by those who would ordinarily interpret the results of simulation in a decision-making context.

2. The use and continuous evaluation of the program will undoubtedly result in improvements to fulfill more closely its objectives.

3. Numerical predictions made by the model should serve as guidelines throughout the planning process, and are not intended to substitute for engineering experience and judgment.

4. Data availability and quality continued to be limiting factors, even for less detailed models. Therefore,

collection efforts should be expanded along with model development.

5. The model should be expanded to characterize receiving water response when storage of wet-weather wastewater streams is considered in combination with treatment.

6. The inclusion of simplified sediment deposition and resuspension algorithms should be considered with any future development.

7. Simplified techniques to approximate the complex mechanisms of pollutant transport in lakes, bays, and estuaries should also be developed and incorporated.

SECTION II

INTRODUCTION AND MODEL OVERVIEW

PROBLEM DEFINITION AND MANAGEMENT TOOLS

In a 1.67 square mile (433 hectare) urban watershed in Durham, North Carolina, it was found that the dissolved oxygen content of the receiving watercourse was independent of the degree of municipal waste treatment beyond secondary during storm flows (Colston, 1974). Approximately one-half of the stream miles in the United States are water quality limited and 30 percent of these stream segments are considered polluted to a certain degree with urban stormwater runoff (Field, *et al*., 1977). The implication is that, generally, secondary treatment of dry-weather wastewater flows is insufficient to meet desired receiving water quality standards; therefore, control of runoff pollution must be considered in areawide wastewater management plans and abatement programs. The results of a nationwide assessment of costs and related water quality impacts derived from non-point sources (Heaney, *et al*., 1977) were, among others, that:

- wet-weather flows represent at least 50 percent of the total wastewater flow from urban areas;
- a generalized optimization model, assuming linear costs, predicted primary type facilities are preferable only up to a 10 percent level of BOD removal for wet-weather flows, with a secondary type facility preferable for higher levels of control; and
- on a national average basis using BOD removal as the effectiveness parameter, approximately 39 percent of the combined sewer problem and 10 percent of the wet-weather flows should be controlled before initiating tertiary treatment of point sources.

The study also confirmed that gross inadequacies exist in our present data base and conclusions are highly sensitive to simplifying assumptions necessary for successful simulation of complex physical processes occurring throughout our watersheds. Nevertheless, mathematical models are needed to predict variable responses to stochastic hydrologic phenomena.

The 208 planning effort (Section 208, PL 92-500) has established the need for various levels of urban wastewater management analysis (Field, et al., 1977) to permit preliminary screening of municipal treatment alternatives. Four distinct levels of evaluation techniques, ranging from simple to complex procedures which can be integrated with one another, are summarized in Table II-1. The first three levels essentially represent various degrees of planning detail with models running on hourly time steps for long simulation periods (years). Mathematical complexity and data requirements are kept at a minimum. Of course, the original detailed (single-event) SWMM is typically used with short time steps (minutes) and short simulation times (hours). Its data requirements are usually very substantial. The approach guiding the development of Level III-Receiving was that the cost-effectiveness of various treatment alternatives can be determined realistically only by a continuous analysis of the frequency of violation of water quality standards.

MODEL OVERVIEW

The essence of a rational water quality and quantity management program is the decision making process. The high cost of pollution control facilities, in terms of both energy utilization and financial burden, obligates the planning agency to select the optimal strategy for areawide wastewater management. Such a process must focus on a systematic procedure that identifies and defines: 1) the cause/effect relationships of the physical environment; 2) the economic realities of control alternatives; and 3) the benefits to be derived from implementation of these controls. A preliminary analysis that provides an approximation of system responses to proposed treatment measures should aid the selection of the best strategy for restoration of water bodies to accepted water quality standards. Such an analysis must never be interpreted as other than a guide to be tempered by professional judgment. The mathematical models applied need not incorporate all phenomena but rather should be relevant to the problem under consideration. The problem of specific interest is to assess the separate and combined effects of the major urban sources of water pollution upon the quality of the receiving waters. Oxygen concentration is considered the key to the quality of natural water bodies, although it certainly is not the only water quality indicator. Thus, the relative impact of these wastewater sources is appraised by their effect on the dissolved oxygen concentrations downstream from the urban area. It is of further interest to distinguish clearly between the two types of urban stormwater runoff, separate sewer flow and combined sewer overflow, and their relative pollutional impacts. In essence, the mathematical model must be responsive to the land use, hydrology, and climatology of the drainage area while performing the following functions:

Table II-1. Levels of Urban Water Management Analysis Developed by EPA Research & Development Programs (modified after Field, et al., 1977)

Level I: a desktop calculator, statistical analysis procedure, no electronic digital computer required.

- University of Florida Methodology - permits the user to estimate the quantity and quality of urban runoff in the combined, storm and unsewered portions of each urban area.

- Hydroscience, Inc. Methodology - use of a stormwater simulator and an analytical method based on probability distribution functions and statistical properties of rainfall, runoff, treatment and receiving water impact.

Level II: a simplified continuous simulation model for planning and preliminary sizing of facilities, developed by Metcalf & Eddy, Inc; or the computerized optimization version of University of Florida Methodology described above.

Level III: a refined continuous simulation model approach. Continuous hydrologic simulation models (e.g., STORM or continuous SWMM) which generate urban runoff hydrographs and pollutographs are followed by continuous receiving water impact analyses (Level III-Receiving model).

- Continuous SWMM - University of Florida

- STORM - Corps of Engineers by Water Resources Engineers, Inc.

Level III-Receiving -- Duke University

Level IV: a sophisticated single event simulation model, e.g. EPA SWMM developed by Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, Inc.

- generate stormwater runoff pollutant loads and dry-weather sanitary flow pollutant loads;
- simulate the pollutant removal efficiency of various treatment schemes;
- simulate the conveyance system, including mixing in combined sewers of wet- and dry-weather pollutants;
- mix the various pollutant inflow combinations with pollutants already in the receiving water (from upstream sources);
- predict the oxygen balance of the polluted waters downstream from the waste sources; and
- predict the frequency with which wastewater inputs result in dissolved oxygen levels in the receiving body of water which exceed a wide range of DO values extending throughout the possible spectrum (say, 0 to 15 mg/l in intervals of 0.5 mg/l).

Data for the study area are used to simulate the hypothetical response of the receiving water to the separate and combined effects of BOD waste inputs from: 1) upstream sources, 2) dry-weather urban sources, and 3) wet-weather urban sources. A system schematic is presented in Figure II-1. The urban community served by a separate sewer system will convey stormwater runoff and municipal sewage through conduits which are not connected together. The BOD concentration of the storm sewer runoff is mixed with the dry-weather flow (DWF) and the solids accumulated in the combined sewer system. An interceptor carries the sanitary design flow to the municipal sewage treatment plant. The combined sewer overflow is either given treatment or allowed to discharge directly to the receiving water. Since complete mixing is assumed, the BOD concentrations of the combined sewer overflow (Q_c) and the flow (DWFCMB) intercepted for treatment by the DWF facility are identical. Any degree of treatment desired may be imposed at both the DWF and the wet-weather flow (WWF) treatment plants. The concentration of the combined BOD inputs in the receiving water is given by:

$$BOD_m = \frac{BOD_u Q_u + BOD_d Q_d + BOD_w Q_w}{Q_u + Q_d + Q_w} \qquad \text{(II-1)}$$

where BOD_m = mixed BOD concentration in receiving water, mg/l,

BOD_u = mixed BOD concentration from sources upstream of urban area, mg/l,

BOD_d = BOD concentration of dry-weather flow treatment plant effluent, mg/l,

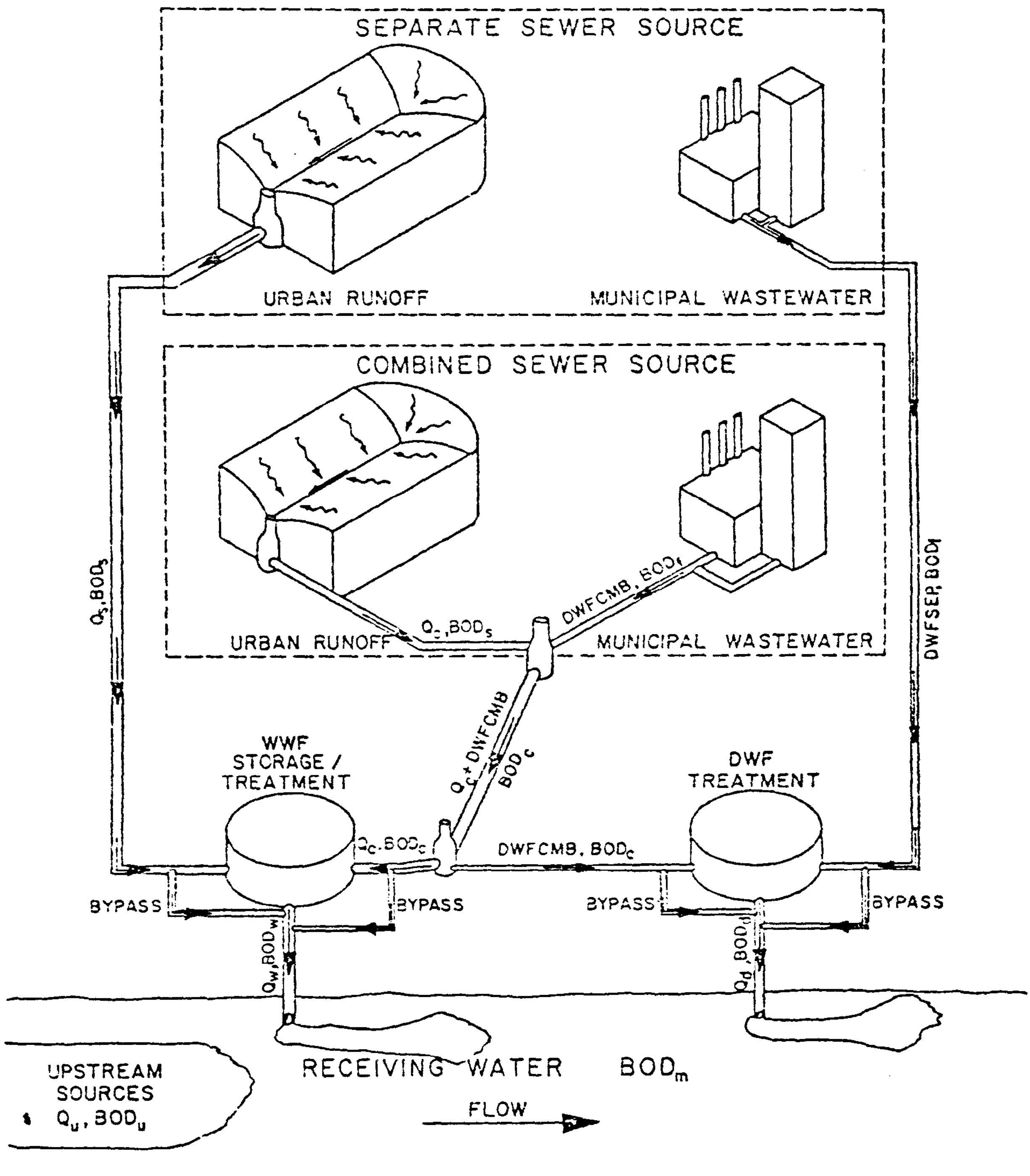


Figure II-1. Urban Wastewater Inputs to Receiving Body of Water.

BOD_w = BOD concentration of wet-weather flow treatment facility effluent, mg/l,

Q_u = upstream flow, cfs,

Q_d = DWF treated effluent, cfs, and

Q_w = WWF treated effluent, cfs.

The technique for calculation of the quantity and quality of stormwater and combined sewer overflows is discussed in further detail subsequently. The BOD concentrations of the DWF and WWF treated effluents are given by:

$$BOD_d = \frac{[BOD_f \cdot DWFSEP + BOD_c \cdot DWFCMB](1-R_d)}{DWFSEP + DWFCMB} \quad \text{(II-2)}$$

$$BOD_w = \frac{[BOD_s \cdot Q_s + BOD_c \cdot Q_c](1-R_w)}{Q_s + Q_c} \quad \text{(II-3)}$$

where BOD_f = BOD concentration of municipal sewage, mg/l,

BOD_c = mixed BOD concentration in the combined sewer, mg/l,

BOD_s = BOD concentration of urban stormwater runoff, mg/l,

DWFSEP = DWF contribution from separate sewer area, cfs,

DWFCMB = DWF contribution from combined sewer area, cfs,

Q_s = urban runoff carried by the separate storm sewer, cfs,

Q_c = urban runoff carried by collection system of combined sewer area, cfs,

R_d = fraction removal of BOD achieved by the DWF treatment facility, and

R_w = fraction removal of BOD achieved by the WWF treatment facility.

The initial conditions of BOD in the river are defined by equation II-1, and the hypothetical impact on the oxygen balance of the receiving stream is estimated by using simplified mathematical modeling approaches. The total hours of runoff-producing rainfall throughout the year are separated into storm events by defining a minimum interevent time. The procedure is discussed in detail subsequently. For a given storm event, the runoff and pollutant loads are summed and the critical DO deficit is estimated as a function of several stream parameters: temperature, flow, oxygen concentration, deoxygenation and reaeration rates, longitudinal dispersion, and BOD concentrations. The minimum DO is calculated subsequently and a frequency analysis is performed. Stream velocity is computed as a function of the discharge and the time and distance to each critical deficit point are obtained for each event.

The options used for the simulations include:

1. five inflow combinations:
   a. river flow + DWF
   b. river flow + DWF + separate storm flow
   c. river flow + DWF + combined storm flow
   d. river flow + separate storm flow + combined storm flow
   e. river flow + separate storm flow + combined storm flow + DWF,
2. four DWF treatment rates (variable),
3. three WWF treatment rates (variable), and
4. three fractions of measured upstream flow may be investigated.

Item 4 is included as a model option to investigate whether the relative impact of urban stormwater runoff is most significant in the upstream portions of river basins. This effect may be simulated by simply reducing the upstream flow to any desired fraction of its actual measured value. Thus, discharge into a dry river bed may be studied.

CALCULATION OF URBAN RUNOFF QUANTITY AND QUALITY

The methods used to generate storm runoff flows and pollutant mass rates or concentrations depend upon the continuous hydrologic simulation model selected by the user. Such techniques are described here briefly for two models which may be applied to both urban and non-urban watersheds: 1) STORM, the H.E.C. Storage, Treatment, Overflow, Runoff Model (Hydrologic Engineering Center, 1976), and 2) the U. S. Environmental Protection Agency's Storm Water Management Model (SWMM), continuous version of Runoff Block (Huber, *et al.*, 1977).

Urban Runoff Quantity -- STORM

STORM computes urban runoff as a function of land use and rainfall/snowmelt losses (Hydrologic Engineering Center, 1976):

$$AR_u = CR_u \; (P_u - f_u) \qquad \text{(II-4)}$$

where AR_u = urban area runoff, in/hr,

CR_u = composite runoff coefficient dependent on urban land use,

P_u = hourly rainfall/snowmelt in inches over the urban area, and

f_u = available urban depression storage, in.

The hourly urban runoff values, expressed in cfs, are saved in a file for later recall by Level III-Receiving (this requires a minor modification to STORM - see Section V). The composite runoff coefficient accounts for losses due to infiltration and is a function of runoff coefficients for pervious and impervious surfaces, land use, and fraction of impervious surface area for each land use.

Urban Runoff Quantity -- SWMM

To use SWMM the drainage area is subdivided into subcatchments, gutters, and pipes. Each catchment is divided into pervious areas and impervious areas, with and without surface detention, for runoff computations from rainfall data in the form of hyetographs read into the Runoff Block (Huber, et al., 1975). Subcatchments are defined by area, width, slope, and ground cover, while gutters and pipes are described by slope, length, and Manning's roughness coefficient. Instant runoff is assumed from impervious areas without surface detention, and no infiltration is computed on impervious areas with detention. A stepwise computation of runoff volume for pervious areas proceeds as follows (Metcalf and Eddy, Inc., et al., 1971):

1. The water depth on the subcatchment is found from the hyetograph from

$$D_1 = D_t + R_t \quad \Delta t \qquad \text{(II-5)}$$

where D_1 = water depth after rainfall

D_t = water depth at time t

R_t = intensity of rain, time interval Δt.

2. The integrated form of Horton's exponential function (Huber, et al., 1977) is used to account for infiltration loss by

$$M(t_p) = \int_0^{t_p} f_{cap}\, dt = f_\infty t_p + \frac{(f_o - f_\infty)}{\alpha} (1 - e^{-\alpha t_p}) \qquad \text{(II-6)}$$

where f_{cap} = infiltration capacity into soil ,

f_∞ = minimum or ultimate value of f (at $t = \infty$),

f_o = maximum or initial value of f (at $t = 0$),

t = time from beginning of storm,

α = decay coefficient,

M = cumulative infiltration at time t_p.

The above equation cannot be solved explicitly for t_p, and thus must be computed iteratively. It should be noted that $t_p \leq t$ which states that the time t_p on the cumulative Horton curve will be less than or equal to actual elapsed time. Therefore, the available infiltration capacity, f_{cap} (t_p) in Figure II-2(b), will be greater than or equal to that given by Horton's equation, shown in Figure II-2(a). Thus, f_{cap} will be a function of actual water infiltrated and not a function of time only. At each time step, the value of f_{cap} depends upon M. Then, the average infiltration capacity, $\bar{f}_{cap}$, available over the next time step is computed by

$$\bar{f}_{cap} = \frac{M(t_1) - M(t_p)}{\Delta t} \qquad \text{(II-7)}$$

The actual infiltration is determined from

$$\bar{I}_t = \min\,[\bar{f}_{cap}, \bar{i}] \qquad \text{(II-8)}$$

where $\bar{I}_t$ = average actual infiltration over the time step,

$\bar{i}$ = average rainfall intensity over the time step,

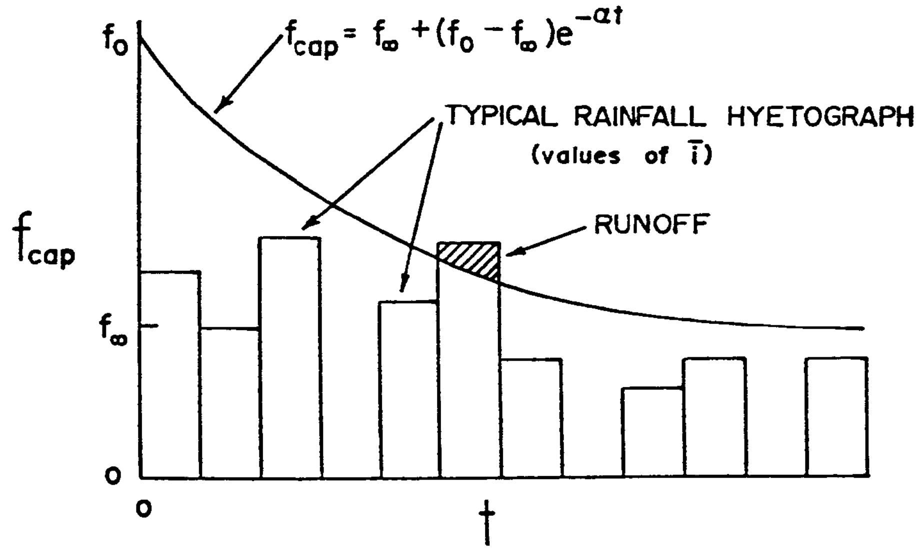
and equation (II-8) simply states that actual infiltration will be the lesser of actual rainfall and infiltration capacity.

3. Infiltration is subtracted from water depth according to

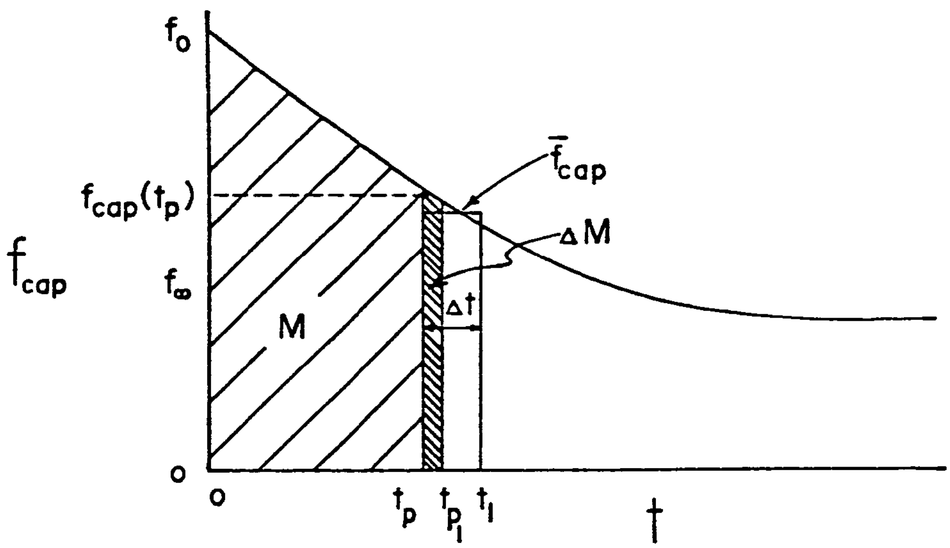
$$D_2 = D_1 - \bar{I}_t\, \Delta t \qquad \text{(II-9)}$$

where D_2 = depth after infiltration.

4. The water depth D_2 is compared to the specified detention depth D_d and, if found greater, the outflow for the subcatchment is found by first applying Manning's equation for velocity



(a) Horton Infiltration Curve and Typical Hyetograph



(b) Cumulative Infiltration, M, Integral Form of Horton's Equation

Figure II-2. Infiltration Relationships for Continuous Hydrologic Simulation (modified after Huber, et al., 1977).

$$V = \frac{1.49}{n} (D_2 - D_d)^{2/3} S^{1/2} \qquad \text{(II-10)}$$

where V = velocity

n = Manning's coefficient

D_d = detention depth

S = ground slope

and then obtaining outflow, Q_w, from

$$Q_w = VW (D_2 - D_d) \qquad \text{(II-11)}$$

where W is the width of the area.

5. Water depths on the subcatchments are computed by the continuity equation:

$$D_{t+\Delta t} = D_2 - \frac{Q_w \Delta t}{A} \qquad \text{(II-12)}$$

where A is the surface area of the subcatchment.

The preceding steps are repeated until computations for all subcatchments are completed, then

6. Gutter inflow, Q_{in}, is found by adding the outflow of the subcatchments tributary to it and the flow from all upstream gutters,

$$Q_{in} = \sum Q_{w,i} + \sum Q_{g,i} \qquad \text{(II-13)}$$

where $\sum Q_{w,i}$ = sum of flow from subcatchments

$\sum Q_{g,i}$ = sum of flow from upstream gutters.

7. Depth of flow in gutters is calculated as follows:

$$Y_1 = Y_t + \frac{Q_{in}}{A_s} \Delta t \qquad \text{(II-14)}$$

where Y_1, Y_t = water depths in gutter

A_s = mean water surface area between Y_1 and Y_t.

8. Outflow from the gutters is computed from Manning's equation also,

$$V = \frac{1.49}{n} (R)^{2/3} (S_i)^{1/2} \qquad \text{(II-15)}$$

where R = hydraulic radius

S_i = invert slope

$$Q_g = VA_c \qquad \text{(II-16)}$$

where A_c is the cross-sectional area at Y_1.

9. Water depth in gutters is found using the continuity equation

$$Y_{t+\Delta t} = Y_1 + \frac{(Q_{in} - Q_g)\ \Delta t}{A_s} \qquad \text{(II-17)}$$

where all symbols are as defined previously.

10. Gutter computations are carried out for all gutters in the system and summed to yield runoff. All of the above processes are repeated for successive time periods until the complete hydrograph is computed.

The algorithms used in Runoff for the continuous version are almost identical to the single event model (Huber, et al., 1977), with the exception of snowmelt. The main difference is basically that the continuous option uses data sets or off-line storage (disk/drum/tape) to access precipitation and temperature input data instead of dimensioned arrays. Also, for continuous simulation, infiltration capacity will be regenerated during dry weather time steps according to the hypothetical drying curve (see Figure II-3):

$$f_{cap} = f_o - (f_o - f_\infty) \exp[-\alpha_d (t - t_w)] \qquad \text{(II-16)}$$

where α_d = decay coefficient for the recovery curve

t_w = hypothetical projected time at which $f_{cap} = f_\infty$ on the recovery curve.

Urban Runoff Quality

The techniques used by both STORM and the surface runoff quality model in SWMM are essentially the same. It is assumed that the amount of pollutant which can be removed during a storm event is dependent on rainfall duration and initial quantity of pollutant. The process can be modeled by a first-order differential equation:

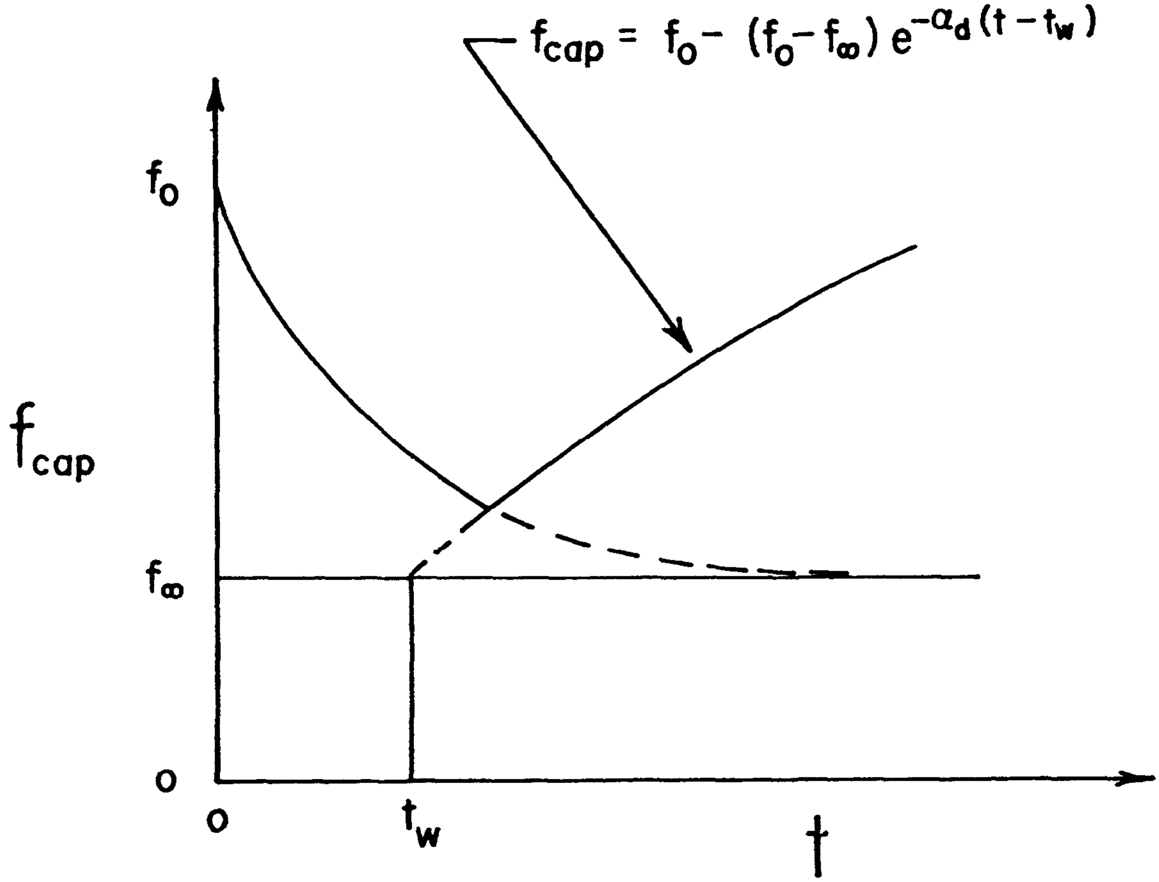


Figure II-3. Regeneration (Recovery) of Infiltration Capacity During Dry Time Steps (modified after Huber, et al., 1977).

$$- \frac{dP}{dt} = kP \qquad \text{(II-17)}$$

which integrates to

$$P_o - P = P_o \; (1 - e^{-kt}) \qquad \text{(II-18)}$$

where P_o = pollutant originally on ground, mg

P = pollutant after time t, mg

k = constant, and is assumed to be directly proportional to the rate of runoff.

The basic water quality parameters modeled by STORM and SWMM are suspended and settleable solids, BOD, total nitrogen (N), total phosphate (PO_4), and total coliform. It is important to emphasize that the BOD values are expressed in terms of the standard BOD_5 test: incubation at a temperature of 20°C for 5 days. The BOD loading rates generated by STORM and SWMM are based on land use and other factors such as number of dry days without runoff since the last storm and the street sweeping intervals. Other water quality parameters modeled by SWMM are grease, oil and COD.

SECTION III

USE OF FREQUENCY CURVES IN HYDROLOGIC AND WATER QUALITY SIMULATION

Rational water resource management must account for hydrologic uncertainty and associated water quality variability. The justification for continuous hydrologic simulation in dealing with problems of urban stormwater runoff quantity and quality is the probability of occurrence of events of various magnitudes (Linsley and Crawford, 1974). The practice of performing frequency analysis on historical data collected from natural phenomena has been in existence for almost a century. Frequency analysis of streamflow data is believed to have been first applied to flood studies by Herschel and Freeman (Foster, 1934). Today, modern electronic computers are used to generate synthetic streamflows because in many cases existing records are not sufficiently extensive to provide estimates of important statistics. Such approximate models are sufficiently realistic to improve the planning process significantly (Fiering and Jackson, 1971).

The conventional approach of selecting single design events during critical time periods (low-flow conditions) for water resource management is inadequate for several important reasons:

- No reliable probability or frequency of occurrence can be determined for the single event (Linsley and Crawford, 1974).

- The most critical impact on receiving water quality does not necessarily occur under low flow conditions, because of intermittent urban runoff pollutant shock loads (Heaney, et al., 1977).

- Studies have demonstrated that high frequency storms over urban catchments cause significantly greater total annual pollutant loadings from combined sewer overflows than low frequency storms associated with higher flows (Vilaret and Pyne, 1971).

- No accepted design event condition exists which also specifies a design antecedent dry-weather period (Heaney, et al., 1977).

- Sizing wet-weather pollution control units for storm intensities associated with the less-frequent events (e.g., two year recurrence-one hour duration storms versus two-week recurrence intervals) requires relatively large storage/treatment capacities (Heaney, et al., 1977).

HYDROLOGIC FREQUENCY STUDIES

The traditional approach upon the problem of determining theoretical probabilities of hydrologic events has been the derivation of *frequency curves*. These curves relate the magnitude of a variable to *frequency of occurrence*, and are an estimate of the cumulative distribution of the population of that variable as prepared from a sample of data (Riggs, 1968). The probability of a single event, say x_1, is defined as the relative number of occurrences of the event after a long series of trials or observations from a historical record:

$$P(X=x_1) = n_1/N \qquad \text{(III-1)}$$

where X = denotes a hydrologic *event*, say streamflow

x = *magnitude* of that event

n_1 = number of occurrences of event of magnitude x_1

N = total number of observations of event X.

The number of occurrences n_1 is the frequency, whereas n_1/N is the *relative frequency*. When the number of values a random variable can take on is restricted to an integer number (say 0, 1, 2, ...), the random variable is called *discrete* and its probability law is usually presented in the form of a probability mass function (PMF):

$$P_X(x_i) = P(X=x_i) \qquad \text{(III-2)}$$

and, by definition

$$\sum_{\text{all } x_i} P_X(x_i) = 1 \qquad \text{(III-3)}$$

where x_i = discrete values of random variable X.

Equation (III-2) describes the probability or frequency distribution of a random variable. An equivalent means is obtained through the use of the *cumulative distribution function* (CDF):

$$F_X(x_i) = P(X \le x_i) = \sum_{\substack{\text{all} \\ x_i \le x}} P_X(x_i) \quad \text{(III-4)}$$

for discrete random variables, and the function increases monotonically from a lower limit of zero to an upper bound of unity.

Unlike the discrete variable, the continuous random variable is free to take on any value on the real axis. If the abscissa (x axis) is separated into a large number of short intervals Δx, and the ordinate is the function $f_X(x)$, such that the area under the curve in an interval represents the probability that the random variable will take on a value in that interval, then:

$$P(x_1 \le X \le x_2) = \int_{x_1}^{x_2} f_X(x)\, dx \quad \text{(III-5)}$$

where

$$f_X(x) \ge 0 \quad \text{(III-6)}$$

$$\int_{-\infty}^{\infty} f_X(x)\, dx = 1 \quad \text{(III-7)}$$

and

$$f_X(x) = \lim_{\Delta X \to 0} \frac{\Delta F(x)}{\Delta x} = \frac{dF(x)}{dx} \quad \text{(III-8)}$$

= probability density function (PDF).

The cumulative distribution function is defined in terms of the PDF as

$$F_X(x) = P(X \le x) = P(-\infty \le X \le x) = \int_{-\infty}^{x} f_X(u)\, du \quad \text{(III-9)}$$

where u = dummy variable of integration.

The relationship between the PDF and CDF of a random variable is illustrated in Figure III-1.

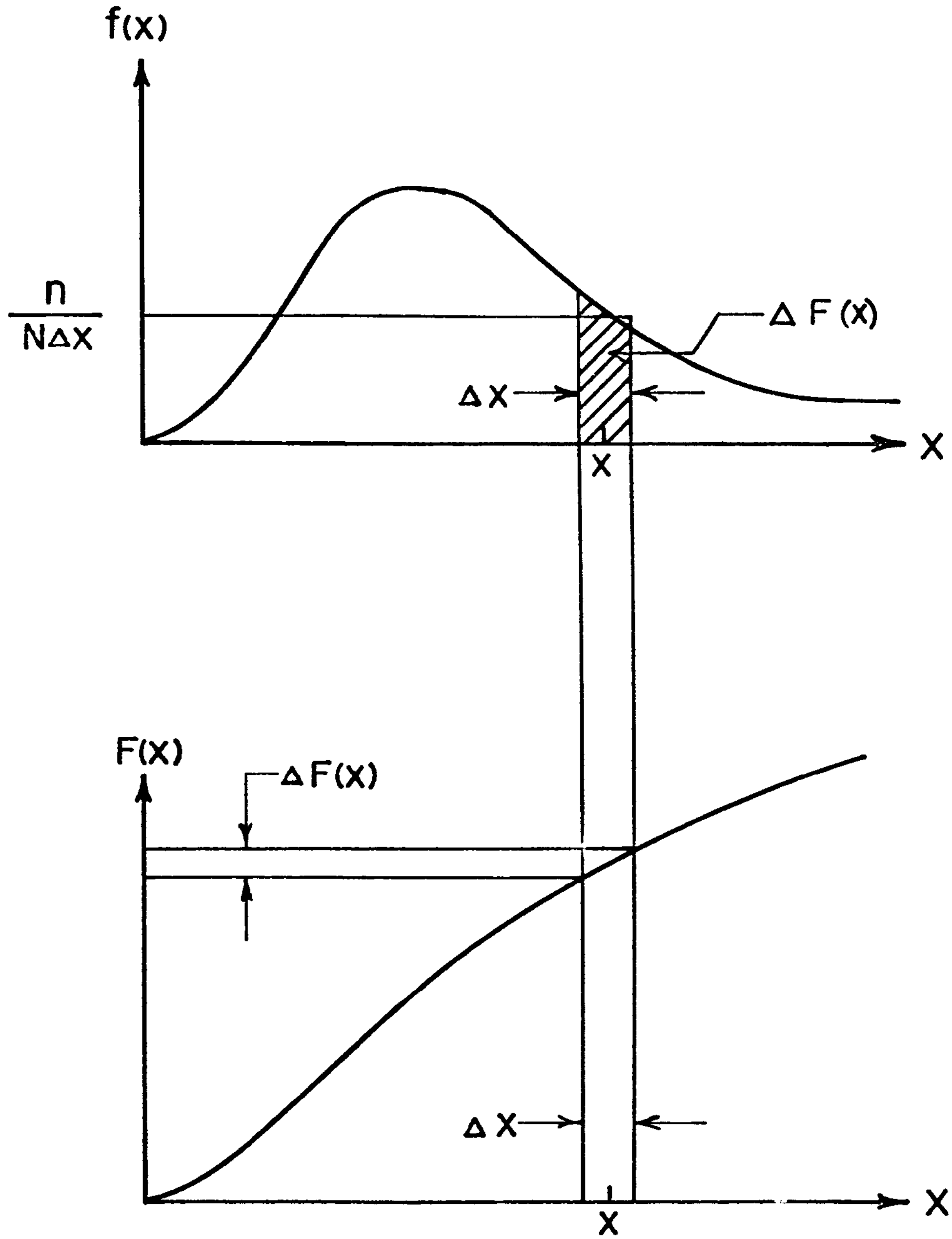


Figure III-1. The Probability Density Function and its Cumulative Distribution Function.

The cumulative distribution function has been defined as the expected number of occurrences less than a given value; however, it is also convenient to examine its complement -- the expected number greater than or equal to the given magnitude:

$$G_X(x) = 1 - F_X(x) = P(X \geq x) \qquad \text{(III-10)}$$

It should be noted again that for hydrologic applications the CDF or its complement may be referred to as frequency curves. Earlier statisticians also used the term cumulative frequency function (Burr, 1942). The area under either the CDF curve or its complement is meaningless: expected frequencies in any given range are found by simply taking the difference between ordinates. For example, $P(x_1 \leq X \leq x_2)$ is evaluated as $F_X(x_2) - F_X(x_1)$. The probability distribution of sampled data taken from a continuous distribution is a special case of discrete distributions and may be computed in the form of the arithmetic summations presented earlier (Benjamin and Cornell, 1970).

Hydrologic applications of frequency curves include: the design of bridge openings, channel capacities, flood-plain zoning, industrial and domestic water-supply systems, storage reservoirs, and forecasting problems (Riggs, 1968). The flow-frequency, or flow-duration, curve specifically accounts for hydrologic uncertainty in the design and planning of flood-control or drought-relief facilities. The duration curve is the integral of the probability curve, and early investigators concluded the latter to be described best by the Gauss-Laplace normal distribution curve (Beard, 1943). A typical flow-duration curve for a hypothetical watershed is shown in Figure III-2.

In later studies, an index of the variation of flow in a stream was developed from duration curves of discharge (Land and Lei, 1950). An extensive treatise on flow-duration curves is available elsewhere (Searcy, 1959). These curves are considered useful even though the events may not be completely independent of each other; that is, they may be serially correlated (Riggs, 1968).

WATER QUALITY FREQUENCY CURVES

Figure III-3 illustrates water quality standard cumulative frequency curves for varying levels of pollutant removal schemes exercised by a hypothetical metropolitan area upstream. At the higher level of control, it is expected that a higher number of events equal or exceed the established water quality standard minimum concentration. Thus, fewer occurrences of water quality standard violations are predicted. These curves are an integral part of the printed output provided by Level III-Receiving. The

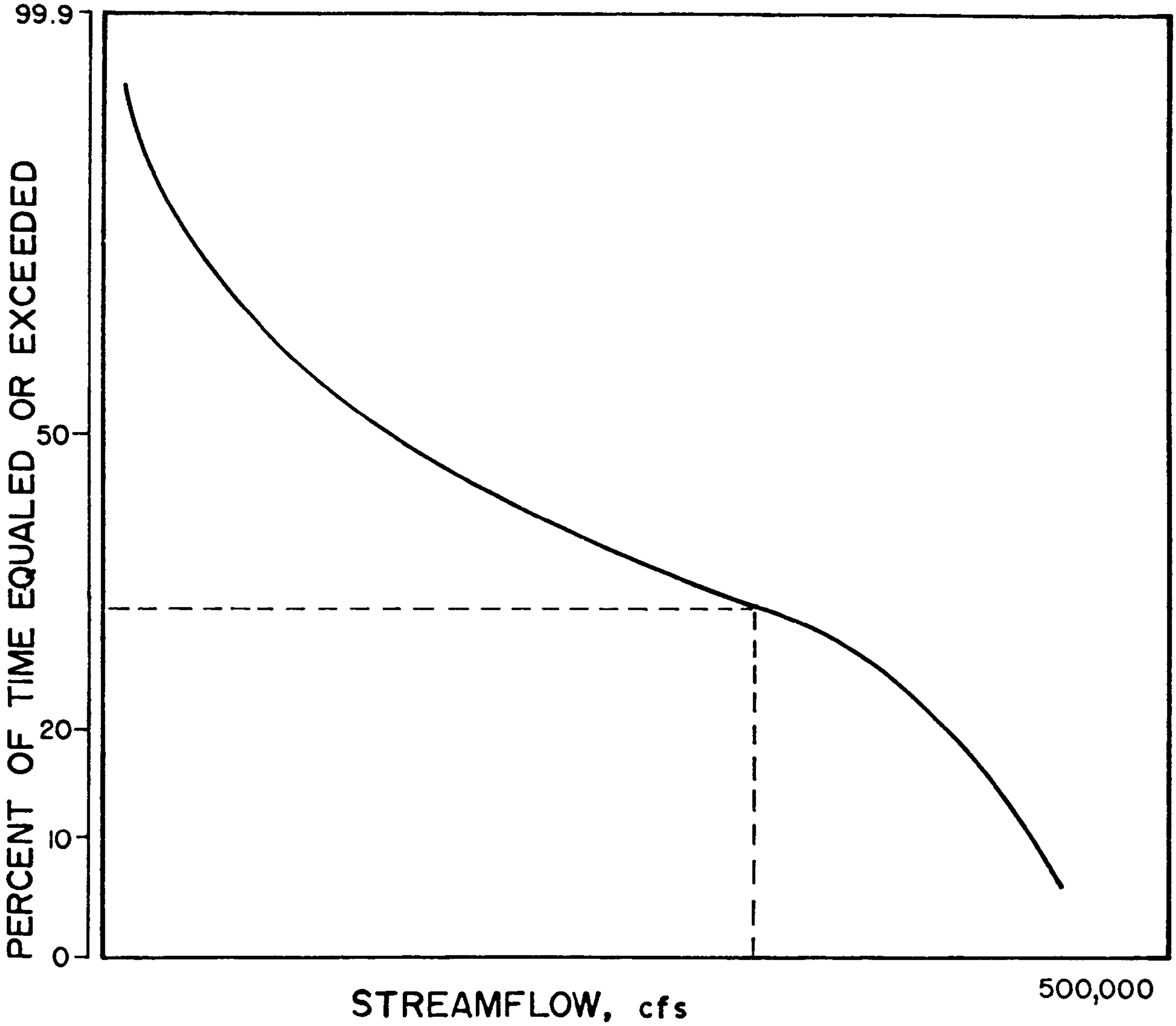


Figure III-2. Flow-Duration Curve for Hypothetical Watershed.

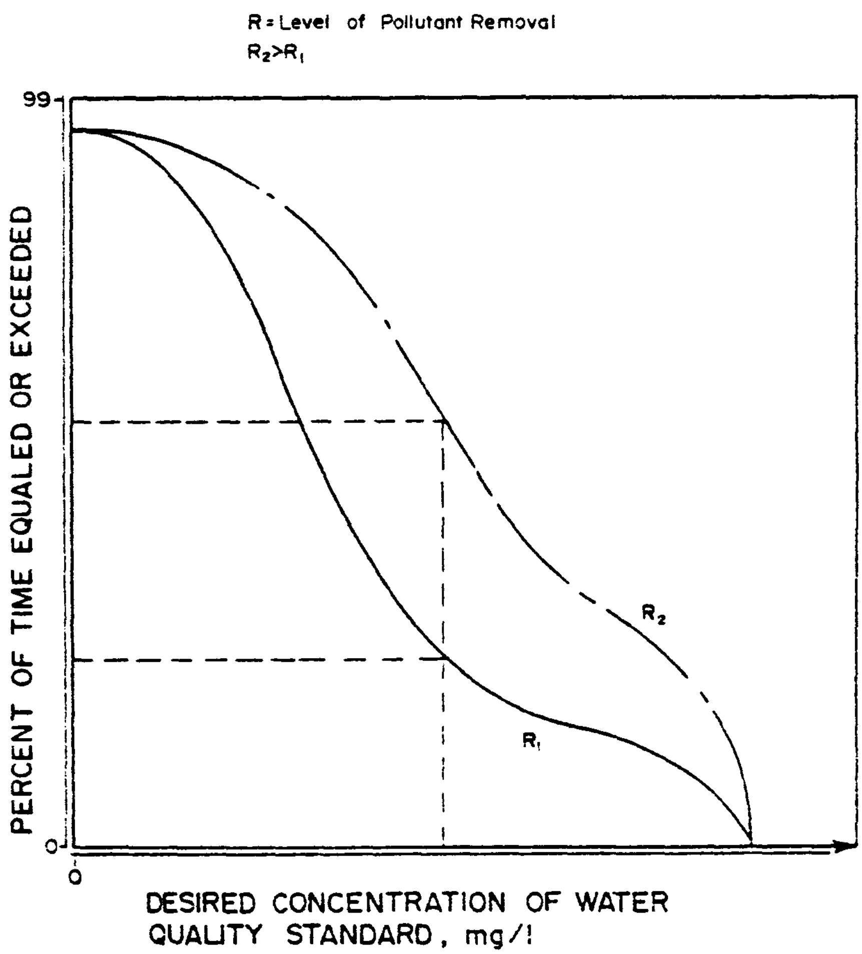


Figure III-3. Cumulative Water Quality Frequency Curves for Hypothetical Watershed.

interpretation of such curves is the subject of further detail in Section VI. Frequencies of dissolved oxygen concentrations are computed in the model for class intervals of 0.5 mg/l, from 0.0 to 15.0 mg/l. The percent of time equaled or exceeded for a given magnitude of the dissolved oxygen stream standard is computed from:

$$\text{\% Time Equaled or Exceeded} = 100 \left[\frac{N-n_i}{N}\right] \tag{III-11}$$

where n_i = cumulative frequency of occurrence (successive partial sums) in class interval i

i = 1, 2, ... , 31

for various levels of pollutant removal and waste inflow combinations.

In contrast to the century-old practice of frequency analysis for flood control, drought severity, and other quantitative hydrologic applications, its use in water quality control has developed within the last decade. Downstream damages, in terms of water treatment costs at a point, have been related to probability of occurrence or exceedence (Kneese and Bower, 1968). The damages varied according to the dilution provided by streamflow. Cumulative frequency curves have been proposed to relate probability to annual, stream waste-assimilative capacity (Velz, 1970) under natural hydrologic variations. In a study by Hydrocomp International and Black & Veatch of the South Platte River (where the modeling area was centered around Denver, Colorado) minimum dissolved oxygen cumulative frequency curves were compared for various dry-weather wastewater treatment plant configurations (Denver Regional Council of Governments, 1974).

SECTION IV

METHODOLOGY

This section describes the development of the water quality model in terms of the basic mathematical formulations. The limitations of a simplified approach to the modeling of receiving water quality are also discussed. As stated previously, the results of an actual model application to Des Moines, Iowa, and the Des Moines River are presented and interpreted in Section VI.

EVENT DEFINITION

The continuous hydrologic simulation models, STORM and the latest version of SWMM, operate on hourly time steps. Rainfall inputs are used by these models to generate the corresponding series of hourly urban runoff. The basic approach to define a wet-weather event is to analyze the runoff time series and establish the minimum number of consecutive dry-weather hours (DWH) that separates independent storm events. The independence of these events is not defined in a strictly climatologic sense, it is in fact statistically derived. The DWH refer to periods during which no runoff was produced. If STORM is selected to generate the hydrologic time series, depression storage and evaporation rates must be satisfied before any runoff is predicted but no runoff occurs during periods of no measurable precipitation. The continuous version of SWMM allows runoff to decay temporally beyond intervals with zero precipitation input. Therefore, for an identical precipitation time series, runoff events generated by SWMM will generally be of longer duration.

The runoff time series is subjected to autocorrelation analysis. For hydrologic processes, it is practical to estimate the autocorrelation coefficients by an open-series approach (Yevjevich, 1972 and Fiering and Jackson, 1971):

$$r_I(k) = \frac{\sum_{i=1}^{n-k} x_i x_{i+k} - \frac{1}{n-k}\left[\sum_{i=1}^{n-k} x_i\right]\left[\sum_{i=k+1}^{n} x_i\right]}{\left[\sum_{i=1}^{n-k} x_i^2 - \frac{1}{n-k}\left(\sum_{i=1}^{n-k} x_i\right)^2\right]^{0.5}\left[\sum_{i=k+1}^{n} x_i^2 - \frac{1}{n-k}\left(\sum_{i=k+1}^{n} x_i\right)^2\right]^{0.5}} \qquad \text{(IV-1)}$$

where $r_I(k)$ = sample estimate of lag-k autocorrelation coefficient for hydrologic process I,

x_i = discrete data series (observations) of hydrologic process I, for i = 1, 2, ..., n,

n = total number of data points or observations, and

k = number of hourly lags.

The tolerance limits for a normal random time series which is circular and of lag 1, $TL[r_I(1)]$, is given by (Anderson, 1942):

$$TL\ [r_I(1)] = \frac{-1 \pm t_\alpha \sqrt{n-2}}{n-1} \qquad \text{(IV-2)}$$

where t_α = standardized normal variate corresponding to probability level $1 - \alpha$.

A circular time series is defined as a series where the last value is followed by the first so that the time series repeats itself. Equation (IV-2) has been extended for use with an open series, for the general lag case (Yevjevich, 1972). At a 95 percent probability level, the tolerance limits are given by:

$$TL\ [r_I(k)] = \frac{-1 \pm 1.645 \sqrt{n-k-1}}{n-k} \qquad \text{(IV-3)}$$

A plot of the serial correlation coefficients, r(k), against the number of lags, k, is called a correlogram. The technique of autocorrelation analysis is essentially a study of the behavior of the correlogram of the process under investigation (Quimpo, 1968). The model compares the value of r(k) obtained from equation (IV-1) with $TL[r_I(k)]$, computed by equation (IV-3), for the corresponding number of hourly lags k. The <u>minimum interevent time</u> (MIT) which separates independent wet-weather events is defined as the minimum value for k for which r(k) is not significantly different from zero at a 95 percent probability level.

Once the MIT has been determined by the mathematical model, its value is compared with the number of DWH preceding each runoff event. A wet-weather event and its duration are defined by the model as follows:

(1) any runoff occurrence having a number of DWH preceding it greater than or equal to the MIT denotes the beginning of the event;

(2) subsequent runoff occurrences are considered part of the event as long as the DWH immediately preceding each occurrence are less than the MIT;

(3) the event runoff duration (in hours) is equal to the sum of all the runoff occurrences in (1) and (2); and

(4) the actual event duration (in hours) must be determined by examining the date and hour of the first runoff value and the date and hour of occurrence of the last runoff value within the event.

The hourly urban runoff and associated pollutant loads within each event (including DWF pollutant loads during DWH periods less than the MIT) are summed, average conditions are determined, and the model proceeds with the receiving water analysis. Of course, the user may impose a value for the MIT chosen arbitrarily, from experience, or obtained from an alternate analysis technique. For example, a MIT of zero suggests that all hourly runoff occurrences are to be considered independent wet-weather events.

SEPARATE STORM, COMBINED AND DRY-WEATHER FLOWS AND LOADINGS

All of the following methodology can be used regardless of the technique employed to generate storm runoff and quality, as long as these values pertain to the entire area being modeled.

Separate Storm Flows and Loadings

Apportionment of the total flow and BOD loading is made on the basis of the relative area served by separate and combined sewers. Runoff from separate sewered areas is thus (refer to Figure II-1):

$$Q_s = \frac{A_s}{A_t} Q_t \qquad \text{(IV-4)}$$

where Q_s = stormwater flows from separate sewered areas, cfs,

A_s = area served by separate sewers, acres,

Q_t = total (storm plus combined) urban runoff, cfs, and

A_t = total area of catchment, acres.

Dry-Weather Flow and Loadings

Dry-weather flow and BOD loadings are assumed known from data on point sources in the area. Thus, Q_d represents the flow (cfs) into receiving waters of treated wastewater, and BOD_d represents the BOD concentration [at 68°F (20°C) for 5 days, mg/l]. The amount of treatment can be varied in the analysis, as stated in the overview.

Combined Flows and Loadings

Dry-weather flow (DWF) is assumed to cause only a negligible increase in flow in a combined sewer during a storm event. However, two factors related to DWF may increase significantly the BOD concentration of the combined sewer stormwater:

(1) the BOD strength of the municipal sewage with which it mixes; and

(2) the BOD exerted by sediment accumulation in each section of the sewer under DWF conditions which is subject to the "first flush" effect induced by the initial runoff.

To incorporate the "first flush" effect, it is assumed that the hourly in-sewer sediment build-up is constant over consecutive dry-weather hours. This assumption is reasonable although it is evident that particle size and specific gravity, depth of flow, and the slope of the conduit are important factors affecting deposition.

Data collected at various combined sewer overflow stations in Des Moines, Iowa, support the first flush theory (Davis and Borchardt, 1974). BOD and total suspended solids (TSS) concentrations decreased with time with little or no relation to the flow pattern. Furthermore, pollutographs (BOD and TSS concentrations versus time) for these stations seem to indicate that the flushing occurs mostly during the first hour of runoff generated by the storm event.

The sewer solids build-up that occurs during consecutive DWH is computed, then the BOD load contribution from these solids is lumped into the first hour of runoff. The first flush BOD load is given by

$$FF = FFLBS \cdot DWH \qquad (IV-5)$$

where FF = first flush BOD load, lbs/hour,

FFLBS = first flush factor, lbs/first flush hour per DWH, and

DWH = number of dry-weather hours preceding each runoff event.

The first flush factor, FFLBS, must be determined from

(1) the total flow generated by the combined sewer area (including dry-weather flow contribution) during the wet year;

(2) the difference in annual average concentration between BOD_c (excluding factor FF) and the measured annual average value; and

(3) the total number of DWH for the entire year under study.

An example of this calculation is presented in the application of the model to Des Moines, Iowa.

Apportionment to the total flow on the basis of relative area gives:

$$Q_c = \frac{A_c}{A_t} Q_t \qquad \text{(IV-6)}$$

where Q_c = combined sewer overflow rate, cfs, and

A_c = area served by combined sewers, acres.

Finally, the mixed BOD concentration in the combined sewer, BOD_c (mg/l), is computed by the following expression:

$$BOD_c = \frac{BOD_t \cdot Q_c + BOD_f \cdot Q_d \cdot (A_c/A_t) + FF \cdot C_1}{Q_c + Q_d \cdot (A_c/A_t)} \qquad \text{(IV-7)}$$

where C_1 = 4.45, a factor to convert FF from lb/hr to cfs · mg/l.

EFFECT ON RECEIVING WATERS

A simplified mathematical modeling approach is used in which deficits and resulting DO concentrations are determined for a large number of waste input combinations, treatment schemes, and receiving water conditions. The development of a detailed and sophisticated model is not justified for the problem context: to provide adequate information on the relative effectiveness of various pollutant control strategies in achieving selected water quality standards. The basic theory of mathematical modeling of one-dimensional bodies of water is presented for the spectrum of natural systems from freshwater streams to tidal rivers and estuaries. The approach is particularly advantageous for a limited data base on natural system geometry, hydrodynamic variables, and discrete rather than continuous water quality measurements.

Assumptions typical of models limited for interim planning are made (Hydroscience, Inc. 1971):

(1) Temporal steady-state conditions prevail, where all

system parameters and inputs are constant with respect to time; however, a relatively short time step (1 hour) is used for simulation in the wet-weather flow model.

(2) Natural system parameters (such as flow, velocity, water depth, deoxygenation and reaeration rates, and longitudinal dispersion) are spatially constant along the flow axis throughout each time step.

(3) All waste inflows to the receiving body of water occur at one point.

(4) The effects of various natural biological processes (algal photosynthesis and respiration, benthal stabilization) are incorporated into a background quality which is reflected by DO deficit (if none, by saturation) upstream from the waste inflow point. Any benthic build-up is incorporated into the BOD decay rate.

(5) Waste treatment facilities operate at constant efficiencies, independent of hydraulic and organic loadings, for the entire period of simulation.

Initial Conditions

Initial conditions of BOD in the river or estuary are defined by equation (II-1). Subsequently, the mixed BOD concentration in the body of water will be denoted by L_o. Thus,

$$L_o \equiv BOD_m \tag{IV-8}$$

The assumption that all waste inflows occur at one point is not unreasonable since critical water quality conditions develop relatively far downstream from urban waste sources, but in some locations the distribution of inflows along the flow axis of the natural system may need to be considered. All of the BOD contributors in equation (II-1) represent standard BOD_5 values. Thus, BOD_m is also in terms of the standard BOD test. The ultimate first-stage (carbonaceous) demand is computed from the BOD_5 value by:

$$(L_o)_c = \frac{BOD_5}{1-e^{-5K_1}} \tag{IV-9}$$

where $(L_o)_c$ = ultimate first-stage BOD demand, mg/l, and

K_1 = first-order BOD decay rate constant, day^{-1}.

The value of $(L_o)_c$ also varies with receiving water temperature, so that:

$$[(L_o)_c]_T = [(L_o)_c]_{20°} [1 + 0.02 (T-20)] \quad \text{(IV-10)}$$

where $[(L_o)_c]_{20°}$ = ultimate first-stage BOD demand @ 20°C, mg/l, and

T = water temperature in °C.

To simplify notation, the temperature-corrected ultimate, carbonaceous BOD demand will hereafter be denoted simply L_o.

The other initial condition required is the initial oxygen deficit, D_o. It is assumed that all waste inflows will be at saturation. Thus, the only contribution to the initial deficit will be from the upstream portion of the body of water. Thus,

$$D_o = \frac{D_u Q_u}{Q_u + Q_d + Q_s + Q_c} \quad \text{(IV-11)}$$

where D_o = initial DO deficit, mg/l, and

D_u = DO deficit in receiving waters upstream of inflow point, mg/l.

If the effluent temperatures are high, an adjustment can be made by increasing D_u.

Oxygen Balance of Polluted Streams and Estuaries

In view of the modeling objectives, pollutant transport processes in these systems may be adequately approximated by the one-dimensional version of the classical convective diffusion equation. This partial differential equation is based on the principle of conservation of mass (continuity) and is given by:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} [E \frac{\partial C}{\partial x} - UC] \pm \Sigma S \quad \text{(IV-12)}$$

where C = concentration of water quality parameter (pollutant), M/L^3,

t = time, T,

$-E \frac{\partial C}{\partial x}$ = mass flux due to longitudinal dispersion along the flow axis, the x direction, M/L^2T,

UC = mass flux due to advection by the fluid containing the mass of pollutant, M/L^2T,

S = sources or sinks of the substance C, M/L^3T,

U = flow velocity, L/T, and

E = longitudinal dispersion coefficient, L^2/T.

The equation assumes no diffusion of pollutants through the natural body of water boundaries (other than what may be included in the source-sink term) and is best suited to predict concentrations relatively far downstream from the point of waste injection. Since critical DO deficits usually occur some distance downstream from the waste source, equation (IV-12) is particularly well suited for such predictions. The main sources of dissolved oxygen in stream or estuarine systems are atmospheric reaeration and oxygen production by photosynthesis. The major sinks include carbonaceous oxygen demand (CBOD), nitrogenous oxygen demand (NBOD), benthal demand, and respiration of aquatic plants. All natural system parameters are assumed spatially constant along the flow axis, and by substituting the various sources and sinks of DO into equation (IV-12) the following expression is obtained:

$$\frac{\partial C}{\partial t} = E\frac{\partial^2 C}{\partial x^2} - U\frac{\partial C}{\partial x} + K_2(C_s - C) - K_1 L - K_n N + P - R_e - B \qquad \text{(IV-13)}$$

where C = concentration of DO in the stream or estuary, mg/l,

E = longitudinal dispersion coefficient, ft^2/sec,

U = freshwater stream or tidal river velocity, ft/sec,

K_2 = atmospheric reaeration coefficient, $hours^{-1}$,

C_s = dissolved oxygen saturation, mg/l,

$C_s - C$ = dissolved oxygen deficit, mg/l = D,

K_1 = deoxygenation constant of carbonaceous BOD, $hours^{-1}$,

L = remaining carbonaceous BOD concentration, mg/l,

K_n = oxidation coefficient of nitrogenous BOD, $hours^{-1}$,

N = remaining nitrogenous BOD concentration, mg/l,

P = oxygen production rate by algal photosynthesis, mg/l-hour,

R_e = algal respiration rate, mg/l-hour, and

B = benthal demand of bottom deposits, mg/l-hour.

For freshwater streams, the advective flux is significantly larger than the mass flux due to longitudinal dispersion. In a tidal river, the advective and dispersive fluxes are both significant. In an estuary, the dispersive component is usually predominant (Hydroscience, Inc., 1971). For steady-state analysis, all system parameters are assumed time invariant, and since it is desired to solve for the DO deficit and

$$\frac{\partial C}{\partial t} = 0 \; ; \quad \frac{\partial C}{\partial x} = - \frac{\partial D}{\partial x} \qquad \text{(IV-14)}$$

equation (IV-13) reduces to a second-order ordinary differential equation:

$$0 = E \frac{d^2D}{dx^2} - U \frac{dD}{dx} + K_1L + K_nN - K_2D - (P - R_e - B) . \qquad \text{(IV-15)}$$

Before equation (IV-15) can be integrated the spatial distributions of both the remaining carbonaceous BOD, L, and the remaining nitrogenous BOD, N, must be determined. From mass balances across a control volume, the following steady-state relationships are obtained:

$$- E \frac{d^2L}{dx^2} + U \frac{dL}{dx} = - K_1L \qquad \text{(IV-16)}$$

$$- E \frac{d^2N}{dx^2} + U \frac{dN}{dx} = - K_nN \qquad \text{(IV-17)}$$

Applying boundary conditions, such that $L = L_o$ and $N = N_o$ at $x = 0$ and $L = N = 0$ at $x = \infty$, equations (IV-16) and (IV-17) integrate to:

$$L = L_o \exp \left[\frac{xU}{2E} \left(1 - \sqrt{1 + \frac{4K_1E}{U^2}} \right) \right] \qquad \text{(IV-18)}$$

$$N = N_o \exp \left[\frac{xU}{2E} \left(1 - \sqrt{1 + \frac{4K_nE}{U^2}} \right) \right] \qquad \text{(IV-19)}$$

for $x \geq 0$.

Substituting expressions (IV-18) and (IV-19) into equation (IV-15), the governing differential equation for dissolved oxygen deficit becomes:

$$0 = E\frac{d^2D}{dx^2} - U\frac{dD}{dx} + K_1L_oe^{mx} + K_nN_oe^{rx} - K_2D - (P - R_e - B) \quad \text{(IV-20)}$$

where

$$m = \frac{U}{2E}\left[1 - \sqrt{1 + \frac{4K_1E}{U^2}}\right]$$

$$r = \frac{U}{2E}\left[1 - \sqrt{1 + \frac{4K_nE}{U^2}}\right]$$

for $x \geq 0$.

Stoichiometrically, the magnitude of the nitrogenous demand may be evaluated from

$$N_o = 4.57 \text{ TKN} \quad \text{(IV-21)}$$

where TKN is the total Kjeldahl nitrogen, which is the total oxidizable organic plus ammonia nitrogen. The oxidation coefficient of nitrogenous BOD, K_n, has been estimated to range from 0.1 to 0.6 per day at 20°C, for a first order decay assumption (Thomann, 1972).

In the model, the effects of the biological processes $(P - R_e - B)$ are assumed to be incorporated into the measured upstream DO deficit. Field measurements of organic and ammonia nitrogen present in all wastewater inputs to receiving waters are seldom available, much less during runoff events. Furthermore, K_n is usually unknown even if some total organic nitrogen measurements were recorded. Thus, nitrogenous oxygen demand is currently neglected, reducing equation (IV-20) to the expression:

$$E\frac{d^2D}{dx^2} - U\frac{dD}{dx} + K_1L_oe^{mx} - K_2D = 0 \quad \text{(IV-22)}$$

Critical Deficit and DO Levels

The solution to equation (IV-22) as a function of time since release is given by

$$D = \frac{L_oK_1}{K_2 - K_1}\left[e^{jt} - \frac{s_1}{s_2}e^{gt}\right] + D_oe^{gt} \quad \text{(IV-23)}$$

where D = DO deficit, mg/l,

K_1 = deoxygenation coefficient, hours^{-1},

K_2 = reaeration coefficient, hours^{-1},

$t = \frac{x}{U}$ = lapsed time, hours,

$$j = \frac{U^2}{2E}\left[1 - \sqrt{1 + \frac{4K_1E}{U^2}}\right], \text{ hours}^{-1},$$

$$g = \frac{U^2}{2E}\left[1 - \sqrt{1 + \frac{4K_2E}{U^2}}\right], \text{ hours}^{-1},$$

$$s_1 = \sqrt{1 + \frac{4K_1E}{U^2}}, \text{ dimensionless, and}$$

$$s_2 = \sqrt{1 + \frac{4K_2E}{U^2}}, \text{ dimensionless.}$$

To determine the time at which the critical (maximum) deficit occurs the partial derivative of the DO deficit equation, equation (IV-23), is taken with respect to time and set equal to zero ($\partial D/\partial t = 0$):

$$0 = \frac{L_oK_1}{K_2 - K_1}\left[je^{jt_c} - \frac{s_1}{s_2}\, ge^{gt_c}\right] + gD_oe^{gt_c} \qquad \text{(IV-24)}$$

Solving for t_c, the following expression is obtained:

$$t_c = \frac{1}{(j - g)}\left[\ln\left(\frac{g}{j}\right) + \ln\left(\frac{s_1}{s_2} - \frac{D_o}{L_o} \cdot \frac{K_2 - K_1}{K_1}\right)\right] \qquad \text{(IV-25)}$$

Equation (IV-25) may be simplified for convenience by making some substitutions,

$$t_c = \frac{1}{(j - g)}\ \ln\left[\frac{g}{j}\left(\frac{s_1}{s_2} - fR_o + R_o\right)\right] \qquad \text{(IV-26)}$$

where t_c = elapsed time at which the critical deficit occurs, hours,

f = self-purification ratio
= K_2/K_1, and

R_o = ratio of the initial DO deficit, D_o, to the initial BOD, L_o, dimensionless.

Finally, the critical deficit is found by substituting the value of t_c, given by equation (IV-26), into equation (IV-23):

$$D_c = \frac{L_o K_1}{K_2 - K_1}\left[e^{jt_c} - \frac{s_1}{s_2} e^{gt_c}\right] + D_o e^{gt_c} \qquad \text{(IV-27)}$$

where D_c = critical (maximum) deficit, mg/l.

The minimum DO level is calculated as

$$C_{min} = C_s - D_c \qquad \text{(IV-28)}$$

where C_{min} = concentration of DO at maximum deficit, mg/l, and

C_s = saturation concentration of DO, mg/l.

The saturation concentration is determined from the regression relationship (American Society of Civil Engineers, 1960),

$$C_s = 14.652 - 0.41022\,T + 0.0079910\,T^2 - 0.000077774\,T^3 \qquad \text{(IV-29)}$$

where T = water temperature, °C.

If the model user wishes to <u>neglect</u> the <u>dispersive</u> <u>flux</u> in a freshwater stream, a value of <u>zero</u> is specified for E. Then, equation (IV-22) reduces to the expression:

$$0 = U\frac{dD}{dx} + K_2 D - K_1 L_o e^{-K_1 t} \qquad \text{(IV-30)}$$

The solution of equation (IV-30) constitutes the Streeter-Phelps formulation in which the deficit as a function of time since release is

$$D = \frac{K_1 L_o}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + D_o e^{-K_2 t} \qquad \text{(IV-31)}$$

where D = DO deficit, mg/l,

K_1 = deoxygenation coefficient, hours^{-1},

K_2 = reaeration coefficient, hours^{-1}, and

t = elapsed time, hours.

The critical (maximum) deficit is found through differentiation to be

$$D_c = \frac{K_1 L_o}{K_2} e^{-K_1 t_c} \qquad \text{(IV-32)}$$

Then the value of t_c is given by:

$$t_c = \frac{1}{K_1 (f-1)} \ln \{f[1 - fR_o + R_o]\} \qquad \text{(IV-33)}$$

Equations (IV-26), (IV-27), (IV-32) and (IV-33) are undefined when: $f = 1$, $L_o = 0$, or $R_o > 1/f$. These conditions may arise when a large number of waste inflow and river flow combinations are simulated (e.g., dry watercourses in which waste inputs constitute the only flow). For example,

1. the deficit load ratio, R_o, is undefined if $L_o = 0$ or both D_o and L_o are zero, since $R_o = D_o/L_o$;
2. the self-purification ratio, f, becomes equal to <u>one</u> and j = g when the reaeration rate K_2 and the deoxygenation rate K_1 coincide in value; and
3. t_c will be negative or undefined when $f = 1$ but R_o is not within the bounds $0 \leq R_o \leq 1/f$.

Application of the theorems of limits (calculus) to the deficit equations led to the incorporation of certain modifications and safeguards. Thus, when

1. $f = 1$, then

$$D_c = L_o e^{R_o - 1} \qquad \text{(IV-34)}$$

2. $f \neq 1$, $L_o = 0$, then

$$D_c = D_o \qquad \text{(IV-35)}$$

3. $f \neq 1$, $L_o \neq 0$, $R_o > 1/f$, then

$$D_c = D_o. \qquad \text{(IV-36)}$$

Deoxygenation and Reaeration Rates

The deoxygenation coefficient, K_1, represents the loss of DO in the waterway due to reduction of BOD. It is expressed as a constant fraction of the remaining unoxidized organic matter in any arbitrary unit of time. The average domestic sewage deoxygenates at about 0.23 per day at 20°C under standardized laboratory conditions. In freshwater streams, the reaction coefficient for BOD ranges from 0.2 to 2.0 per day for water temperatures from 20°C to 25°C (Hydroscience, Inc., 1971). There are at least four generally accepted methods to determine the value of K_1 from the BOD curve, for a wastewater sample. These include: (1) the least-squares technique, (2) the slope method, (3) the moments method, and (4) the logarithmic method (Nemerow, 1974).

The magnitude of K_1 in streams is related to the average water depth. The explanation behind this correlation lies in the fact that the smaller the depth the greater the contact with biological film in the stream bed, one of the most important factors in natural oxidative processes (Hydroscience, Inc., 1971). From data reported in the literature, a straight-line plot between the variables is obtained (within certain bounds) as shown in Figure IV-1. A mathematical representation is given by:

$$K_1 = \gamma_1 H^{\gamma_2} \qquad \text{(IV-37)}$$

where K_1 = deoxygenation coefficient at 20°C, day^{-1},

γ_1, γ_2 = regression coefficients

H = stream depth, ft.

The above relationship appears reasonable within a range of depths from 1 foot to 10 feet. Thus, K_1 must be limited by program variables (XK1MAX and XK1MIN) to upper and lower bounds, respectively. These may be selected by the user, and supplied to the model as input data, so as to further extend or restrict the range of applicability of equation (IV-37) to suit local stream conditions. A temperature correction yields:

$$K_1(T) = K_1(20°)\ 1.047^{T-20} \qquad \text{(IV-38)}$$

where T = water temperature, °C, and conversion is made to units of $hour^{-1}$ in the wet weather flow model. The magnitude of XK1MAX, XK1MIN, γ_1 and γ_2 may be adjusted during calibration procedures.

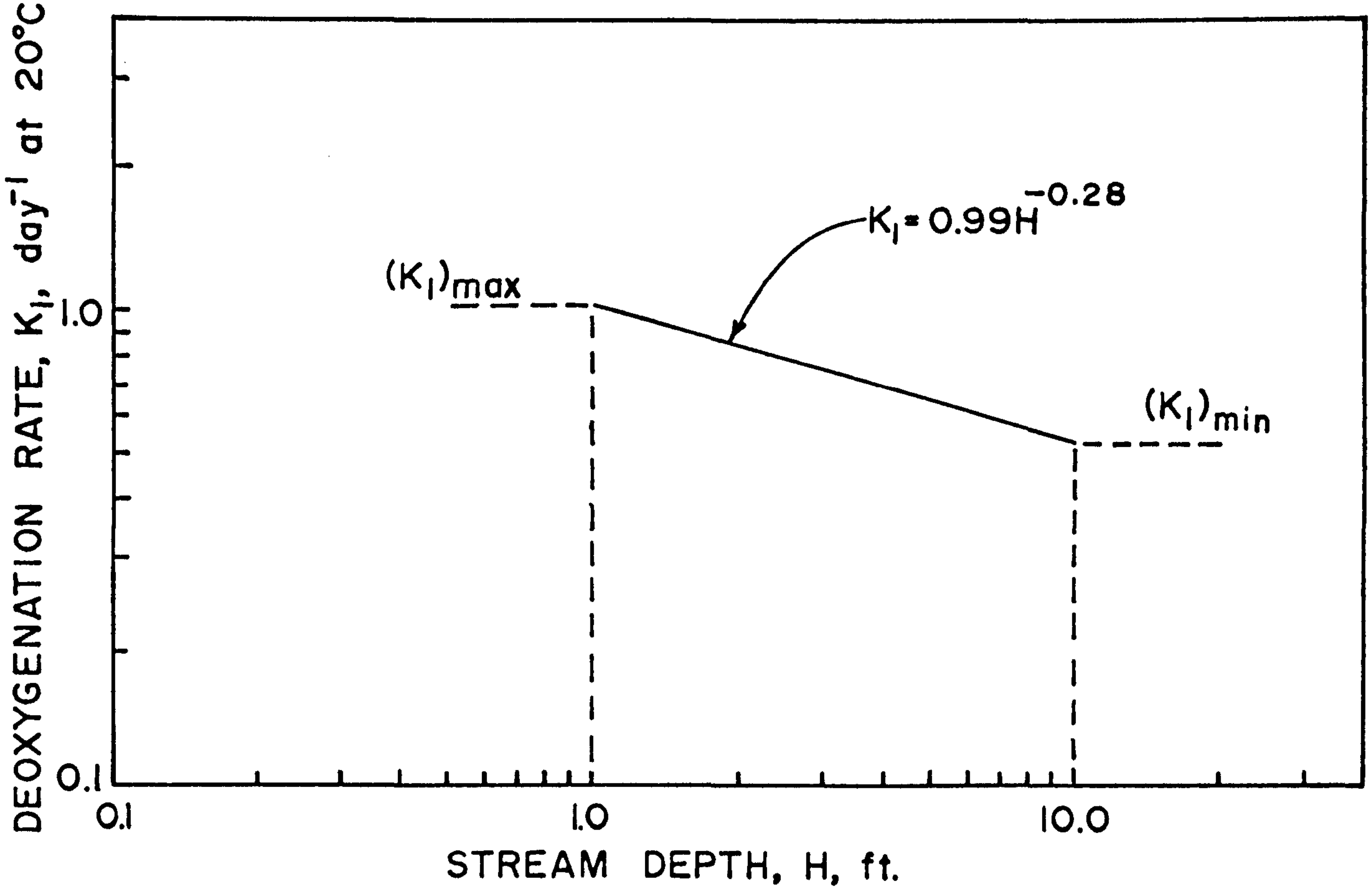


Figure IV-1. Deoxygenation Rate As A Function of Stream Depth (modified after Hydroscience, Inc. 1971). Equation shown is a specific function which corresponds to $\gamma_1 = 0.99$ and $\gamma_2 = -0.28$.

Numerous formulations exist for prediction of the reaeration coefficient K_2, almost all of which depend upon velocity, U, and depth, H. The equation below (Langbein and Durum, 1967) was chosen because it is most closely related to subsequent procedures applied to obtain U and H:

$$K_2 = 2.303 \left[3.3 \frac{U}{H^{1.33}} \right] \qquad \text{(IV-39)}$$

where K_2 = reaeration coefficient at 20°C, day^{-1},

U = stream velocity, ft/sec, and

H = stream depth, ft.

The problem lies in obtaining values of U and H, since the streamflow varies with time. In the absence of measurements, or if the data cannot be obtained in an expedient manner (as in the ensuing application to the Des Moines River), an approximation can be made (Leopold and Maddock, 1953) which uses strong correlations between velocity versus flow and depth versus flow, namely:

$$U = \alpha_1 Q^{\alpha_2} \qquad \text{(IV-40)}$$

$$H = \beta_1 Q^{\beta_2} \qquad \text{(IV-41)}$$

where Q = streamflow, cfs, and

$\alpha_1, \alpha_2, \beta_1, \beta_2$ = regression coefficients.

When equations (IV-40) and (IV-41) are substituted into (IV-39) and conversion is made to units of $hour^{-1}$, the reaeration coefficient is established as a function of streamflow, Q:

$$K_2(20°) = 0.3167 \left(\frac{\alpha_1}{\beta_1^{1.33}} \right) Q^{\alpha_2 - 1.33\beta_2} \qquad \text{(IV-42)}$$

The reaeration rate is corrected for temperature by:

$$K_2(T) = K_2(20°)\, 1.024^{T - 20} \qquad \text{(IV-43)}$$

Total Volume of DO Deficit

Another measure of the relative effect of one waste source versus another on receiving water quality is the integral, or summation, of the deficit equation over all time:

$$\forall = \int_0^\infty D\,dt = \int_0^\infty \left\{ \frac{L_o K_1}{K_2 - K_1} \left[e^{jt} - \frac{s_1}{s_2} e^{gt} \right] + D_o e^{gt} \right\} dt \qquad \text{(IV-44)}$$

After integration, equation (IV-44) becomes

$$\forall = \frac{L_o K_1}{K_2 - K_1} \left\{ \left[\frac{e^{jt}}{j} \right]_0^\infty - \frac{s_1}{s_2} \left[\frac{e^{gt}}{g} \right]_0^\infty \right\} + D_o \left[\frac{e^{gt}}{g} \right]_0^\infty \qquad \text{(IV-45)}$$

As defined in equation (IV-23), the coefficients j and g apply only to the solution of equation (IV-22) for the region downstream from the point of waste discharge ($x \geq 0$). For nonzero values of K_1, K_2 and E

$$\left[1 - \sqrt{1 + \frac{4K_1E}{U^2}} \right] < 0 \qquad \text{(IV-46)}$$

$$\left[1 - \sqrt{1 + \frac{4K_2E}{U^2}} \right] < 0 \qquad \text{(IV-47)}$$

and consequently $j, g < 0$. Thus, equation (IV-45) may be evaluated between the limits shown to yield:

$$\forall = \frac{L_o K_1}{K_2 - K_1} \left[\frac{s_1}{s_2 g} - \frac{1}{j} \right] - \frac{D_o}{g} \qquad \text{(IV-48)}$$

where $\forall$ may be interpreted as the total volume of deficit, with units of mg-hours/l. Values of $\forall$ are displayed by the model for each inflow combination.

Again, if the longitudinal dispersion coefficient is equal to zero, equation (IV-31) is the appropriate expression for the deficit. When integrated over all time, the relationship obtained is

$$\forall = \int_0^\infty D\,dt = \frac{D_o + L_o}{K_2} \qquad \text{(IV-49)}$$

The results of applying either equation (IV-48) or (IV-49) may be compared for each model option as another indication of relative impacts. The physical significance of $\forall$ is perhaps better understood by dimensional analysis after the quantity is multiplied by stream velocity and cross-sectional area:

$$\forall \cdot (U \cdot A) = \forall \cdot (Q) \qquad \text{(IV-50)}$$

$$= \frac{\text{mg-hours}}{1} \cdot \frac{\text{ft}^3}{\text{sec}}$$

$$= \frac{M\,T}{L^3} \cdot \frac{L^3}{T}$$

$$= M$$

$$= \text{mass of DO under the deficit curve.}$$

Determination of the Longitudinal Dispersion Coefficient, E

The discharge of freshwater streams into tidal waters, coupled with the intrusion of saline waters into tidal waters and the simultaneous retreat of fresh waters, results in a complex hydrodynamic situation of economic importance. Estuaries are used for diverse purposes such as commercial fishing, shellfish harvesting, navigation, recreation, water supply and waste disposal. Thus, receiving water quality criteria must be established to provide a cost-effective balance: economical wastewater treatment before disposal and an acceptable degradation to the receiving body of water. The geometry of tidal estuaries may vary widely. For example, sections landward from the mouth expand in San Francisco Bay whereas they contract in the Delaware estuary (Ippen, 1966). The rise and fall of the tide at the mouth is associated with an exchange of water masses: temporary storage of large amounts of seawater in the estuary during high tide and the drainage of this water seaward during low tide (Ippen, 1966). The total volume of water exchanged is referred to as the *tidal prism*. The total volume of freshwater inflow to the estuary from upland sources equals the discharge rate totaled over the tidal period. The freshwater inflow rate, Q_f, is variable with time. Nevertheless, the ratio of freshwater volume to the tidal prism is useful for general classification. The Delaware River estuary is characterized by a low ratio of freshwater-to-seawater volume (~1:100) while by contrast the Mississippi River estuary exhibits a much higher ratio (~1:1) due to low Gulf tides and higher discharge rates (Ippen, 1966).

Of particular importance with respect to the relative magnitude of the freshwater to salt-water prism ratio is the degree of mixing of the freshwater into the salt water. The higher the value of this ratio the less diffusion takes place, the estuary is termed *stratified* and a distinct *salinity wedge* exists (Ippen, 1966). As might be expected, a well-defined salt water wedge underlays the fresh waters in the Mississippi and the Amazon estuaries. A low ratio indicates an advanced state of diffusion and the estuary is classified as *well-mixed* with only small variations in the vertical salinity profiles (which become more uniform with increased mixing through tidal action). A gradual decrease in salinity is observed as one proceeds upstream in the Delaware River estuary, and may serve as an example of the well-mixed state (Pyatt, 1964 and Ippen, 1966).

The equilibrium of an estuary can only be maintained if the quantities of solids, freshwater and minerals in solution *each* remain in balance: continuity of matter (McDowell and O'Connor, 1977). The salinity wedge discussed above derives its shape primarily due to density gradients: the density difference between the water at the seaward end of an estuary and freshwater entering from rivers causes net landward movement of water near the estuary bed and a compensating seaward movement near the water surface. If turbulent mixing is so intense that there is only a small variation in density over depth at any point, a horizontal density gradient must exist ranging from 1 g/cm^3 at the upper tidal limit to the density of seawater ($\sim$ 1.026 g/cm^3) at some distance offshore. The Mississippi River is tidal for up to 265 miles (426 km) landward from its mouth. In the Amazon River, densities do not approach typical ocean values for as far as 622 miles (1000 km) seaward from its mouth (McDowell and O'Connor, 1977).

One-dimensional mathematical models such as equation (IV-13) encompass a wide range of time-averaging concepts; therefore, classifications such as "unsteady", "quasi-steady state" or "steady" are meaningless unless precisely defined with respect to:

1. the duration of the time period to be used in averaging , and

2. the quantity to which the descriptive term applies (Harleman, 1971).

The length of the time-averaging period (Δt) will, for example, determine whether the *time average* of the *velocity fluctuations* will be referred to as:

1. the *tidal velocity* - $\Delta t \sim 1$ minute, "unsteady" quantity;

2. the *mean flood* (or *ebb*) *velocity* - $\Delta t \sim 6$ hours, also "unsteady";

3. the *non-tidal advective velocity* - $\Delta t \sim 12$ hours, equal to the velocity due to freshwater inflow, U_f, "steady" or "unsteady" depending on the time variation in the magnitude of the freshwater inflow; or

4. the *mean, non-tidal advective velocity* - $\Delta t \geq 25$ hours (Harleman, 1971).

The time of zero tidal velocity within the tidal cycle is the time of slack water tide: *high water slack* if the velocity change is from flood to ebb and *low water slack* from ebb to flood tide. Equation (IV-13) represents the real time mass transfer equation in an idealized estuary of constant cross-sectional area, where U is the tidal velocity as a function of time only (independent of x) and the longitudinal dispersion coefficient E is constant. By considering concentration distributions only at times of slack tide, the tidal advective velocity disappears and U becomes the non-tidal advective velocity due to freshwater inflow ($U_f = Q_f/A$). Then, the solution to equation (IV-22) constitutes the "quasi-steady state" spatial concentration distribution for water quality conditions at either high or low water slack.

As stated earlier, estuaries may exhibit either relatively homogeneous salinity in a particular cross section or pronounced vertical gradients in addition to their longitudinal salinity characteristics. Application of the one-dimensional equations to a fully stratified or saline-wedge estuary should be excluded. The one-dimensional, quasi-steady state analysis is a compromise between the desirability of a rigorous mathematical approach and the practical necessity to achieve workable engineering solutions and evaluations for planning purposes. A detailed assessment of estuarine models and the tradeoffs involved in their application is available elsewhere (TRACOR, Inc., 1971). It should also be noted that analyses limited to any fixed fraction of the tidal period are classified as quasi-steady state.

Various methods have been developed to determine the longitudinal, lateral, and vertical diffusion coefficients that govern dye dispersion rates (Diachishin, 1963). These procedures are appropriate for a multi-dimensional approach. The longitudinal dispersion coefficient, E, for an estuary or tidal river may be evaluated empirically from observed quasi-steady state chloride concentration profiles for a particular net advective flow (Hydroscience, Inc., 1972). The procedure assumes homogeneous mixing in the cross-section and constant E. Considering chlorides as conservative substances, the underlying equation is:

$$C = C_o \, e^{\frac{Ux}{E}} \qquad \text{(IV-51)}$$

for $x \leq 0$

where C = chloride concentration, mg/l

C_o = maximum concentration at $x = 0$, mg/l

U = net advective velocity, miles/day

E = dispersion coefficient, $miles^2$/day

x = distance upstream, negative, miles (usually $x = 0$ at mouth of estuary).

Taking the natural logarithm of equation (IV-51) yields:

$$\ln C = \frac{U}{E} x + \ln C_o \qquad \text{(IV-52)}$$

A semi-logarithmic plot of ln chlorides versus distance x upstream should yield a straight line with slope (U/E) and intercept at the ordinate given by $\ln C_o$. The longitudinal dispersion coefficient, E, is then computed by dividing the net advective velocity by the slope. In the saline portion of an estuary, dispersive flux of mass is usually predominant and determination of E becomes important. In the tidal, but non-saline sections of the river both advective and dispersive fluxes may be significant. Upstream of the tidal influence the longitudinal mixing decreases considerably and may be disregarded altogether in the analysis.

SECTION V

PROGRAMMING CONSIDERATIONS

User requirements for application of Level III-Receiving may be broadly classified into: (1) computer facilities and programming considerations, (2) data requirements, and (3) calibration and verification procedures. Items (2) and (3) are discussed in detail in the next section; however, a few remarks are in order at this point concerning input data. All program subroutines may be executed during a single job submission, or selectively as the data reduction process is completed for each subprogram. Such flexibility is made available through the use of control cards in the input stream. Collection of data from municipal and other sources may be accomplished in a few days. Reduction of the data to the appropriate format for program input is estimated at one man-week for a one year period of simulation, and is largely independent of the size of the urban drainage area modeled. An increase in the length of the simulation time period does not imply an increase in computer system core requirements; however, it will obviously increase time of execution.

COMPUTER SYSTEM CORE REQUIREMENTS

The program has been tested with two different Central Processing Units (CPU) and comparable supporting hardware. The Duke University Computation Center (DUCC) is connected by a high-speed microwave link to a dual IBM 370/165 configuration located at the Triangle Universities Computation Center (TUCC) in the Research Triangle Park. The Northeast Regional Data Center (NERDC), located at the University of Florida, is equipped with an AMDAHL 470-V6/II.

Level III-Receiving users have the option of running under FORTRAN IV compilers comparable to either of the two standard IBM compilers, G or H. IBM's minimum system requirements for installation of the FORTRAN IV (G) compiler and the FORTRAN IV (H) compiler are: respectively, 128K bytes and 256K bytes of storage. Furthermore, the user may run Level III-Receiving from the actual card version (program source and data decks) or from a pre-compiled Load Module of the program stored on disk. All of these options result in varying core storage capacity requirements for the program. At TUCC, the FORTRAN G compiler is much faster and is recommended for all debugging runs. However, the FORTRAN H compiler has an optimization feature which results in the compiled coding being "optimized" for faster running in the execution step. Unless the user actually alters the program, debugging should be unnecessary and most errors will be due to incorrect formatting or sequencing of input data. Therefore, the program should be compiled in H and the coding stored on disk for future production runs. An additional feature is the IBM OS Loader, which replaces the Link-Edit and Go steps with a single, faster operation. Core storage capacity and average compilation times are presented in Table V-1 for Level III-Receiving under TUCC's IBM 370/165 system. By comparison, the FORTRAN compiler of the AMDAHL 470-V6/II at NERDC required 110K bytes of core storage for execution.

Additional computer system requirements include peripheral storage devices which may consist of disk/tape/drum units depending upon machine configuration and user-selected input options (see Card Group I, Table VI-13).

PROGRAM COMPILATION AND EXECUTION TIMES AND COSTS

The IBM 370/165 compilation and execution times with total costs for various subprogram options are listed in Table V-2. The savings incurred by storing the compiled subroutines of the program in a permanent job library (Load Module) suggest that the procedure is worthwhile if Level III-Receiving is going to be used frequently. Of course, at most computer installations there is a daily or monthly charge for storing Load Modules. For example, at TUCC the charge for online disk space is $0.50 per track per month. Thus, $4 per month (8 tracks) is the approximate charge for the Level III-Receiving Load Module. The total costs and total CPU time for four program options are shown in Table V-3 for the AMDAHL system at NERDC. As noted, commercial rates are higher.

JOB CONTROL LANGUAGE

The user must supply the necessary job control language (JCL) which is compatible with the computer system and particular installation involved. The JOB card is highly installation-dependent and often differs for identical CPU configurations at different installations. However, other JCL is fairly standard on IBM operating systems, and several examples are provided here as typical JCL required for the model on systems running IBM OS/360.

1. To execute the program from card input only (IPROG = 0,ITSAG = 0, see Table VI-13) —

TABLE V-1. COMPILATION TIMES[1] AND REQUIRED CORE CAPACITY[2]

Compiler	Compile Time, sec	Link-Edit Time, sec	Compile Core bytes	Execute Core bytes
FORTRAN G	29.4	10.3	146K	104K
FORTRAN H	60.3	9.9	300K	100K
FORTRAN G with IBM OS Loader	28.6	none	146K	200K

[1]Average values.

[2]IBM 370/165 system, Triangle Universities Computation Center, Research Triangle Park, North Carolina.

TABLE V-2. EXECUTION TIMES AND COSTS AT TUCC[1]

Program Options[2]				Input/Output Time, sec	Total CPU Time, sec	Total Cost $
IPROG[3]	ICORR[4]	IWWFM[5]	IDWFM[6]			
0	1	0	0	5.9	38.7	4.85
0	0	1	0	49.9	28.7	11.77
0	0	0	1	28.1	9.4	5.70
0	1	1	1	80.7	80.3	22.12

[1]Triangle Universities Computation Center, FORTRAN IV (H) - compiled Load Module on disk, for one year period of simulation, IBM 370/165 system. Commercial rates are approximately three times the university rates at TUCC.

[2]See Card Group I, Table VI-13.

[3]Input data from cards only when = 0.

[4]Autocorrelation analysis performed if = 1.

[5]Wet-weather flow model run if = 1.

[6]Dry-weather flow model run if = 1.

TABLE V-3. COMPILATION AND EXECUTION TIMES AND COSTS OF NERDC[1]

Program Options[2]				Total CPU Time, sec	Total Cost $
IPROG[3]	ICORR[4]	IWWFM[5]	IDWFM[6]		
0	1	0	0	46.84	11.12
0	0	1	0	17.85	10.04
1	0	1	0	20.67	10.85
0	0	0	1	8.66	5.59

[1]Northeast Regional Data Center, FORTRAN compiler for AMDAHL 470-V6/II, for one year period of simulation. Commercial rates are approximately twice those indicated at NERDC.

[2]See Card Group I, Table VI-13.

[3]Input data from cards only when = 0, and from cards and SWMM tape when = 1.

[4]Autocorrelation analysis performed if = 1.

[5]Wet-weather flow model run if = 1.

[6]Dry-weather flow model run if = 1.

```
// ... JOB card ...
//     EXEC FTHCLG
//C.SYSIN DD *
          :
     (the FORTRAN IV source deck)
          :
/*
//G.SYSIN DD *
          :
     (your input data deck)
          :
/*
//
```

where above instructions apply to the FORTRAN H compiler. To use the FORTRAN G compiler simply replace the second card with // EXEC FTGCLG

2. To execute the program from a previously created Load Module (IPROG = 0, ITSAG = 0, see Table VI-13)—

```
// ... JOB ...
//G    EXEC  PGM=program name within load module data
                 set
//STEPLIB DD DSN=data set name,DISP=SHR
//FT01F001 DD DDNAME=SYSIN
//FT03F003 DD SYSOUT=A,DCB=(RECFM=FBA,
//          BLKSIZE=133,LRECL=133)
//SYSIN DD *
        :
     (your input data deck)
        :
/*
//
```

For an actual run at TUCC the first three cards were replaced by

```
//LEVELIII JOB DU.D06.AT4119,MEDINA,M=1,T=3,R=150K,P=350
//G  EXEC    PGM=LEVELIII
//STEPLIB DD DSN=DU.D06.AT4119.MEDINA.LOAD,DISP=SHR
```

```
          :
    (program source deck)
          :

/*
//G.FTwwF001 DD DSN=data set name,DISP=NEW,
//    SPACE=space allocation,UNIT=unit,VOL=SER=volume
      number
//G.FTddF001 DD DSN=data set name,DISP=NEW,
//    SPACE=space allocation,UNIT=unit,VOL=SER=volume
      number
//G.SYSIN DD *
          :
    (input data deck)
          :

/*
//
```

where in card //G.FTwwF001 DD DSN=..., ww refers to a two-digit number (usually greater than 6) which is equal to the value of IDISKW selected by the user (see Card Group IV, Card Type 10, Table VI-13). Similarly, dd above refers to a two-digit number specified by IDISKD (Card Group V, Card Type 14, Table VI-13). For example, where ITSAG=1, IDISKW=9 and IDISKD=10 an actual run at TUCC would use the sequence

```
//G.FT09F001 DD DSN=&&TEMP1,DISP=NEW,
//    SPACE=(TRK,(1,1)),UNIT=DISK,VOL=SER=DUK111
//G.FT10F001 DD DSN=&&TEMP2,DISP=NEW,
//    SPACE=(TRK,(1,1)),UNIT=DISK,VOL=SER=DUK111
```

ii) if the user wishes a plot of the DO concentrations versus wet-weather events only, then ITSAG=1, IDISKW=ww and IDISKD=0. Thus, only the

//G.FTwwF001 DD DSN=... sequence need be specified. Conversely, for DO versus dry-weather events only, then ITSAG=1, IDISKW=0 and IDISKD=dd. Only the sequence

//G.FTddF001 DD DSN=... would be required.

The scratch data set(s) specified when ITSAG=1 are temporary, as the name implies, and should be deleted after execution of the program is completed.

3. To execute the program from both cards and a user-created data set (which would contain the urban runoff hydrographs and pollutographs, IPROG = 2, ITSAG = 0) —

```
// ... JOB ...
//   EXEC   FTHCLG
//C.SYSIN DD *
         :
     (program source card deck)
         :

/*
//G.FTxxF001 DD DSN=data set name,
//     DISP=SHR,UNIT=unit type,VOL=SER=volume number
//G.SYSIN DD *
         :
     (data which is on cards)
         :

/*
//
```

In card //G.FTxxF001 DD DSN=..., xx refers to a 2-digit number (usually greater than 6) which is equal to the value of IFILE (see Card Group I, Table VI-13) selected by the user. For example,

```
//G.FT08F001 DD DSN=DU.D06.AT4119.MEDINA.DSTRM,DISP=SHR,
//              UNIT=DISK,VOL=SER=DUKAAA
```

includes, as part of the data set name: the valid computer system account number, the name of the person responsible for creating the data set, and an identification name.

4. To execute the program and obtain a composite plot of DO concentrations versus chronologically sorted wet-weather and dry-weather events (ITSAG = 1), two scratch data sets must be specified in the job control language —

   i) for card input of urban runoff hydrographs and pollutographs (IPROG = 0)

```
// ... JOB ...
// EXEC FTHCLG
//C.SYSIN DD *
```

5. To create a Load Module for Level III-Receiving —

```
//...JOB...
//FORTRAN EXEC FTHCL,PARM.C='OPT=2,NODECK',
//   REGION.C=300K
//C.SYSIN DD *
          .
          .
          .
     (program source deck)
          .
          .
          .

/*
//L.SYSLMOD DD DSN-DU.D06.AT4119.MEDINA.LOAD(LEVELIII),
//   DISP=(MOD,KEEP),VOL=SER=DUK222,UNIT=DISK,
//   SPACE=(TRK,(15,10,2),RLSE)
//
```

6. In the event that the user might wish to alter the Level III Receiving program and recompile the whole program or just selected subroutines, the following JCL would be in order for the recompile runs:

```
//...JOB...
//FORTRAN EXEC FTHCL,PARM.C='OPT=2,NODECK',
//   REGION.C=300K
//C.SYSIN DD *
          .
          .
          .
     (program source deck - entire program or
      just one or more subroutines)
          .
          .
          .

/*
//L.SYSLMOD DD DSN=DU.D06.AT4119.MEDINA.LOAD,
//   DISP=OLD,VOL=SER=DUK222,UNIT=DISK,
//   SPACE=(TRK,(15,10,2))
//L.SYSIN DD *
   INCLUDE SYSLMOD(LEVELIII)
   ENTRY MAIN
   NAME LEVELIII(R)

/*
//COMPRESS EXEC PGM=IEBCOPY,COND=(5,LT)
//SYSPRINT DD SYSOUT=A
//SYSUT3 DD SPACE=(TRK,(5,2)),UNIT=SYSDA
//SYSUT4 DD SPACE=(TRK,(5,2)),UNIT=SYSDA
//LOADMOD DD DSN=DU.D06.AT4119.MEDINA.LOAD,
//   DISP=OLD,VOL=SER=DUK222,UNIT=DISK
//SYSIN DD *
   COPY INDD=LOADMOD,OUTDD=LOADMOD
```

```
/*
//
```

INTERFACING WITH CONTINUOUS SIMULATION MODELS

Urban runoff flows and pollutant concentrations and mass rates, derived from storm events over the drainage area of interest, must be generated by continuous models simulating the washoff process. These concurrent time series are read by the program through the standard card reader devices, or from peripheral storage units (disk/tape/drum). Since the program has the built-in capability of accessing a user-created data set, any continuous hydrologic and water quality model may be considered. The interfacing of Level III-Receiving with STORM and continuous SWMM is discussed subsequently. Regardless of the models used, it should be noted by the user that the urban runoff quantity and quality time series must represent <u>hourly</u> values.

Use of STORM Output

Version 2.0, L7520, of STORM (Hydrologic Engineering Center, 1976) does not store model output on peripheral devices. Thus, the program itself must be modified to do so for the quantity and quality variables of interest. For example, for the July 1976 version to store runoff in cfs and BOD_5 mass rate in lbs/hour, two statements must be added to SUBROUTINE OUTPUT immediately above its RETURN and END statements:

```
C     EVENT OUTPUT
      SUBROUTINE OUTPUT
         .
         .
         .
     (~607 FORTRAN statements)
         .
         .
         .
      WRITE(8,7150)QTOTCF,POLLRT(3)
 7150 FORMAT(2F7.1)
      RETURN
      END
```

where POLLRT(3) would be replaced by POLCON(3) if BOD_5 concentrations are desired. The information will be transferred to output device number 8. Thus, the type of file required to interface Level III-Receiving with STORM stores hourly values of urban runoff in the sequence:

flow, BOD_5
flow, BOD_5

```
flow, BOD5
  :    :
```

The typical Job Control Language specified to accomplish this task follows:

```
//STORM JOB ...
//   EXEC PGM=STORM
//STEPLIB DD PSN=DU.D06.AT4096.MEDINA.STORM1,DISP=SHR,
//   UNIT=DISK,VOL=SER=DUKBBB
//FTO6F001 DD SYSOUT=A
//FT08F001 DD DSN=DU.D06.AT4119.MEDINA.DSTRM.DISP=(NEW,
     KEEP),
//   UNIT=DISK,VOL=SER=DUKAAA,SPACE=(TRK,(3,1),RLSE),
//   DCB=(RECFM=FB,LRECL=14,BLKSIZE=7294)
//FT11F001 DD UNIT=SYSDA,SPACE=(CYL,(2,1))
//FT12F001 DD UNIT=SYSDA,SPACE=(CYL,(2,1))
//FT13F001 DD SYSOUT=A,DCB=(RECFM=FA,BLKSIZE=133)
//FT14F001 DD SYSOUT=A,DCB=(RECFM=FA,BLKSIZE=133)
//FT15F001 DD SYSOUT=A,DCB=(RECFM=FA,BLKSIZE=133)
//FT05F001 DD *
       :
    (STORM input data cards)
       :

/*
//
```

Once the data set has been created, the user simply follows the instructions for data preparation provided in Section VI to access the data set. For the example above, IPROG = 2 and IFILE = 8 (see Card Group I, Table VI-13). The job is submitted in accordance with the example provided under item (3), JOB CONTROL LANGUAGE.

Use of Continuous SWMM Output

Level III-Receiving has been programmed to interface directly with continuous SWMM output files. Thus, the user does not modify SWMM to provide input to the simplified receiving water quality model. The JCL required for a Level III-Receiving job submission which accesses the SWMM tape storing the urban runoff quantity and quality time series is, as follows:

```
//LEVELIII JOB DU.D06.AT4119,MEDINA,M=1,T=3,R=100K,P=350
//G  EXEC  PGM=LEVELIII
//STEPLIB DD DSN=DU.D06.AT4119.MEDINA.LOAD,
//             DISP=SHR
```

```
//FT01F001 DD DSNAME=SYSIN
//FT03F001 DD SYSOUT=A,DCB=(RECFM=FBA,
//            BLKSIZE=133,LRECL=133)
//FT09F001 DD DSN=MEDINA.SWMMF,DISP=OLD,
//            VOL=SER=DO6A01,UNIT=TAPE
//SYSIN DD *
       .
       .
       .
     (Level III-Receiving input data card deck)
       .
       .
       .

/*
//
```

The above instructions apply to the pre-compiled Load Module of the program which was created previously. The user specified IPROG = 1 and IFILE = 9 (see Card Group I, Table VI-13). In addition, within the first card of the input deck is specified the value of JNS, the input junction number, which identifies the inlet to the receiving waterway which is of interest for the particular simulation.

The type of file created by SWMM stores hourly values in the sequence:

time,flow,BOD_5,suspended solids,coliform bacteria
time,flow,BOD_5,suspended solids,coliform bacteria
⋮ ⋮ ⋮ ⋮ ⋮

where flow is given in cfs and the pollutants in units of mass rate (lbs/min for BOD_5 and suspended solids, MPN/min for coliform bacteria). Through the use of dummy variables, Level III-Receiving reads from the SWMM tape all of the above values but retains for further computation only <u>flow</u> and BOD_5 <u>mass</u> rate. The mass rate is converted to units of lbs BOD_5/hour.

It is important to reemphasize that Job Control Language examples are useful, but actual instructions may vary to some extent from installation to installation and machine configurations. All of the above instructions are valid on the dual IBM 370/165 system at TUCC, Research Triangle Park, North Carolina.

SECTION VI

MODEL OPERATION

This section describes the program operation, provides instructions on data preparation and input data card formats, defines key variables, shows sample runs, and presents the results of calibration and verification. The complete FORTRAN IV source program is listed in Appendix B.

PROGRAM OPERATION

The relationship among the main program and its subroutines are shown in Figure VI-1. The main program (hereafter referred to as subroutine MAIN) provides overall control and includes in its entirety the wet-weather flow model (WWFM). The first input data card to subroutine MAIN allows the user to select which subprograms will be executed during simulation, and is discussed at greater length in the next subsection. The WWFM is a mathematical abstraction of the physical system depicted earlier in Figure II-1. The user is encouraged to review the referenced schematic for better comprehension of model objectives. Stormwater runoff flows and pollutant loads or concentrations generated by an urban, continuous hydrologic simulation model (e.g. STORM or SWMM) are read either directly from card input or from peripheral devices (tape/disk/drum) depending on the machine configuration. The WWFM in subroutine MAIN simulates the conveyance system, including mixing in combined sewers of wet-weather and dry-weather pollutants during periods of runoff; the pollutant removal efficiency of various treatment schemes; mixing of the various pollutant inflow combinations with upstream sources in the receiving waters to determine initial conditions of BOD, DO, streamflow and other parameters; and computes the oxygen balance of the polluted waters downstream from the waste sources. The procedure continues for each independent storm event as defined by the minimum interevent time (MIT). Pollutant loadings and receiving water quality conditions are averaged over <u>each event's total duration</u>, which includes wet-weather and dry-weather hours. The spatial distribution of dissolved oxygen concentrations along the flow axis is computed for each event for a distance downstream chosen by the model user. Frequency analyses are performed on either the resultant DO concentrations at a specified location downstream, or critical (minimum) DO concentrations as predicted by the model for the entire period

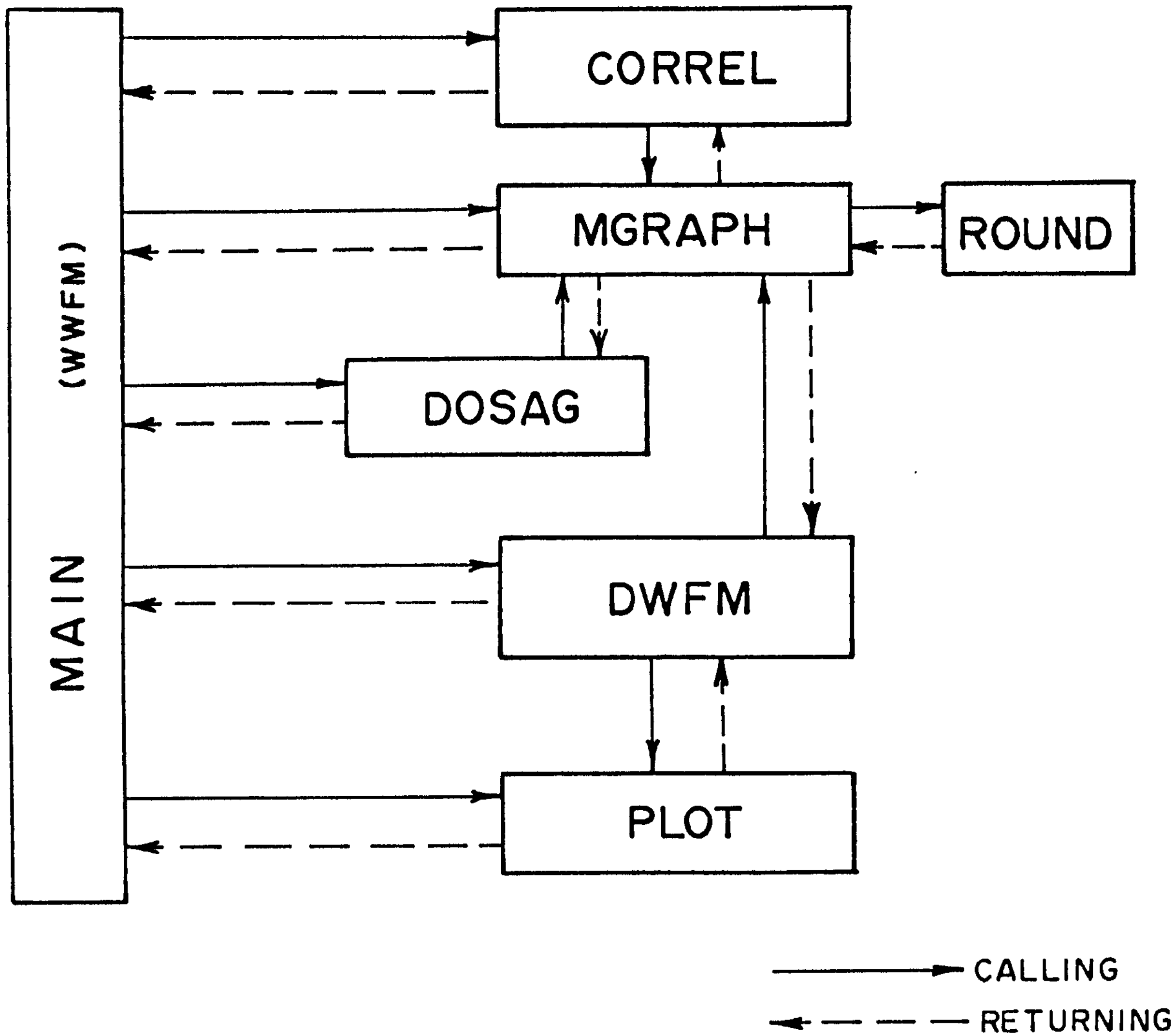


Figure VI-1. Level III-Receiving Subprograms of simulation.

Subroutine CORREL subjects the hydrologic time series (either rainfall or runoff) to autocorrelation analysis. It automatically defines the MIT used in the WWFM to separate wet-weather events. The methodology has been discussed previously in Section IV. This subroutine may be executed independently of the WWFM, but may be accessed only through subroutine MAIN. Subroutine MGRAPH, a single and multiple-curve plotting subprogram, is called by CORREL to display the correlogram of the time series. MGRAPH, in turn, calls subroutine ROUND to set the appropriate scale on the coordinate axes from examination of minimum and maximum values to be plotted.

Subroutine DWFM performs the same functions as the WWFM, <u>during periods of no urban runoff</u>. Thus, a model assumption is that no combined sewer overflows occur. Therefore, there is no "first-flush" effect, and there are no storm events over which to average pollutant loads. It may be executed independently of all other subroutines, except MAIN. Subroutine PLOT is called by the WWFM (contained in subroutine MAIN) and also by subroutine DWFM to display frequency <u>histograms</u> of receiving water DO concentrations, optionally. Likewise, subroutine MGRAPH is called by both models to plot <u>cumulative</u>, multiple frequency curves of DO concentrations.

Subroutine DOSAG is called from subroutine MAIN to display in tabular form and chronological order: the computed dissolved oxygen concentration at a user-specified location downstream, for each event simulated by the WWFM only, the DWFM only, or <u>both</u>. Thus, the listing may include DO concentrations resulting from wet-weather event pollutant loadings as well as DWF pollutant loadings during periods of no urban runoff. Consequently, the subprogram <u>sorts</u> the values according to date of occurrence in order to produce a composite chronological record. These DO concentrations are read by DOSAG from scratch data sets created automatically (ITSAG = 1) by the WWFM and the DWFM. Subroutine MGRAPH is called by subroutine DOSAG to provide a plot corresponding to the tabular listing. The plot ordinate (dissolved oxygen concentration) is scaled according to magnitude; however, the abscissa represents the total number of simulated events, numbered sequentially and not scaled according to their time of occurrence since the beginning of simulation. Each event number is identified according to date in a tabular format which precedes each plot. If the simulated events are not distributed evenly throughout the period of simulation, the DO profile may be distorted with respect to the abscissa. Thus, the user is cautioned to scale the profile appropriately by manual plotting with reference to the tabular output. The utility of the model-generated DO-versus-event plot is best appreciated during calibration procedures, when measured values may be quickly hand-plotted on the printed output to visualize the degree of adjustment required of model parameters.

INSTRUCTIONS FOR DATA PREPARATION

The input data cards should be sequenced as illustrated in Figure VI-23 and prepared according to the format specifications given in Table VI-13 , at the end of this section. The data cards are organized into 5 major card groups and 15 card types. Each card group may contain one or more card types. The total number of cards depends on the length of the simulation period and the number of computational options selected by the user. Card group I consists of one card which controls the execution of three major subprograms: 1) subroutine CORREL, 2) the WWFM in subroutine MAIN, and 3) the DWFM. It also specifies the type of input device used to transfer information into program storage (memory) for further processing. If input from other than cards applies (IPROG = 1, or 2), the unit number (IFILE) of the input device (tape/disk/drum) must be provided. Programming considerations such as job control language (JCL) have been discussed in detail in Section V. As stated previously, the SWMM input junction number (JNS, required if IPROG = 1) refers to the receiving water inlet number. If the number of outlets where hydrographs and pollutographs are being stored equals one (NOUTS = 1), then it follows that JNS = 1 also.

Subroutine CORREL requires the preparation of Card Group II. A maximum number of data points of N = 8760 may be analyzed currently, as well as a maximum number of hourly lags of NLAGS = 800. For most applications, these size limitations are quite adequate. Certainly, the minimum interevent time will be well defined within that range. However, if cyclical aspects of the time series are of interest, the user may easily increase the size of the applicable arrays within the subroutine. Card group II would be skipped if ICORR = 0, and card group III would then follow directly behind card group I.

Card group III is required if either IWWFM or IDWFM = 1, and consists of four cards. Card group IV is required if IWWFM = 1. Card type 11 <u>or</u> 12, <u>or</u> 13 (whichever is applicable depends on IPROG = 0, 1, <u>or</u> 2) is <u>repeated</u> for each hourly runoff event. Similarly, the rest of the card groups and card types are prepared in accordance with user-selected control options and given format specifications.

<u>Estimates of Model Coefficients</u>

Good initial estimates of various model coefficients are desirable to reduce the calibration process to a minimum. Even though there is no real substitute for the actual in situ field measurement, it is helpful to examine ranges of reported values when the former is not possible. The parameters of interest are: the longitudinal dispersion coefficient, E; maximum and minimum values of the deoxygenation rate constant, K_1, of carbonaceous BOD_5 @ 20°C (XK1MAX and XK1MIN); regression coefficients α_1 (ALPHA1) and α_2 (ALPHA2), which relate stream velocity to discharge; regression coefficients β_1 (BETA1) and β_2 (BETA2), which relate stream depth to discharge; and regression coefficients γ_1 (GAMMA1) and γ_2 (GAMMA2), which relate stream depth to deoxygenation rate of carbonaceous BOD.

A simplified technique for the determination of the longitudinal dispersion coefficient from observed quasi-steady state chloride concentration profiles (Hydroscience, Inc., 1972) has been presented in Section IV. Similarly, first estimates of K_1 can be obtained from semi-logarithmic plots of observed long term BOD_5 stream data as a function of distance downstream. Neglecting longitudinal dispersion E in equation (IV-16), the simplified relationship

$$U \frac{dL}{dx} = - K_1 L \qquad \text{(VI-1)}$$

is obtained, which integrates to

$$L = L_o \, e^{-K_1 \frac{x}{U}} \qquad \text{(VI-2)}$$

where

L = BOD_5 concentration, mg/l

L_o = BOD_5 concentration @ x = 0, mg/l

U = receiving water velocity, ft/hr

K_1 = deoxygenation rate constant, $hour^{-1}$, and

x = distance downstream, feet

Equation (VI-2), in natural logarithms, becomes

$$\ln L = - \frac{K_1}{U} x + \ln L_o \qquad \text{(VI-3)}$$

From a straight-line fit, the slope of the curve can be determined, and thus:

$$K_1 = (\text{Slope})\ U \qquad \text{(VI-4)}$$

If model variables XK1MAX and XK1MIN are both assigned the same numerical value (say, as obtained from above equation), Level III-Receiving will adjust K_1 only for stream temperature and not stream depth (see Figure IV-1). When converted to units of hour^{-1}, the magnitudes of XK1MAX and XK1MIN in Figure IV-1 correspond to 0.0417 and 0.0220, respectively. The user also has the flexibility of selecting limiting values which bracket the estimates obtained from equation (VI-4), or have been chosen from experience. Representative values of K_1 @ 20°C and E (where applicable) are listed for selected streams, tidal rivers and estuaries in Table VI-1.

In an estensive study of the hydraulic geometry of stream channels (Leopold and Maddock, 1953) average values of α_2 = 0.34 and β_2 = 0.40 were found for 20 river cross sections representing a large variety of rivers in the Great Plains and the Southwest. These mean values provide an indication of order of magnitude only. For example, from plots of depth versus discharge for the Kansas River System in Kansas and Nebraska, the coefficients were determined to be:

$$\alpha_1 = 1.60$$

$$\alpha_2 = 0.03$$

$$\beta_1 = 0.11$$

$$\beta_2 = 0.45$$

which can be used as initial estimates for a river system of similar physiographic characteristics and mean annual discharge. The relationship between deoxygenation rate, K_1, and average stream depth, H, is influenced by factors such as stream bed conditions (stable, rocky versus unstable, sandy channel), density of benthal communities, and the nature of the residual organic matter transported by the waterway. All of these factors are incorporated into the regression coefficients γ_1 and γ_2. In the absence of sufficient field data to yield a logarithmic plot such as depicted in Figure IV-1, the user should simply adopt the values shown (γ_1 = 0.99 and γ_2 = -0.28) as initial estimates subject to further adjustment by subsequent calibration procedures.

TABLE VI-1. REPRESENTATIVE DEOXYGENATION RATE AND DISPERSION COEFFICIENTS (MODIFIED AFTER HYDROSCIENCE, INC., 1972)

Receiving Watercourse	Category	Discharge, cfs (cu m/sec)	K_1 @ 20°C, $hour^{-1}$	E, ft^2/hour (sq m/hour)
A. Rivers				
Clinton River, Michigan	Shallow	33 (0.93)	0.140	-
N. Branch Potomac River, Maryland and West Virginia	Shallow	100 (2.83)	0.017	-
N. Branch Susquehanna River, New York	Medium	1000 (28.3)	0.015	-
Ohio River	Deep	6000 (170)	0.010	-
Lower Sacramento River, California	Deep	10,000 (283)	0.017	-
	Depth, ft (m)	**Net Non-Tidal Flow, cfs (cu m/sec)**	**K_1 @ 20°C, $hour^{-1}$**	**E, ft^2/hour (sq m/hour)**
B. Estuaries				
Delaware River	25 (7.62)	2500 (71)	0.013	5,800,000 (540,000)
Savannah River	10 to 28 (3.05 to 8.53)	7000 (198)	0.013	1.16×10^7 (1.08×10^6)
Cape Fear River North Carolina	9.7 to 20 (2.96 to 6.1)	1000 (28.3)	0.010	2,300,000 (216,000)
Wappinger Creek, New York	9 (2.7)	2 (0.06)	0.013	581,000 (54,000)

SAMPLE APPLICATION

An example of an application of Level III-Receiving to the city of Des Moines, Iowa, is presented in this subsection. It has already been established that there is a need for continuous hydrologic simulation to assess the frequency with which runoff events cause adverse effects in the receiving waters. It would be quite difficult to generate a realistic pollutant distribution for a long sequence of synthetic flows. There are other important reasons that justify selection of a real study area. The only way to establish the necessary validity which renders a mathematical model such as Level III-Receiving useful for planning purposes is to conduct verification procedures and calibrate against field-measured data. Furthermore, when evaluating the effectiveness of proposed control measures it is important to base comparisons against existing conditions in the study area.

Selection of the study area was based primarily on data availability. Davis and Borchardt, of Henningson, Durham & Richardson, Inc., Omaha, Nebraska, conducted an extensive sampling program of combined sewer overflows, stormwater discharges, and surface waters in the Des Moines, Iowa Metropolitan Area for the U. S. Environmental Protection Agency. The objective was a combined sewer overflow abatement plan for the metropolitan area. The sampling program was conducted from March 1968 to October 1969. Other considerations revolved around the fact that Des Moines, Iowa is somewhat typical of many urban centers throughout the country.

(1) it has a medium-sized population;

(2) its domestic and industrial dry weather flows receive secondary treatment;

(3) its wastewaters are discharged into a non-tidal receiving stream; and

(4) the urban area receives a mean annual precipitation approximately equal to the national average, 31.27 inches (795 mm).

The city is located near the confluence of the Des Moines River and the Raccoon River as shown in Figure VI-2. It has a population of approximately 200,000 out of a total of 288,000 for the metropolitan area (Davis and Borchardt, 1974). River sampling stations are shown in Figure VI-3. As stated earlier, the relative impact of urban sources of water pollution is expected to increase as the size of the upstream drainage area decreases. To simulate this effect the model application to Des Moines investigates the response of the receiving water when

Figure VI-2. Map of Des Moines Area (Davis & Borchardt, 1974)

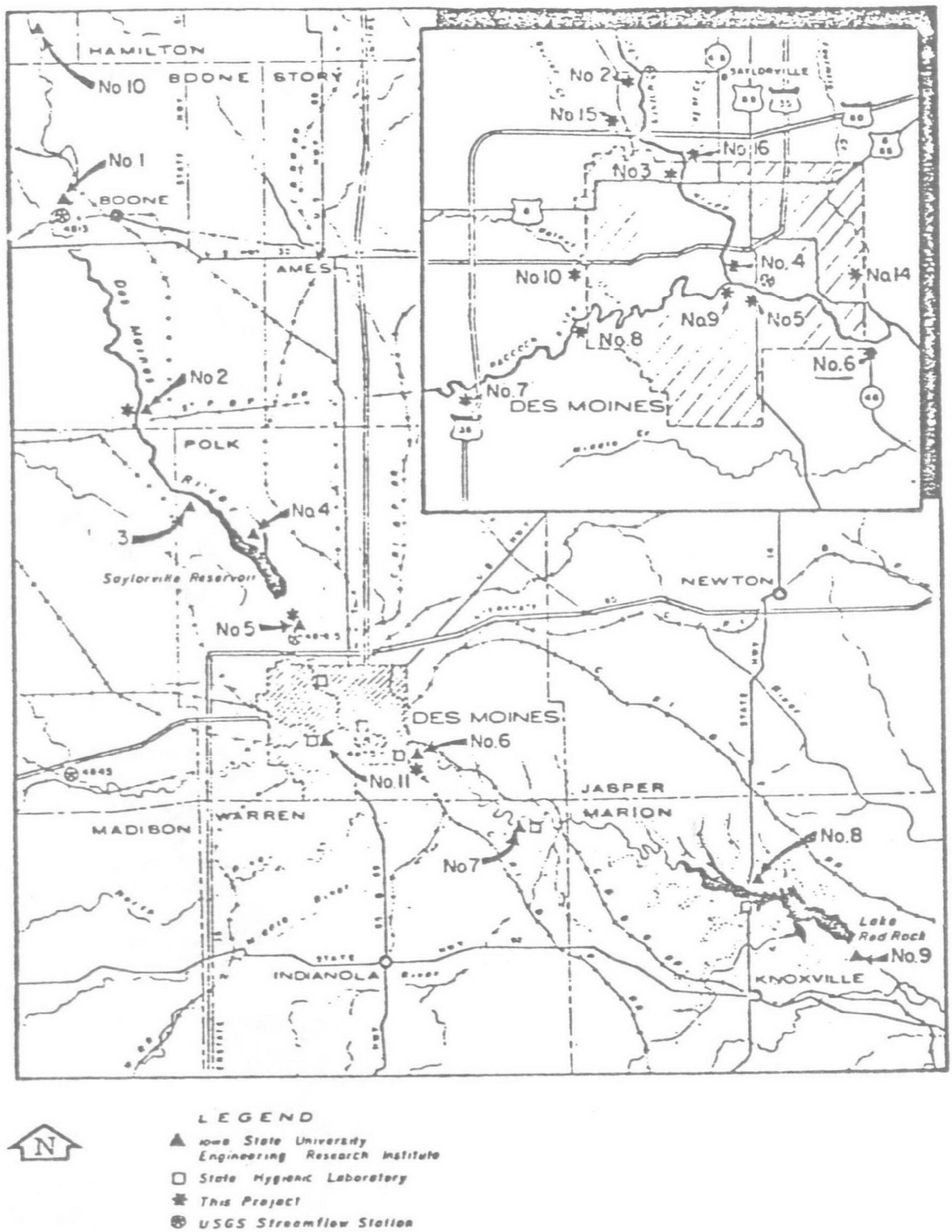


Figure VI-3. River Sampling Stations (Davis and Borchardt, 1974) upstream river flow, Q_u, is reduced to various fractions of measured flow. This option and others used for the Des Moines simulations are summarized in Table VI-2. Note that although the model allows for three DWF treatment rates (J = 1, 2, 3) to be set per run, the user may vary the rates so that an unlimited number of combinations may be investigated.

Data Sources

Data requirements may be broken into categories describing needs for the hydrologic simulation, to obtain urban runoff hydrographs and pollutographs, and those for Level III-Receiving input. All land use, population density, areas, curb lengths, etc., were obtained from data prepared by the American Public Works Association (APWA) for STORM simulations (Manning, et al., 1977). Hourly rainfall measurements for the year 1968 were obtained from the National Oceanic and Atmospheric Administration's Environmental Data Service, National Climatic Center, Asheville, North Carolina. The precipitation time series is presented in Figure VI-4. The abscissa represents the 10-month period, in hours from March 1 to December 30, 1968. An examination of the rainfall record provides considerable insight as to storm groupings, their intensity and duration, frequency of occurrence, and the extreme temporal variability. The broken line on the abscissa indicates dry-weather periods at least 9 hours in length. Figure VI-4 provides the necessary information to define a minimum interevent time.

The area served by combined sewers was obtained from a combined sewer overflow abatement study for Des Moines, Iowa (Davis and Borchardt, 1974) as well as: dry-weather flow values, receiving water upstream flows, temperatures, and BOD and DO levels in the Des Moines River. Total urban runoff (Q_t) and its BOD concentrations are obtained from the STORM simulation on an hourly basis. A value for the longitudinal dispersion coefficient of E= 180,000 ft^2/hour was assumed since the river reach of interest is not tidal or estuarine.

The first flush factor, FFLBS, was determined as follows:

$$\text{DWH/year} = 6{,}993 \text{ hour}$$

$$\text{Total flow combined} = 1.55 \times 10^8 \text{ cf/yr} \quad (4.39 \times 10^6 \text{ cu m/yr}).$$

Mixed concentration of storm water (from STORM) plus DWF = BOD_c = 62 mg/l. The annual average BOD concentration in the combined sewer was measured to be 72 mg/l (Davis and Borchardt, 1974):

$$\text{BOD difference} = 10 \text{ mg/l} = 0.0006243 \text{ lbs/ft}^3$$

TABLE VI-2. OPTIONS USED FOR DES MOINES SIMULATIONS

The following five inflow combinations (M)[1] are used:

1. River flow + DWF
2. River flow + DWF + separate storm flow
3. River flow + DWF + combined storm flow
4. River flow + separate storm flow + combined storm flow
5. River flow + DWF + separate storm flow + combined storm flow

and the following four DWF treatment rates (J) are used:

1. 0% (no treatment)
2. 30% (primary)
3. 85% (secondary)
4. 95% (tertiary)

and the following three WWF treatment rates (L) are used:

1. 0% (no treatment)
2. 25%
3. 75%

and the following three river flows (K) are used:

1. 0% of measured flow
2. 25% of measured flow
3. 100% of measured flow

and the fraction of combined area is varied four times:

1. 0% of total urban area
2. 8.16% of total urban area (existing conditions)
3. 50% of total urban area
4. 100% of total urban area

---

[1]Parameters J, K, L and M were used as subscripts in the computer output and serve to aid in labeling the various combinations.

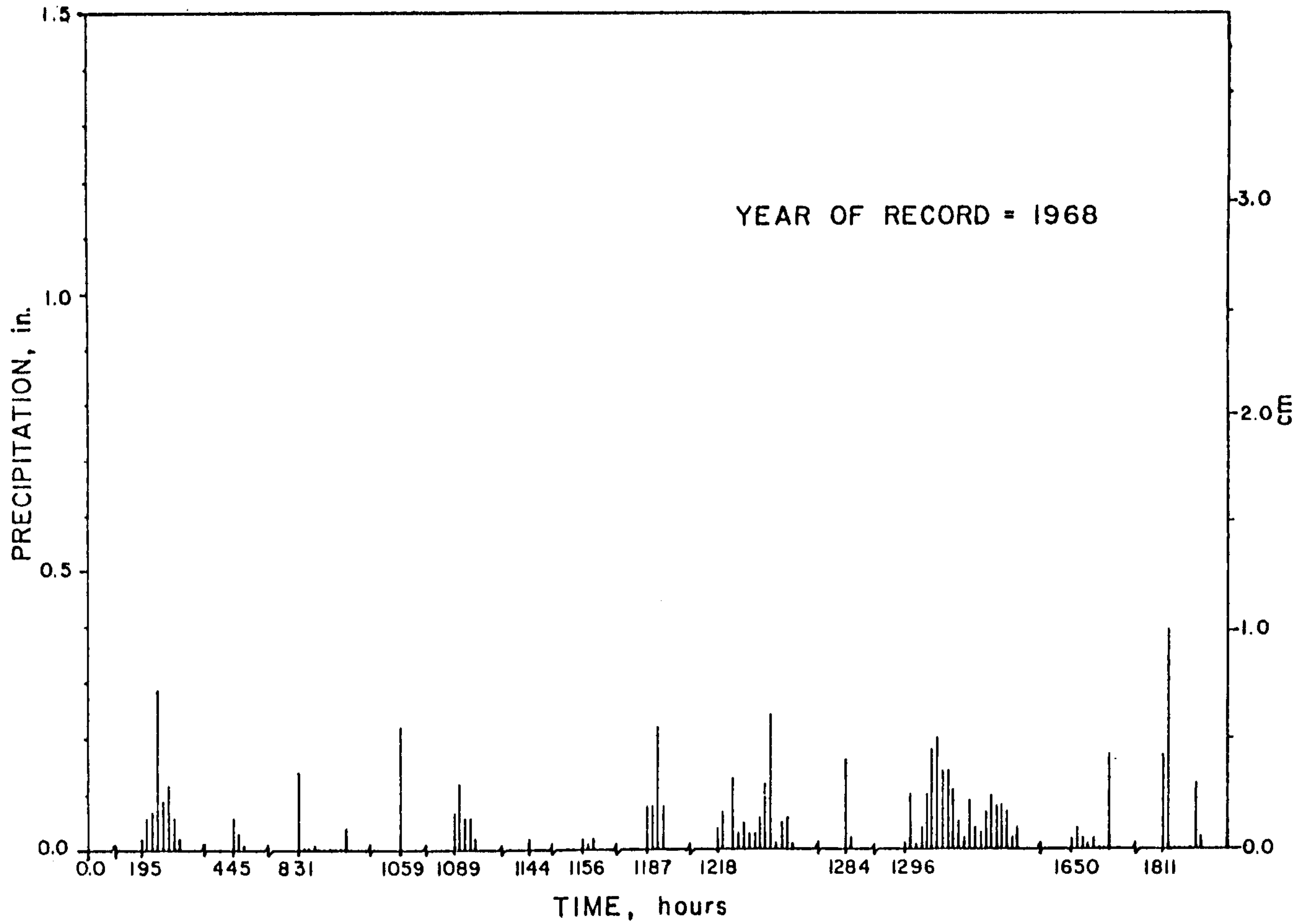


Figure VI-4. Point Rainfall for Des Moines, Iowa

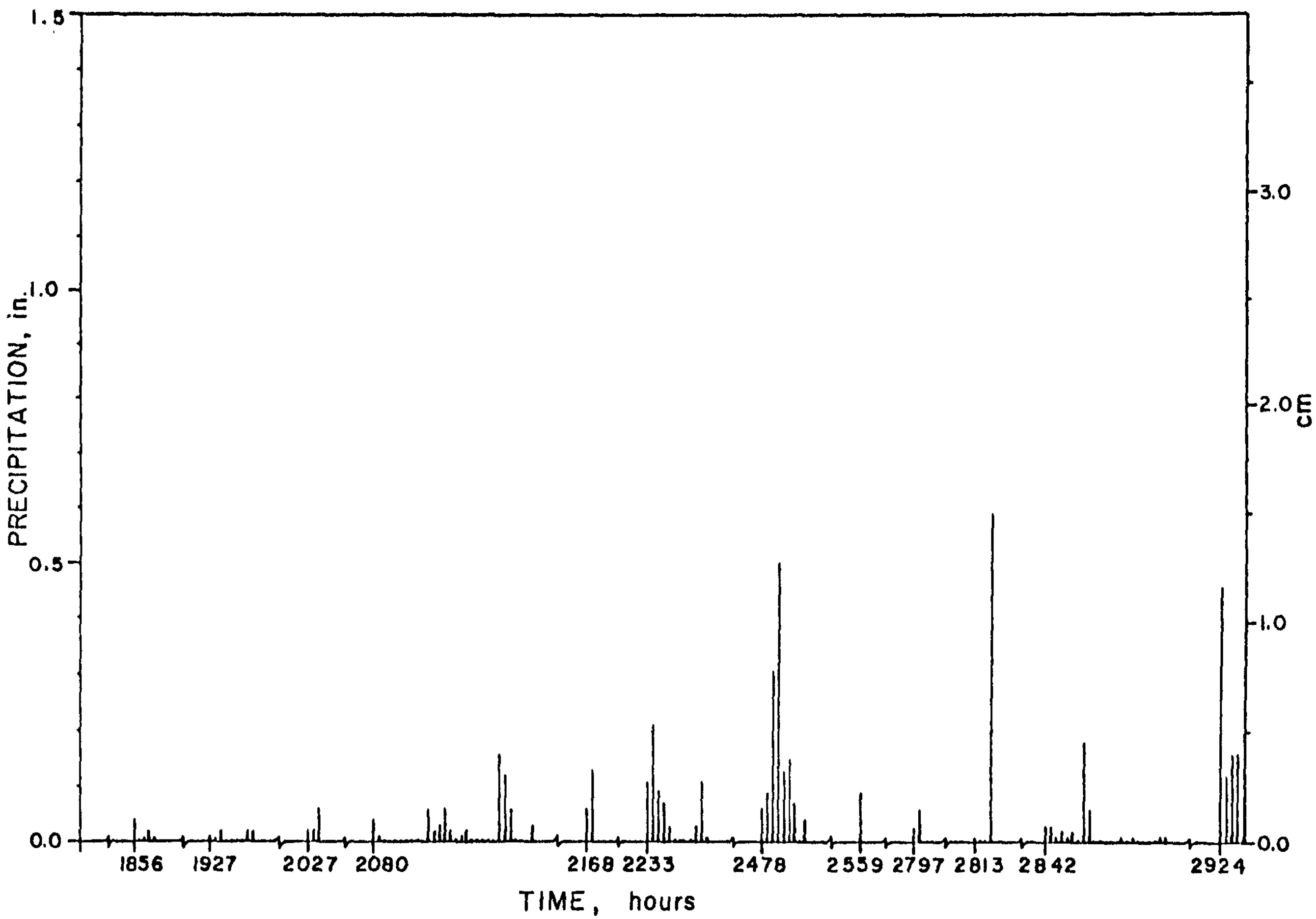


Figure VI-4. (Continued)

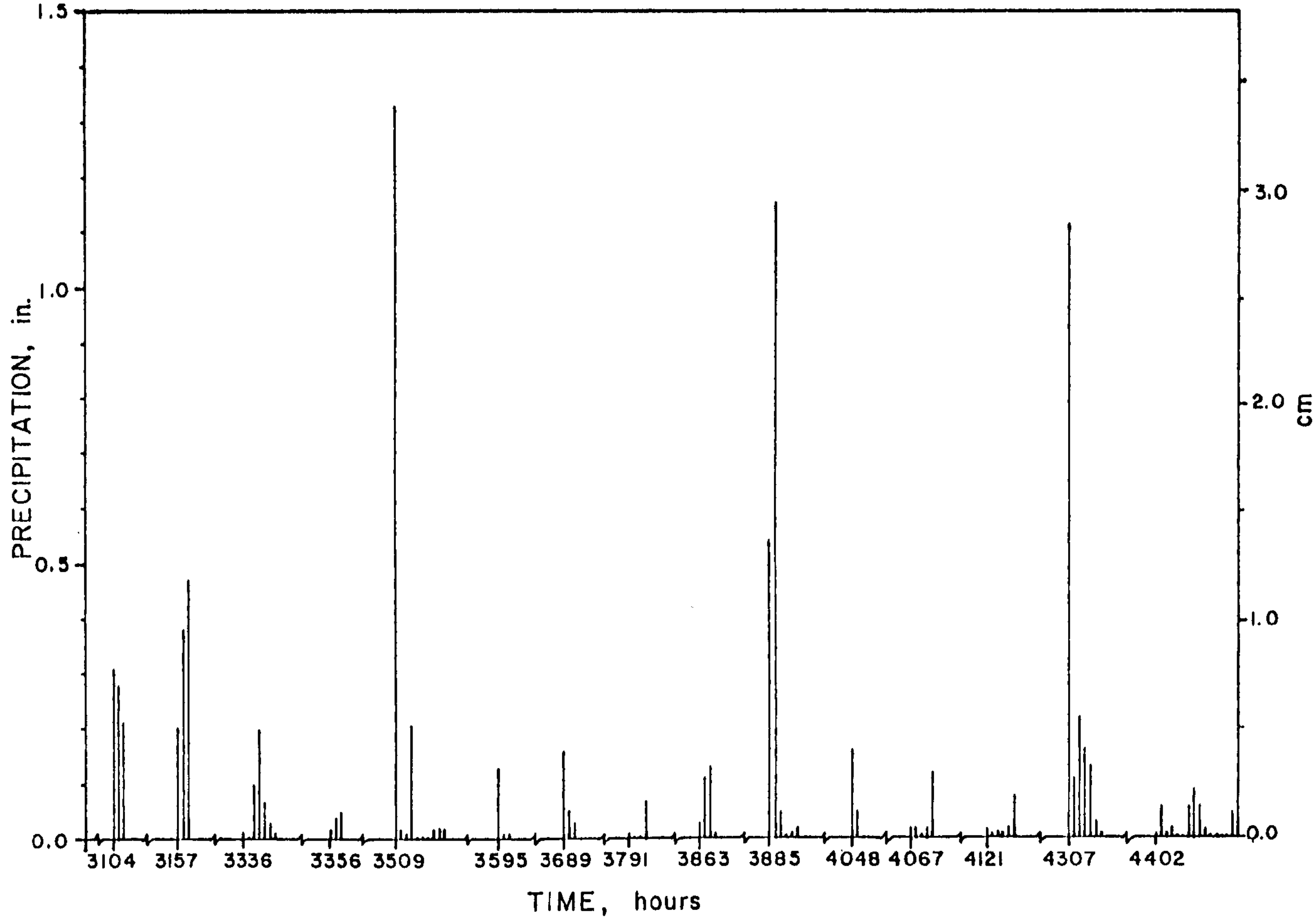


Figure VI-4. (Continued)

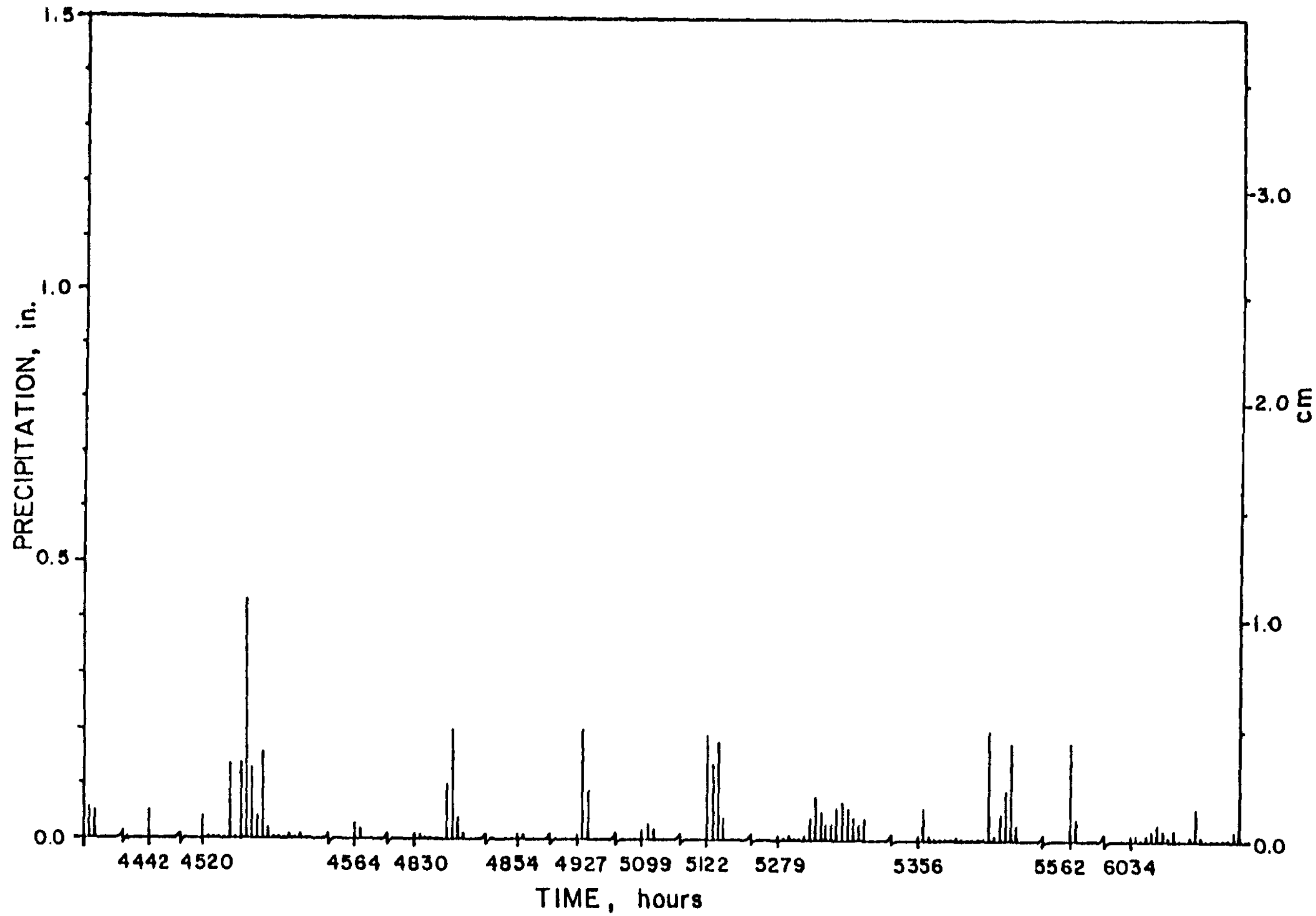


Figure VI-4. (Continued)

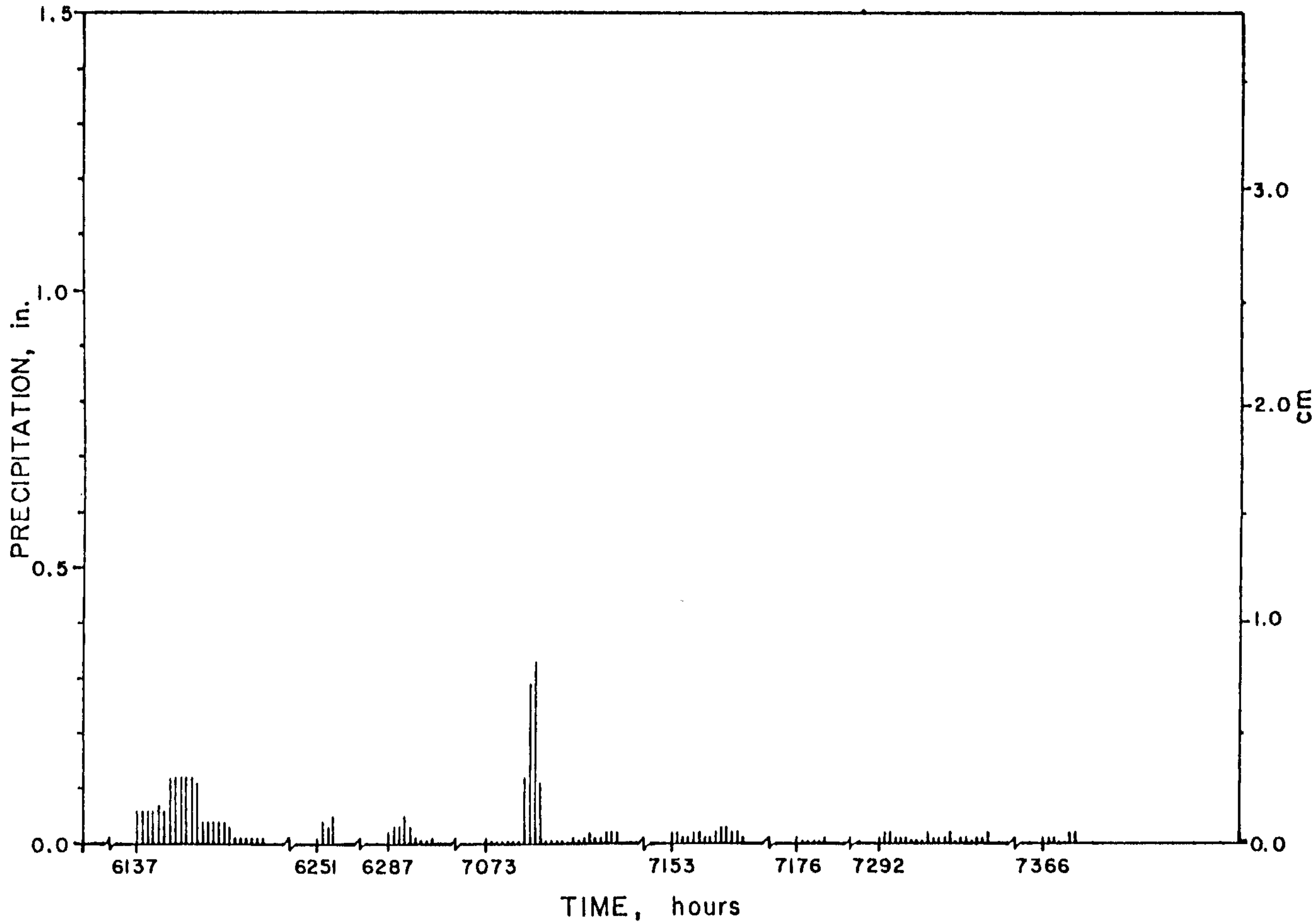


Figure VI-4. (Continued)

$$\text{BOD load} = (0.0006243 \text{ lbs/cf})(1.55 \times 10^8 \text{ cf/yr})$$

$$= 96{,}766.50 \text{ lbs/yr } (43{,}892.50 \text{ kg/yr})$$

that can be attributed to first flush effects

$$\text{FFLBS} = \frac{96{,}766.50 \text{ lbs/yr}}{(6993 \text{ DWH/yr})}$$

$$= 13.84 \text{ lbs/DWH}$$

This factor as demonstrated earlier, is then used in equation (IV-5) to estimate the first flush BOD load, FF, during the first hour of runoff generated by each storm event.

<u>Calibration and Verification</u>

An important element of the total effort required to develop a mathematical model of receiving water quality is devoted to calibration and verification - the improvement of model accuracy. The procedure recommended for steady-state water quality models includes:

1. examination of model output using preliminary coefficients on a diverse set of data (different waste loads and temperatures under conditions of high and low flow, and variable initial stream quality);

2. assessment of the closeness of fit of observed field data to computed values;

3. adjustment of the model coefficients until the desired accuracy is obtained; and

4. achievement of a mathematical abstraction that reasonably reproduces observed stream response and establishes the necessary validity for planning purposes.

The verification procedure was preceded by calibration of the urban runoff BOD_5 loading rates for Des Moines, Iowa, as computed by STORM. The dust and dirt surface loading factors were adjusted to obtain an annual average BOD_5 concentration of 53 mg/l for urban stormwater runoff. The above concentration was the average value determined by the field monitoring program in the separate sewer system (Davis and Borchardt, 1974). Level III-Receiving, as discussed in the methodology, simulates the mixing of stormwater runoff and sanitary sewage in the combined sewer system.

The annual average BOD_5 concentration of combined sewer overflows was computed to be 75 mg/l, including the effects of first flush. The average value determined by the field monitoring program in the combined sewer system was determined to be 72 mg/l.

Upper and lower bounds of the carbonaceous BOD deoxygenation rate coefficient, K_1, were set to 0.0417 and 0.022 hour^{-1} at 20°C in accordance with results of field data surveys (Hydroscience, Inc., 1971). These values (program variables XK1MAX and XK1MIN) should be adjusted to local conditions if such a range has been measured. Initial estimates of the regression coefficients relating deoxygenation rate to stream depth were refined during calibration to final values of: $\gamma_1 = 0.99$ and $\gamma_2 = -0.28$. The model, of course, adjusts for temperature variation through equation (IV-38). From initial estimates obtained for the Kansas River System in Kansas and Nebraska, the regression coefficients relating velocity to streamflow and depth to streamflow were adjusted to: $\alpha_1 = 1.300$, $\alpha_2 = 0.060$, $\beta_1 = 0.200$, and $\beta_2 = 0.450$. The atmospheric reaeration coefficient, K_2, is calculated internally as a function of streamflow, the above regression coefficients, and temperature through equations (IV-42) and (IV-43). Therefore, no adjustment of this model coefficient is necessary. Measured and computed values of DO at a distance of 5.6 miles (9.0 km) downstream from the confluence of the Raccoon and Des Moines Rivers are compared in Figure VI-5. All model coefficients were calibrated to obtain a satisfactory fit between the computed profile and the individual DO measurements listed in Table VI-3 (Davis and Borchardt, 1974). The DO measurements in Figure VI-5 have been connected by a dashed line to represent a profile; however, it should be noted that gaps in the time history suggest that such a profile is only an approximate representation.

Depending on planning objectives and desired model accuracy, further verification may be accomplished by simulating the stream response to hydrologic and waste inputs for another year if field measurements are available. Included in Figure VI-5 are average total streamflow values for each wet-weather event (as defined by the minimum intervent time). Differences between measured and computed DO concentrations may be attributed to such factors as: (1) the time of day during which the sample was taken; (2) the lag time between sampling and laboratory analysis and the temperature variations in the receiving water during the day; and (3) a lack of data on photosynthesis, algal respiration, and benthic demand. The time scale in days represents the wet year beginning on March 8 and ending December 30, 1968. Again, it should be reemphasized that these DO values are not the minimum DO's resulting from maximum deficits. The maximum deficits occur much further downstream (18-40 miles or 29-64 km) and water quality standards are violated much

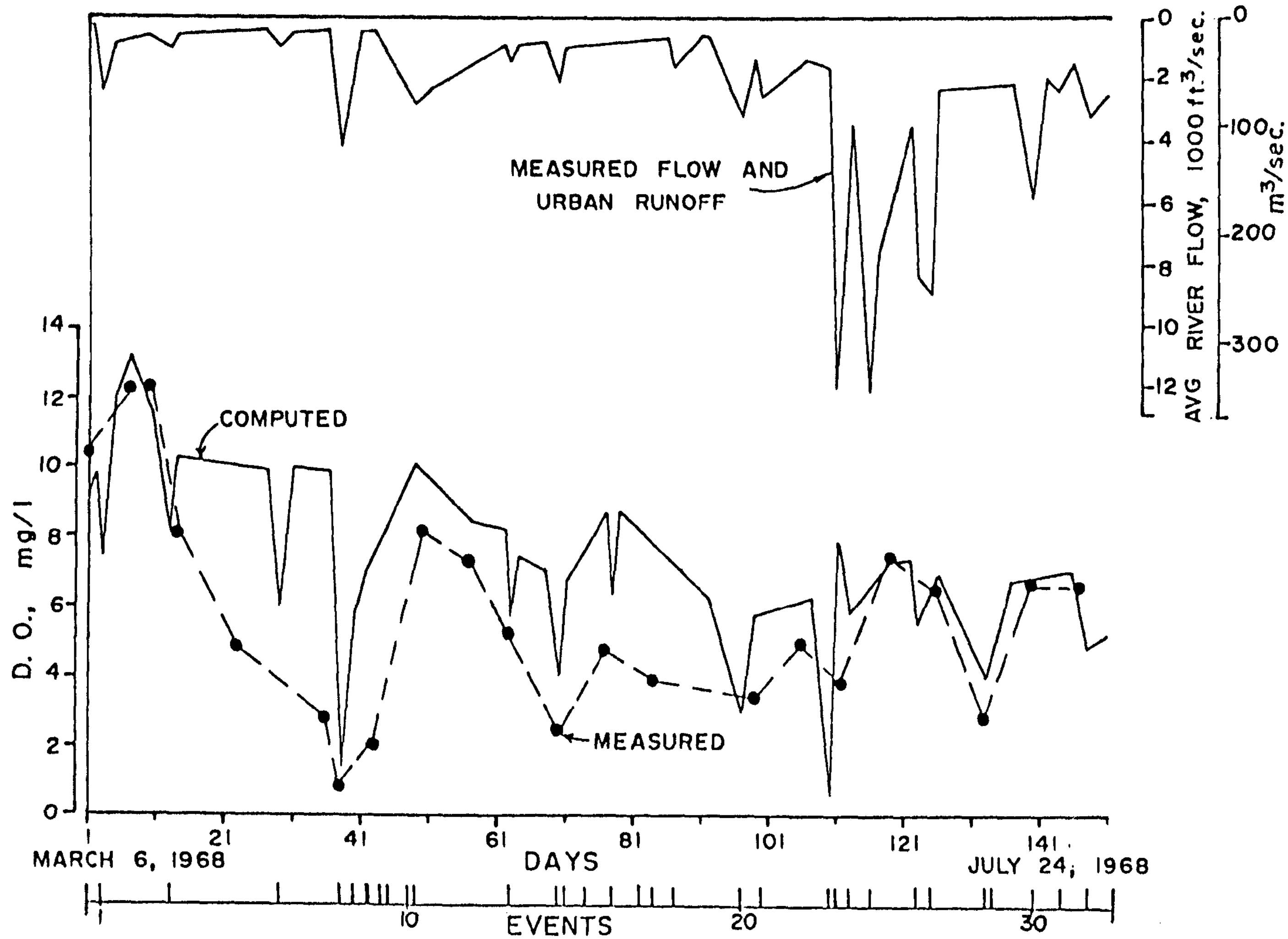


Figure VI-5. Application to Des Moines, Iowa. Measured and computed values of DO at 5.6 mi (9.0 km) downstream from confluence of Raccoon and Des Moines Rivers.

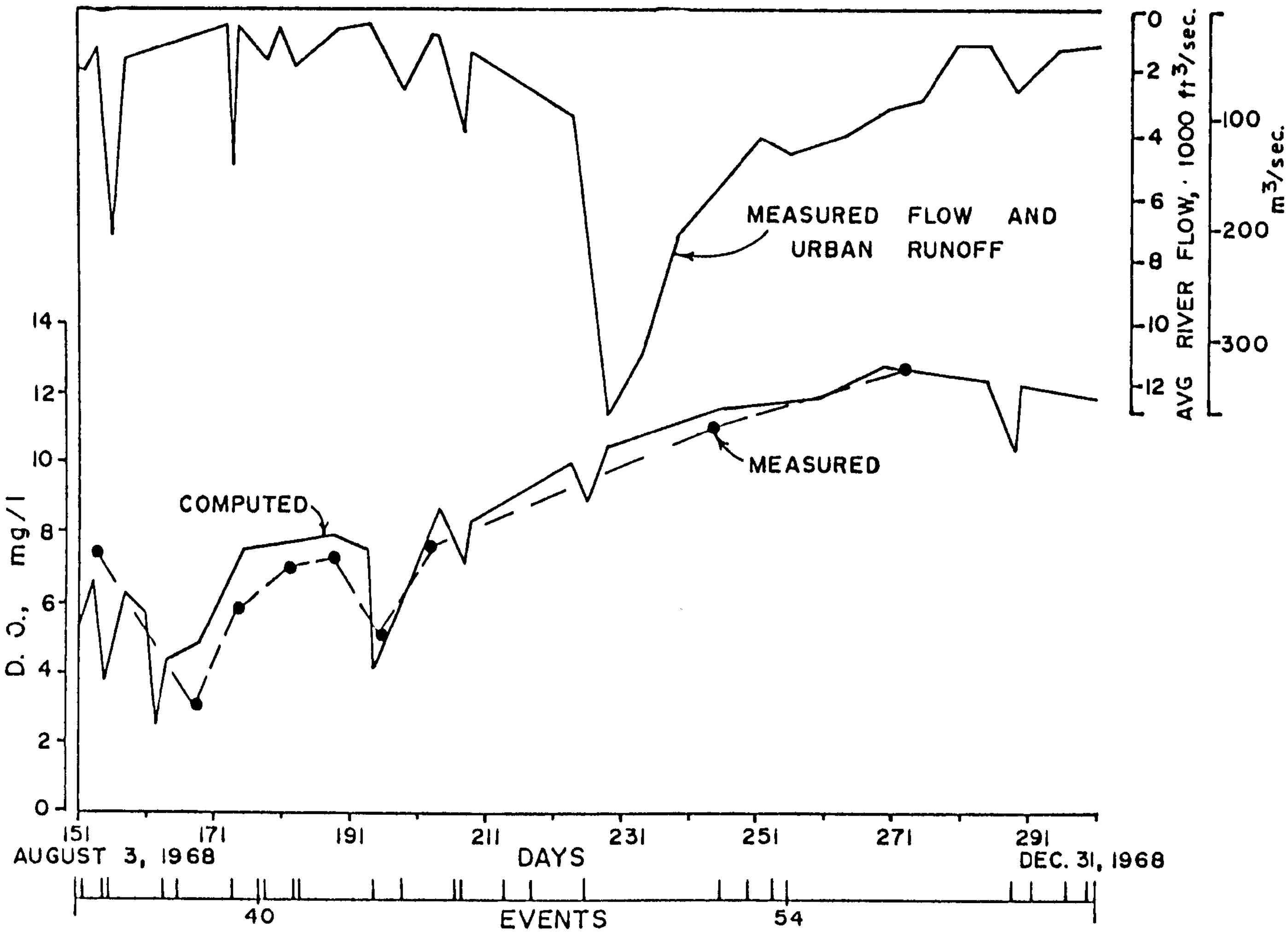


Figure VI-5. (Continued)

TABLE VI-3. MEASURED DO CONCENTRATIONS[1] DOWNSTREAM FROM DES MOINES, IOWA[2]

Date (Month/Day/Year)	DO Concentration (mg/l)	Date (Month/Day/Year)	DO Concentration (mg/l)
3/06/68	10.3	6/19/68	5.0
3/12/68	12.2	6/25/68	3.8
3/15/68	12.2	7/02/68	7.4
3/19/68	8.1	7/09/68	6.5
3/28/68	4.8	7/16/68	2.9
4/10/68	2.8	7/23/68	6.7
4/12/68	0.8	7/30/68	6.6
4/17/68	2.0	8/06/68	7.4
4/24/68	8.1	8/21/68	3.0
5/01/68	7.3	8/27/68	5.9
5/07/68	5.2	9/03/68	7.0
5/14/68	2.5	9/10/68	7.3
5/21/58	4.8	9/17/68	5.1
5/28/68	3.9	9/24/68	7.6
6/04/68	0.3	11/05/68	11.0
6/12/68	3.4	12/03/68	12.7

[1] Henningson, Durham & Richardson, Inc., Omaha, Nebraska (Davis and Borchardt, 1974)

[2] Distance of 5.6 mi (9.0 km) downstream from the confluence of the Raccoon and Des Moines Rivers, sampling location No. 6 (see Figure VI-3).

more frequently.

Sample Input Data and Printed Output

A map of the study area and its point rainfall history for the year 1968 have been presented in Figures VI-2, VI-3, and VI-4. Input data for Des Moines, Iowa (including the required receiving water parameters for the Des Moines River) are shown in Table VI-4. Card Groups and card types are identified also, in accordance with Table VI-13.

The ensuing tables and figures are examples of printed output. Due to the volume of such output, only a partial listing of the typical information displayed by the model is provided. Table VI-5 illustrates the first page of output, which identifies the model name and personnel to contact for information and assistance. Computed values of the autocorrelation function are shown in Table VI-6 and the correlogram of the hydrologic times series is plotted in Figure VI-6. Input data common to the wet weather flow and dry weather flow subprograms are displayed in Table VI-7, as well as the study area identification label and the values of key parameters and control variables of the WWFM. Output typical of each wet-weather event simulated is presented in Table VI-8. Figure VI-7 displays the spatial distribution of DO downstream from the point of waste discharge for a distance of 150 miles (240 km), for various waste inflow combinations (M = 1,..., 5). This distance corresponds to 100 segments of length DX = 1.50 miles, a user-selected parameter. Figures VI-8 and VI-9 represent, respectively, plots of critical DO frequency histogram and cumulative frequency curves. Table VI-9 consists of a chronologically sorted listing of composite wet and dry weather events and their corresponding DO concentration values, at a distance 5.61 miles (9.0 km) downstream from the point of waste discharge. The distance for which the event DO profile is desired is selected by the user (program variable X). Figure VI-10 is a plot of the DO concentrations in Table VI-9 versus the event number. Thus, the abscissa of the plot is not truly time-scaled. However, since each table is followed by a plot (repeated until the entire period of simulation is included), a time-scaled profile can be easily obtained manually.

Interpretation of Output - Results

A detailed economic analysis of urban water pollution control alternatives in Des Moines, Iowa and its integration with an evaluation of receiving water quality impacts has been presented elsewhere as part of a more comprehensive nationwide assessment (Heaney, *et al.*, 1977). Some of the results of the cost-effectiveness approach are summarized throughout this subsection to further aid the potential user in the interpretation

TABLE VI-4. INPUT DATA FOR LEVEL III-RECEIVING, DES MOINES APPLICATION

Data	Card Group Number
1 1 1 0 0 0	I
7344 800	II
3 170.	
4 0.02 0.06 0.07 0.29 0.09 0.12 0.06 0.02	
3 234.	
4 0.06 0.03 0.01	
3 382.	
4 0.10 0.14	
3 2.	
4 0.01	
3 5.	
4 0.04	
3 218.	
4 0.22	
3 29.	
4 0.07 0.12 0.06 0.06 0.02	
3 50.	
4 0.02	
3 11.	
4 0.02 0.01 0.02	
3 28.	
4 0.08 0.08 0.22 0.04	
3 27.	
4 0.04 0.07	
3 1.	
4 0.13 0.03 0.05 0.03 0.03 0.06 0.12 0.24 0.01 0.05 0.06 0.01	
3 51.	
4 0.16 0.02	
3 10.	
4 0.01 0.01 0.01 0.04 0.01 0.13 0.20 0.14 0.14 0.11 0.05 0.02 0.09 0.04 0.03	
4 00.07 0.10 0.08 0.08 0.07 0.02 0.04	
3 332.	
4 0.02 0.04 0.02 0.01 0.02	
3 2.	
4 0.17	
3 145.	
4 0.17 0.29	
3 4.	
4 0.12 0.02	
3 37.	
4 0.04	
3 7.	
4 0.02 0.01	
3 56.	
4 0.01	
3 1.	
4 0.02	
3 4.	
4 0.02 0.02	
3 91.	

(Continued)

TABLE VI-4. (Continued)

Data — Card Group Number

```
W      0.01 0.01 0.06
D       51.
W      0.04 0.01
D       3.
W      0.06 0.02 0.03 0.06 0.02
D       1.
W      0.01 0.02
D       5.
W      0.16 0.12 0.06
D       3.
W      0.03
D       58.
W      0.06 0.13
D       63.
W      0.11 0.21 0.09 0.07 0.02
D       4.
W      0.03 0.11 0.01
D      233.
W      0.06 0.09 0.31 0.50 0.13 0.15 0.07
D       1.
W      0.04
D       72.
W      0.09
D      236.
W      0.02 0.06                                        > II
D       14.
W      0.01
D       2.
W      0.59
D       25.
W      0.03 0.03 0.01 0.02 0.01 0.02
D       1.
W      0.18 0.06
D       5.
W      0.01
D       1.
W      0.01
D       4.
W      0.01 0.01
D       59.
W      0.46 0.12 0.16 0.16
D      176.
W      0.32 0.28 0.21
D       50.
W      0.20 0.38 0.47
D      176.
W      0.01
D       1.
W      0.10 0.20 0.07 0.03 0.01
D       13.
```

(Continued)

TABLE VI-4. (Continued)

Data | Card Group Number

```
W      0.02 0.04 0.05
D      151.
W      1.33 0.02 0.01 0.21
D        2.
W      0.02 0.02 0.02
D       76.
W      0.13 0.01 0.01
D       91.
W      0.16 0.05 0.03
D       99.
W      0.01
D        2.
W      0.07
D       68.
W      0.03 0.11 0.13 0.01
D       19.
W      0.54 1.16 0.05
D        1.
W      0.01 0.02
D      164.
W      0.16 0.05
D       17.
W      0.02 0.02
D        1.
W      0.20 0.12
D       49.
W      0.02 0.01 0.01 0.01 0.02 0.08
D      188.
W      1.12 0.11 0.22 0.16 0.13 0.03 0.01
D       91.
W      0.01 0.06 0.01 0.02
D        2.
W      0.06 0.09 0.06 0.02
D        4.
W      0.05 0.06 0.05
D       23.
W      0.05
D       69.
W      0.04
D        4.
W      0.14
D        1.
W      0.14 0.43 0.13 0.04 0.15 0.02
D        3.
W      0.01
D        1.
W      0.01
D       25.
W      0.03 0.02
D      264.
```

II

(Continued)

TABLE VI-4. (Continued)

Data — Card Group Number

```
W      0.01 0.01
D         4.
W      0.10 0.20 0.04 0.01
D        87.
W      0.01 0.20 0.09
D       177.
W      0.02 0.03 0.02
D        20.
W      0.19 0.14 0.18 0.04
D       145.
W      0.01
D         1.
W      0.01
D         2.
W      0.01 0.04 0.08 0.05 0.03 0.03 0.06 0.07 0.06 0.04 0.03 0.04
D        60.
W      0.01 0.06 0.01
D         4.
W      0.01
D         4.
W      0.02 0.01 0.05 0.09 0.18 0.03
D       187.
W      0.18 0.04
D       470.
W      0.01 0.01                                                          II
D         1.
W      0.01 0.02 0.03 0.02 0.01 0.02
D         2.
W      0.01 0.02 0.01
D         5.
W      0.01
D        83.
W      0.06 0.06 0.06 0.06 0.07 0.06 0.12 0.12 0.12 0.12 0.12 0.11 0.04 0.04 0.04
W      0.04 0.04 0.03 0.01 0.01 0.01 0.01 0.01 0.01
D        90.
W      0.01 0.04 0.03 0.05
D        32.
W      0.02 0.03 0.03 0.05 0.03 0.01
D         2.
W      0.01
D       762.
W      0.01
D         5.
W      0.12 0.29 0.33 0.11
D         5.
W      0.01
D         1.
W      0.01 0.02 0.01 0.01 0.02 0.02 0.02
D        55.
W      0.02 0.02 0.01 0.01 0.02 0.02 0.01 0.01 0.02 0.03 0.03 0.02 0.02 0.01
```

(Continued)

TABLE VI-4. (Continued)

Data

Card Group Number

```
D        9.
W      0.01
D        4.
W      0.01
D      102.
W      0.01 0.02 0.02 0.01 0.01 0.01
D        3.
W      0.02 0.01 0.01 0.01 0.02                                              II
D        1.
W      0.01 0.01
D        1.
W      0.01 0.01 0.02
D       52.
W      0.01 0.01 0.01
D        2.
W      0.02 0.02
D       37.

   1     2     3
 49000.00       5.61        190000.0      54.62     325.06     0.0417     0.0083  1.5   III
0.30 0.35 0.95 0.0   0.25 1.00
1.300 0.060 0.200 0.45  0.990 -0.28
    ANALYSIS OF CRITICAL DISSOLVED OXYGEN LEVELS IN THE
    DES MOINES RIVER..DOWNSTREAM..FROM..DES MOINES,IOWA
 45000.00    4000.00    3987.50      13.84 0.0  0.25 0.75
         0    1    1    1    2    9    5
30868         3  202    138.9   10520.4      680.0  9.0  9.5 15.0
30868         4    0   1133.4   57619.8      680.0  9.0  9.5 15.0
30868         5    0   1322.3   53538.0      680.0  9.0  9.5 15.0
30868         6    0   5477.9  160339.0      680.0  9.0  9.5 15.0
30868         7    0   1700.1   21015.5      680.0  9.0  9.5 15.0
30868         8    0   2266.7   23274.6      680.0  9.0  9.5 15.0
30868         9    0   1133.4    7888.4      680.0  9.0  9.5 15.0
30868        10    0    377.8    2026.5      680.0  9.0  9.5 15.0
31868         5  234    944.5   24529.1      510.0 12.0  9.6 13.2
31868         6    0    566.7   12414.4      510.0 12.0  9.6 13.2
31868         7    0    188.9    3719.2      510.0 12.0  9.6 13.2     IV
40368         6  382   1700.1   87744.9      380.0 13.0  8.3  9.9
40368         7    0   2644.5  102168.0      380.0 13.0  8.3  9.9
40368        10    2     94.4    2239.3      380.0 13.0  8.3  9.9
40368        15    5    566.7   13731.8      380.0 13.0  8.3  9.9
41268        19  218   3966.8  168627.0      243.0 15.0 11.5 10.7
41468         1   29   1133.4   27392.7      380.0 16.5 13.1  8.5
41468         2    0   2266.7   51147.3      380.0 16.5 13.1  8.5
41468         3    0   1133.4   17342.3      380.0 16.5 13.1  8.5
41468         4    0   1133.4   15304.3      380.0 16.5 13.1  8.5
41468         5    0    377.8    3895.8      380.0 16.5 13.1  8.5
41668         3   50    188.9    7643.8      310.0 16.8 13.6  9.2
41668        20   11    188.9    2762.2      310.0 16.8 13.6  9.2
41668        21    0    188.9    2688.3      310.0 16.8 13.6  9.2
```

Continued

TABLE VI-4. (Continued)

Data

									Card Group Number
41668	22	0	377.8	5377.4	310.0	16.8	13.6	9.2	
41868	3	28	1322.3	23751.4	480.0	14.5	13.0	9.5	
41868	4	0	1511.2	23900.8	480.0	14.5	13.0	9.5	
41868	5	0	4155.7	76938.2	480.0	14.5	13.0	9.5	
41868	6	0	755.6	5796.8	480.0	14.5	13.0	9.5	
41968	10	27	566.7	5245.9	600.0	13.5	12.0	9.5	
41968	11	0	1322.3	13594.0	600.0	13.5	12.0	9.5	
41968	13	1	2408.4	27422.9	600.0	13.5	12.0	9.5	
41968	14	0	566.7	3580.2	600.0	13.5	12.0	9.5	
41968	15	0	944.5	6464.1	600.0	13.5	12.0	9.5	
41968	16	0	566.7	3252.2	600.0	13.5	12.0	9.5	
41968	17	0	566.7	3152.4	600.0	13.5	12.0	9.5	
41968	18	0	1133.4	7387.3	600.0	13.5	12.0	9.5	
41968	19	0	2266.7	13691.0	600.0	13.5	12.0	9.5	
41968	20	0	4533.5	48109.0	600.0	13.5	12.0	9.5	
41968	21	0	188.9	560.6	600.0	13.5	12.0	9.5	
41968	22	0	944.5	3841.6	600.0	13.5	12.0	9.5	
41968	23	0	1133.4	4810.8	600.0	13.5	12.0	9.5	
41968	24	0	188.9	526.5	600.0	13.5	12.0	9.5	
42268	4	51	2833.4	29285.3	780.0	11.0	9.0	9.5	
42268	5	0	377.8	2006.4	780.0	11.0	9.0	9.5	
42268	17	11	188.9	1094.7	780.0	11.0	9.0	9.5	
42268	18	0	188.9	1070.3	780.0	11.0	9.0	9.5	
42268	19	0	755.6	4688.7	780.0	11.0	9.0	9.5	IV
42268	20	0	1888.9	13445.4	780.0	11.0	9.0	9.5	
42268	21	0	3400.1	26451.5	780.0	11.0	9.0	9.5	
42268	22	0	3777.9	25393.0	780.0	11.0	9.0	9.5	
42268	23	0	2644.5	12328.4	780.0	11.0	9.0	9.5	
42268	24	0	2644.5	11104.8	780.0	11.0	9.0	9.5	
42368	1	0	2077.8	7024.8	1600.0	9.8	8.0	9.5	
42368	2	0	944.5	2156.7	1600.0	9.8	8.0	9.5	
42368	3	0	377.8	675.9	1600.0	9.8	8.0	9.5	
42368	4	0	1700.1	4769.1	1600.0	9.8	8.0	9.5	
42368	5	0	755.6	1493.7	1600.0	9.8	8.0	9.5	
42368	6	0	566.7	1024.5	1600.0	9.8	8.0	9.5	
42368	7	0	1322.3	3101.7	1600.0	9.8	8.0	9.5	
42368	8	0	1888.9	5044.7	1600.0	9.8	8.0	9.5	
42368	9	0	1511.2	3465.1	1600.0	9.8	8.0	9.5	
42368	10	0	1511.2	3346.1	1600.0	9.8	8.0	9.5	
42368	11	0	1322.3	2672.5	1600.0	9.8	8.0	9.5	
42368	12	0	377.8	524.9	1600.0	9.8	8.0	9.5	
42368	13	0	755.6	1215.7	1600.0	9.8	8.0	9.5	
50768	10	332	188.9	5908.6	766.0	13.0	13.5	7.8	
50768	11	0	755.6	22321.0	766.0	13.0	13.5	7.8	
50768	12	0	377.8	9766.9	766.0	13.0	13.5	7.8	
50768	13	0	188.9	4565.4	766.0	13.0	13.5	7.8	
50768	14	0	377.8	3772.4	766.0	13.0	13.5	7.8	
50768	17	2	3022.3	65573.1	766.0	13.0	13.5	7.8	
51368	19	145	3022.3	77081.8	590.0	11.4	18.1	7.3	
51368	20	0	5477.9	99496.8	590.0	11.4	18.1	7.3	

(Continued)

TABLE VI-4. (Continued)

Data

									Card Group Number
51468	1	4	2077.8	17081.1	672.0	11.0	19.0	7.2	
51468	2	0	377.8	1903.1	672.0	11.0	19.0	7.2	
51568	16	37	566.7	4708.2	660.0	11.0	18.1	7.4	
51568	19	2	188.9	1423.1	660.0	11.0	18.1	7.4	
51568	20	0	188.9	1384.7	660.0	11.0	18.1	7.4	
51868	17	68	283.3	3751.1	600.0	10.4	15.8	8.6	
51868	22	4	188.9	2443.4	600.0	10.4	15.8	8.6	
51868	23	0	377.8	4774.4	600.0	10.4	15.8	8.6	
52268	20	92	188.9	3776.1	500.0	9.9	14.1	9.5	
52268	21	0	1133.4	22268.6	500.0	9.9	14.1	9.5	
52568	1	51	566.7	11623.0	470.0	8.9	14.6	9.5	
52568	2	0	188.9	3481.1	470.0	8.9	14.6	9.5	
52568	11	8	944.5	17924.9	470.0	8.9	14.6	9.5	
52568	12	0	377.8	5994.9	470.0	8.9	14.6	9.5	
52568	13	0	566.7	3547.8	470.0	8.9	14.6	9.5	
52568	14	0	1133.4	16335.5	470.0	8.9	14.6	9.5	
52568	15	0	377.8	4319.5	470.0	8.9	14.6	9.5	
52568	17	1	94.4	1001.1	470.0	8.9	14.6	9.5	
52568	18	0	377.8	4066.9	470.0	8.9	14.6	9.5	
52568	24	5	2833.4	38777.3	470.0	8.9	14.6	9.5	
52668	1	0	2266.7	22265.0	520.0	8.6	14.7	9.6	
52668	2	0	1133.4	7570.4	520.0	8.6	14.7	9.6	
52668	6	3	377.8	2005.1	520.0	8.6	14.7	9.6	
52968	17	58	944.5	10359.2	530.0	8.0	15.0	9.4	IV
52968	18	0	2455.6	28333.5	530.0	8.0	15.0	9.4	
53168	10	63	1388.9	25916.9	540.0	7.9	20.1	8.8	
53168	11	0	3966.8	52047.3	540.0	7.9	20.1	8.8	
53168	12	0	1700.1	12037.3	540.0	7.9	20.1	8.8	
53168	13	0	1322.3	7643.3	540.0	7.9	20.1	8.8	
53168	14	0	377.8	1550.4	540.0	7.9	20.1	8.8	
53168	19	4	377.8	1643.9	540.0	7.9	20.1	8.8	
53168	20	0	2077.8	13098.5	540.0	7.9	20.1	8.8	
53168	21	0	188.9	636.4	540.0	7.9	20.1	8.8	
61068	15	233	944.5	23044.2	420.0	7.2	24.0	6.4	
61068	16	0	1700.1	35941.8	420.0	7.2	24.0	6.4	
61068	17	0	5355.7	112762.0	420.0	7.2	24.0	6.4	
61068	18	0	9444.7	122066.0	420.0	7.2	24.0	6.4	
61068	19	0	2455.6	7681.9	420.0	7.2	24.0	6.4	
61068	20	0	2933.4	8521.3	420.0	7.2	24.0	6.4	
61068	21	0	1322.3	2526.0	420.0	7.2	24.0	6.4	
61068	23	1	621.8	563.9	420.0	7.2	24.0	6.4	
61368	24	72	1511.2	12134.0	980.0	6.7	23.3	6.1	
62368	21	236	188.9	5168.3	860.0	5.0	25.0	6.3	
62368	22	0	1133.4	29019.5	860.0	5.0	25.0	6.3	
62468	16	17	10955.9	230164.0	1100.0	5.0	25.0	6.1	
62568	18	25	377.8	1974.4	1890.0	5.0	25.0	6.0	
62568	19	0	566.7	2811.7	1990.0	5.0	25.0	6.0	
62568	20	0	188.9	840.8	1890.0	5.0	25.0	6.0	
62568	21	0	377.8	1650.0	1890.0	5.0	25.0	6.0	
62568	22	0	188.9	769.4	1890.0	5.0	25.0	6.0	

(Continued)

TABLE VI-4. (Continued)

Data

Card Group Number: IV

62568	23	0	377.8	1515.3	1890.0	5.0	25.0	6.0
62668	1	1	3266.0	16100.0	3500.0	4.9	25.1	6.1
62668	2	0	1133.4	3154.7	3500.0	4.9	25.1	6.1
62668	10	7	55.1	143.6	3500.0	4.9	25.1	6.1
62668	16	5	188.9	564.8	3500.0	4.9	25.1	6.1
62968	4	59	8500.3	79205.1	7900.0	4.4	24.3	6.8
62968	5	0	2266.7	5834.3	7900.0	4.4	24.3	6.8
62968	6	0	3022.3	7190.4	7900.0	4.4	24.3	6.8
62968	7	0	3022.3	5981.2	7900.0	4.4	24.3	6.8
70668	16	176	5855.7	86070.0	3400.0	5.5	24.5	7.8
70668	17	0	5289.0	35769.1	3400.0	5.5	24.5	7.8
70668	18	0	3966.8	14742.6	3400.0	5.5	24.5	7.8
70868	21	50	3589.0	23320.2	2500.0	6.4	25.9	7.9
70868	22	0	7178.0	36585.4	2500.0	6.4	25.9	7.9
70868	23	0	9878.0	28169.6	2500.0	6.4	25.9	7.9
71668	10	178	1723.7	26632.5	1190.0	13.0	25.0	6.8
71668	11	0	3777.9	41687.2	1190.0	13.0	25.0	6.8
71668	12	0	1322.3	7880.8	1190.0	13.0	25.0	6.8
71668	13	0	566.7	2651.0	1190.0	13.0	25.0	6.8
71668	14	0	188.9	789.5	1190.0	13.0	25.0	6.8
71768	4	13	188.9	988.3	950.0	9.4	25.1	6.9
71768	5	0	755.6	3940.2	950.0	9.4	25.1	6.9
71768	6	0	944.5	4453.1	950.0	9.4	25.1	6.9
72368	14	151	24934.1	254336.0	2420.0	2.0	25.0	7.5
72368	15	0	377.8	27.9	2420.0	2.0	25.0	7.5
72368	16	0	188.9	13.0	2420.0	2.0	25.0	7.5
72368	17	0	3966.8	256.6	2420.0	2.0	25.0	7.5
72368	20	2	188.9	40.2	2420.0	2.0	25.0	7.5
72368	21	0	377.8	76.7	2420.0	2.0	25.0	7.5
72368	22	0	377.8	71.3	2420.0	2.0	25.0	7.5
72768	3	76	2266.7	14329.3	1400.0	6.0	26.0	9.3
72768	4	0	188.9	839.9	1400.0	6.0	26.0	9.3
72768	5	0	188.9	809.0	1400.0	6.0	26.0	9.3
73168	1	91	2933.4	31335.5	1700.0	12.0	26.0	11.0
73168	2	0	944.5	6548.9	1700.0	12.0	26.0	11.0
73168	3	0	566.7	3314.7	1700.0	12.0	26.0	11.0
80468	7	99	188.9	2685.7	1600.0	9.6	26.0	12.0
80468	10	2	1322.3	17781.2	1600.0	9.6	26.0	12.0
80768	7	68	566.7	9449.8	1180.0	9.5	26.1	11.0
80768	8	0	2077.8	30471.0	1180.0	9.5	26.1	11.0
80768	9	0	2455.6	25863.9	1180.0	9.5	26.1	11.0
80768	10	0	188.9	1231.5	1180.0	9.5	26.1	11.0
80868	6	19	10200.3	102666.0	1650.0	10.2	26.3	10.2
80868	7	0	21911.8	62372.7	1650.0	10.2	26.3	10.2
80868	8	0	944.5	12.6	1650.0	10.2	26.3	10.2
80868	10	1	188.9	19.0	1650.0	10.2	26.3	10.2
80868	11	0	377.8	36.5	1650.0	10.2	26.3	10.2
81568	8	164	3022.3	39035.9	930.0	10.0	26.9	6.4
81569	9	0	944.5	7478.4	930.0	10.0	26.9	6.4
81668	3	17	377.8	3104.9	880.0	3.0	26.8	5.8

(Continued)

TABLE VI-4. (Continued)

Data

									Card Group Number
81668	4	0	377.8	2888.9	880.0	8.0	26.8	5.8	
81668	6	1	377.8	2723.7	880.0	8.0	26.8	5.8	
81668	7	0	2266.7	15264.5	880.0	8.0	26.8	5.8	
81868	9	49	377.8	3332.6	780.0	5.0	26.7	5.0	
81868	10	0	188.9	1555.1	780.0	5.0	26.7	5.0	
81868	11	0	188.9	1500.7	780.0	5.0	26.7	5.0	
81868	12	0	188.9	1448.5	780.0	5.0	26.7	5.0	
81868	13	0	377.8	2798.1	780.0	5.0	26.7	5.0	
81868	14	0	1511.2	10665.2	780.0	5.0	26.7	5.0	
82668	11	188	21156.2	270266.0	600.0	4.6	21.9	7.5	
82668	12	0	2077.8	424.5	600.0	4.6	21.9	7.5	
82668	13	0	4155.7	598.6	600.0	4.6	21.9	7.5	
82668	14	0	3022.3	242.7	600.0	4.6	21.9	7.5	
82668	15	0	2455.6	135.1	600.0	4.6	21.9	7.5	
82668	16	0	566.7	18.1	600.0	4.6	21.9	7.5	
82668	17	0	188.9	5.2	600.0	4.6	21.9	7.5	
83068	3	81	188.9	1388.6	800.0	5.6	21.4	9.8	
83068	4	0	1133.4	7616.1	800.0	5.6	21.4	9.8	
83068	5	0	188.9	1060.9	800.0	5.6	21.4	9.8	
83068	6	0	377.8	2025.4	800.0	5.6	21.4	9.8	
83068	9	2	1133.4	5689.5	800.0	5.6	21.4	9.8	
83068	10	0	1700.1	6855.7	800.0	5.6	21.4	9.8	
83068	11	0	1133.4	3407.2	800.0	5.6	21.4	9.8	
83068	12	0	377.8	920.1	800.0	5.6	21.4	9.8	
83068	17	4	944.5	2523.6	800.0	5.6	21.4	9.8	IV
83068	18	0	1133.4	2615.8	800.0	5.6	21.4	9.8	
83068	19	0	944.5	1911.8	800.0	5.6	21.4	9.8	
83168	19	23	944.5	3458.3	710.0	6.0	21.6	10.3	
90368	17	69	755.6	6903.6	544.0	7.0	22.0	12.1	
90368	22	4	2644.5	21334.8	544.0	7.0	22.0	12.1	
90368	24	1	2644.5	14373.3	544.0	7.0	22.0	12.1	
90468	1	0	8122.5	37000.7	1000.0	7.1	21.8	12.0	
90468	2	0	2455.6	3384.0	1000.0	7.1	21.8	12.0	
90468	3	0	755.6	610.4	1000.0	7.1	21.8	12.0	
90468	4	0	3022.3	3721.3	1000.0	7.1	21.8	12.0	
90468	5	0	377.8	203.8	1000.0	7.1	21.8	12.0	
90468	9	3	188.9	144.1	1000.0	7.1	21.8	12.0	
90468	11	1	188.9	158.3	1000.0	7.1	21.8	12.0	
90568	13	25	566.7	1756.4	1280.0	7.2	21.6	12.0	
90568	14	0	377.8	1056.2	1280.0	7.2	21.6	12.0	
91668	15	264	188.9	5001.0	460.0	7.1	19.2	7.6	
91668	16	0	188.9	4813.9	460.0	7.1	19.2	7.6	
91668	21	4	1888.9	43919.1	460.0	7.1	19.2	7.6	
91668	22	0	3777.9	61350.1	460.0	7.1	19.2	7.6	
91668	23	0	755.6	6441.8	460.0	7.1	19.2	7.6	
91668	24	0	188.9	1381.9	460.0	7.1	19.2	7.6	
92068	16	87	188.9	2824.5	720.0	7.4	19.4	8.6	
92068	17	0	3777.9	55933.6	720.0	7.4	19.4	8.6	
92068	18	0	1700.1	13807.8	720.0	7.4	19.4	8.6	
92868	4	176	377.8	8111.8	1200.0	7.5	15.5	9.9	

(Continued)

TABLE VI-4. (Continued)

Data

									Card Group Number
92868	5	0	566.7	11326.6	1200.0	7.5	15.5	9.9	
92868	6	0	377.8	6807.5	1200.0	7.5	15.5	9.9	
92968	3	20	3589.0	68974.6	1350.0	7.4	16.3	9.9	
92968	4	0	2644.5	30502.1	1350.0	7.4	16.3	9.9	
92968	5	0	3400.1	31192.9	1350.0	7.4	16.3	9.9	
92968	6	0	755.6	3443.8	1350.0	7.4	16.3	9.9	
100568	8	145	188.9	3173.3	1800.0	6.8	16.0	10.2	
100568	10	1	188.9	3083.1	1800.0	6.8	16.0	10.2	
100568	13	2	188.9	3013.6	1800.0	6.8	16.0	10.2	
100568	14	0	755.6	11809.4	1800.0	6.8	16.0	10.2	
100568	15	0	1511.2	21543.7	1800.0	6.8	16.0	10.2	
100568	16	0	944.5	10400.4	1800.0	6.8	16.0	10.2	
100568	17	0	566.7	5254.5	1800.0	6.8	16.0	10.2	
100568	18	0	566.7	4845.6	1800.0	6.8	16.0	10.2	
100568	19	0	1133.4	9643.6	1800.0	6.8	16.0	10.2	
100568	20	0	1322.3	10133.2	1800.0	6.8	16.0	10.2	
100568	21	0	1133.4	7346.9	1800.0	6.8	16.0	10.2	
100568	22	0	755.6	4065.3	1800.0	6.8	16.0	10.2	
100568	23	0	566.7	2715.7	1800.0	6.8	16.0	10.2	
100568	24	0	755.6	3617.5	1800.0	6.8	16.0	10.2	
100868	13	60	188.9	1747.4	1700.0	6.5	14.5	10.3	
100868	14	0	1133.4	11178.3	1700.0	6.5	14.5	10.3	
100868	15	0	188.9	1427.5	1700.0	6.5	14.5	10.3	
100868	20	4	188.9	1457.6	1700.0	6.5	14.5	10.3	IV
100968	1	4	3777.9	42336.2	2000.0	6.4	13.0	10.4	
100968	2	0	188.9	870.7	2000.0	6.4	13.0	10.4	
100968	3	0	944.5	5039.4	2000.0	6.4	13.0	10.4	
100968	4	0	1700.1	9736.4	2000.0	6.4	13.0	10.4	
100968	5	0	3400.1	22705.4	2000.0	6.4	13.0	10.4	
100968	6	0	566.7	1653.9	2000.0	6.4	13.0	10.4	
101768	2	187	3400.1	67355.7	3500.0	5.8	12.0	10.7	
101768	3	0	755.6	8192.7	3500.0	5.8	12.0	10.7	
110568	19	470	188.9	9772.6	5600.0	4.5	4.4	11.5	
110568	21	1	47.2	2371.9	5600.0	4.5	4.4	11.5	
110568	22	0	374.4	18576.1	5600.0	4.5	4.4	11.5	
110568	23	0	566.7	25791.4	5600.0	4.5	4.4	11.5	
110568	24	0	374.4	15501.9	5600.0	4.5	4.4	11.5	
110668	1	0	188.9	7237.7	5400.0	4.4	4.0	11.6	
110668	2	0	377.8	13939.5	5400.0	4.4	4.0	11.6	
110668	6	3	377.8	13066.7	5400.0	4.4	4.0	11.6	
110668	7	0	188.9	6094.2	5400.0	4.4	4.0	11.6	
111068	1	89	944.5	36888.7	4500.0	4.2	4.0	11.8	
111068	2	0	1133.4	37740.0	4500.0	4.2	4.0	11.8	
111068	3	0	1133.4	31414.9	4500.0	4.2	4.0	11.8	
111068	4	0	1133.4	26434.1	4500.0	4.2	4.0	11.8	
111068	5	0	1322.3	26695.5	4500.0	4.2	4.0	11.8	
111068	6	0	1133.4	18921.3	4500.0	4.2	4.0	11.8	
111068	7	0	2266.7	38246.1	4500.0	4.2	4.0	11.8	
111068	8	0	2266.7	31267.4	4500.0	4.2	4.0	11.8	
111068	9	0	2266.7	26496.0	4500.0	4.2	4.0	11.8	

(Continued)

TABLE VI-4. (Continued)

Data

									Card Group Number
122768	6	0	377.8	6026.3	1200.0	5.4	4.0	12.3	
122768	7	0	188.9	2798.0	1200.0	5.4	4.0	12.3	
122768	8	0	188.9	2717.8	1200.0	5.4	4.0	12.3	
122768	9	0	188.9	2640.6	1200.0	5.4	4.0	12.3	
122768	13	3	188.9	2617.8	1200.0	5.4	4.0	12.3	
122768	14	0	188.9	2544.7	1200.0	5.4	4.0	12.3	
122768	15	0	188.9	2474.5	1200.0	5.4	4.0	12.3	
122768	16	0	188.9	2407.1	1200.0	5.4	4.0	12.3	
122768	17	0	377.8	4794.1	1200.0	5.4	4.0	12.3	IV
122768	19	1	94.4	1105.9	1200.0	5.4	4.0	12.3	
122768	20	0	188.9	2207.7	1200.0	5.4	4.0	12.3	
122768	22	1	94.4	1070.9	1200.0	5.4	4.0	12.3	
122768	23	0	188.9	2139.9	1200.0	5.4	4.0	12.3	
122768	24	0	377.8	4289.0	1200.0	5.4	4.0	12.3	
123068	6	53	188.9	2871.2	1150.0	5.8	4.0	12.2	
123068	7	0	188.9	2789.3	1150.0	5.8	4.0	12.2	
123068	10	2	188.9	2744.8	1150.0	5.8	4.0	12.2	
123068	11	0	377.8	5443.1	1150.0	5.8	4.0	12.2	
999999									
80	1	1	2	3	10				
30668		257.0	13.0	13.0	16.1				
30768		300.0	10.0	11.3	15.0				
31068		800.0	6.0	6.0	14.0				
31268		621.0	6.0	2.5	13.7				
31568		523.0	10.0	7.0	15.6				
31968		516.0	13.0	10.5	12.7				
32868		383.0	10.0	11.0	10.7				
40168		340.0	11.0	9.0	10.0				
40568		410.0	14.0	7.0	10.0				
41068		264.0	15.0	10.0	10.7				
41568		320.0	17.0	13.0	9.0				
41768		355.0	17.0	14.0	9.5				
42068		700.0	12.0	13.0	9.6				
42468		2520.0	9.0	7.0	9.4				
42568		2200.0	9.0	7.0	9.6				V
50168		1340.0	14.0	17.0	10.9				
50568		900.0	13.0	13.7	8.8				
50668		830.0	13.0	13.0	8.6				
50868		740.0	12.0	14.0	7.6				
51068		700.0	12.0	16.0	7.6				
51168		660.0	11.8	16.5	7.4				
51268		600.0	11.5	17.0	7.3				
51768		600.0	10.8	16.6	8.0				
52068		560.0	10.0	15.0	9.0				
52168		523.0	10.0	14.0	9.5				
52368		480.0	9.6	14.2	9.6				
52768		525.0	7.8	14.8	9.6				
52968		540.0	7.8	15.0	9.0				
53068		560.0	7.8	16.0	8.6				
60468		483.0	8.0	26.5	7.8				

(Continued)

TABLE VI-4. (Continued)

Data

Card Group Number: IV

111068	10	0	2266.7	23096.2	4500.0	4.2	4.0	11.8
111068	11	0	2266.7	20571.4	4500.0	4.2	4.0	11.8
111068	12	0	2077.8	16379.7	4500.0	4.2	4.0	11.8
111068	13	0	755.6	3712.7	4500.0	4.2	4.0	11.8
111068	14	0	755.6	3624.3	4500.0	4.2	4.0	11.8
111068	15	0	755.6	3543.2	4500.0	4.2	4.0	11.8
111068	16	0	755.6	3468.2	4500.0	4.2	4.0	11.8
111068	17	0	755.6	3398.5	4500.0	4.2	4.0	11.8
111068	18	0	566.7	2311.4	4500.0	4.2	4.0	11.8
111068	19	0	188.9	638.3	4500.0	4.2	4.0	11.8
111068	20	0	188.9	635.7	4500.0	4.2	4.0	11.8
111068	21	0	188.9	633.1	4500.0	4.2	4.0	11.8
111068	22	0	188.9	630.5	4500.0	4.2	4.0	11.8
111068	23	0	188.9	628.0	4500.0	4.2	4.0	11.8
111068	24	0	188.9	625.6	4500.0	4.2	4.0	11.8
111468	20	91	755.6	9165.6	3800.0	3.9	4.0	12.0
111468	21	0	566.7	6064.2	3800.0	3.9	4.0	12.0
111468	22	0	944.5	9887.0	3800.0	3.9	4.0	12.0
111668	7	32	188.9	2109.5	4000.0	3.8	4.0	12.0
111668	8	0	566.7	6428.7	4000.0	3.8	4.0	12.0
111668	9	0	566.7	5954.9	4000.0	3.8	4.0	12.0
111668	10	0	944.5	9752.6	4000.0	3.8	4.0	12.0
111668	11	0	566.7	4926.5	4000.0	3.8	4.0	12.0
111668	12	0	188.9	1431.1	4000.0	3.8	4.0	12.0
121868	16	771	2077.8	151981.0	1200.0	4.3	4.0	11.6
121868	17	0	5477.9	285417.0	1200.0	4.3	4.0	11.6
121868	18	0	6233.5	175859.0	1200.0	4.3	4.0	11.6
121868	19	0	2077.8	22928.4	1200.0	4.3	4.0	11.6
121968	3	7	94.4	610.1	1700.0	4.4	4.0	12.5
121968	4	0	377.8	2603.6	1700.0	4.4	4.0	12.5
121968	5	0	188.9	1195.8	1700.0	4.4	4.0	12.5
121968	6	0	188.9	1175.9	1700.0	4.4	4.0	12.5
121968	7	0	377.8	2441.5	1700.0	4.4	4.0	12.5
121968	8	0	377.8	2368.7	1700.0	4.4	4.0	12.5
121968	9	0	377.8	2300.9	1700.0	4.4	4.0	12.5
122168	17	55	188.9	1993.8	2300.0	4.6	4.0	12.5
122168	18	0	377.8	3995.6	2300.0	4.6	4.0	12.5
122168	19	0	188.9	1847.8	2300.0	4.6	4.0	12.5
122168	20	0	188.9	1803.0	2300.0	4.6	4.0	12.5
122168	21	0	377.8	3634.3	2300.0	4.6	4.0	12.5
122168	22	0	377.8	3473.5	2300.0	4.6	4.0	12.5
122168	23	0	188.9	1603.0	2300.0	4.6	4.0	12.5
122168	24	0	188.9	1567.7	2300.0	4.6	4.0	12.5
122268	1	0	377.8	3188.0	1900.0	4.8	4.0	12.4
122268	2	0	566.7	4782.6	1900.0	4.8	4.0	12.4
122268	3	0	566.7	4522.8	1900.0	4.8	4.0	12.4
122268	4	0	377.8	2729.6	1900.0	4.8	4.0	12.4
122268	5	0	377.8	2635.8	1900.0	4.8	4.0	12.4
122268	6	0	188.9	1210.9	1900.0	4.8	4.0	12.4
122768	5	118	377.8	6391.0	1200.0	5.4	4.0	12.3

(Continued)

TABLE VI-4. (Continued)

Data

Card Group Number: V

60568	460.0	8.0	25.0	7.4
61268	1210.0	7.0	23.0	5.9
61968	1230.0	5.0	24.0	6.8
62068	1290.0	5.0	24.0	6.6
62768	7000.0	4.6	24.0	6.6
63068	7600.0	4.2	22.0	7.0
70268	5990.0	4.0	21.0	7.5
70568	3800.0	5.0	24.6	7.8
70968	2290.0	7.0	26.0	8.0
71568	1300.0	12.0	25.0	6.6
72068	2000.0	5.2	24.0	7.2
72568	1800.0	2.3	26.0	8.0
72968	1400.0	8.0	25.0	10.0
80568	1400.0	9.0	26.0	12.0
80668	1250.0	9.0	26.0	12.5
81068	1600.0	11.0	26.5	8.8
81368	1070.0	13.0	27.0	11.3
81768	860.0	5.0	26.0	5.0
82068	680.0	3.4	26.0	4.2
82168	650.0	3.0	26.6	4.0
82568	500.0	4.0	22.0	6.0
82768	593.0	5.0	23.0	8.8
90268	600.0	6.4	22.0	11.0
91068	680.0	8.0	20.0	11.5
91568	460.0	7.0	20.0	8.2
92468	902.0	8.0	20.0	9.8
92568	880.0	7.8	17.0	9.8
93068	1400.0	7.0	16.5	10.0
100468	1800.0	6.8	16.8	10.0
100768	1650.0	6.4	15.6	10.3
101068	2300.0	6.3	14.4	10.5
101568	3400.0	6.0	12.3	10.5
102068	13000.0	5.6	10.0	10.8
102568	11000.0	5.2	8.0	11.0
103068	7200.0	4.8	6.0	11.1
110468	6000.0	4.6	4.4	11.5
110768	5000.0	4.4	4.0	11.7
111268	4000.0	4.0	4.0	12.0
111568	3900.0	4.0	4.0	12.0
112068	4400.0	3.6	4.0	12.0
112568	3800.0	3.3	4.0	12.5
113068	3100.0	3.1	4.0	13.0
120368	2970.0	3.0	4.0	12.9
120568	2900.0	3.1	4.0	13.0
121068	1150.0	3.5	4.0	12.8
121568	1104.0	4.0	4.0	12.5
122068	2204.0	4.4	4.0	12.5
122568	1304.0	5.0	4.0	12.4
122768	1104.0	5.8	4.0	12.3
123168	1104.0	5.9	4.0	12.2

TABLE VI-5. MODEL OUTPUT IDENTIFICATION BANNER

LEVEL III-
RECEIVING

```
***********************************************************
**       FOR INFORMATION AND ASSISTANCE:                 **
**       DR. MIGUEL A. MEDINA,JR.                        **
** DEPT. OF CIVIL ENGINEFRING, DUKE UNIVERSITY           **
** DURHAM,N.C.    TELEPHONE:  919-684-2434, EXT. 46      **
**                  -OR-                                 **
**                  DR. WAYNE C. HUBER                   **
**  DEP'T. OF ENV. ENG. SCIENCES, UNIV. OF FLORIDA       **
**  GAINESVILLE, FLA.      TFLEPHONE: 904-392-0846       **
***********************************************************
```

```
******************************
**                          **
** VERSION: SEPTEMBER, 1978 **
**                          **
******************************
```

TABLE VI-6. SAMPLE COMPUTED VALUES OF THE AUTOCORRELATION FUNCTION

DISCRETE VALUES

1.00	0.37	0.16	0.13	0.06	0.07	0.07	0.02	0.02	0.01
0.01	0.01	0.00	0.00	-0.00	-0.00	-0.01	-0.01	-0.00	-0.00
-0.01	0.00	0.02	0.01	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.00	-0.01	0.01	-0.00	-0.01	-0.01	-0.01	-0.01	-0.00
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	0.01	0.02	0.02	0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.00	-0.01	-0.00	-0.00	-0.01	-0.01	-0.01
-0.01	-0.00	-0.01	0.00	0.01	0.07	0.01	0.00	0.01	0.00
0.01	0.01	0.00	0.00	0.00	0.02	0.00	0.00	-0.00	0.00
-0.00	0.00	0.00	0.01	0.01	0.01	0.00	-0.00	-0.00	-0.00
-0.02	-0.02	0.00	0.00	0.00	-0.01	-0.01	-0.01	0.01	0.00
0.01	0.01	0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.01	0.00	-0.00
0.00	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.01
-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00	-0.01	-0.01
-0.01	-0.01	-0.00	0.00	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.02
0.02	0.02	0.01	-0.01	-0.00	-0.01	-0.00	-0.00	0.00	0.03
0.04	0.03	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.01
-0.00	0.02	0.01	0.01	-0.00	-0.01	-0.01	0.01	0.02	-0.00
-0.00	-0.00	0.01	0.01	0.01	0.02	0.05	0.01	-0.00	0.01
-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.01	-0.01	-0.01	-0.01
-0.01	-0.00	0.01	0.02	0.01	0.03	-0.00	0.00	0.01	-0.00
0.00	-0.00	0.01	0.00	0.02	0.03	0.02	0.01	0.02	0.00
-0.00	-0.01	-0.01	-0.01	-0.01	0.00	0.01	-0.00	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	0.01	-0.01	-0.00
-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	0.01	0.01
0.01	-0.00	0.01	0.00	-0.00	-0.00	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00	0.01	0.01
0.01	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.01	-0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
-0.01	-0.01	0.00	-0.00	0.03	0.01	-0.00	-0.01	-0.01	-0.01
-0.01	0.01	0.02	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00
-0.00	0.07	0.06	0.03	0.02	0.02	-0.00	-0.00	0.00	0.00
-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	0.01	0.00	-0.00
-0.00	-0.01	-0.01	0.01	0.02	-0.00	0.09	0.19	0.01	-0.01
-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00	-0.00
-0.00	-0.00	-0.01	-0.01	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00

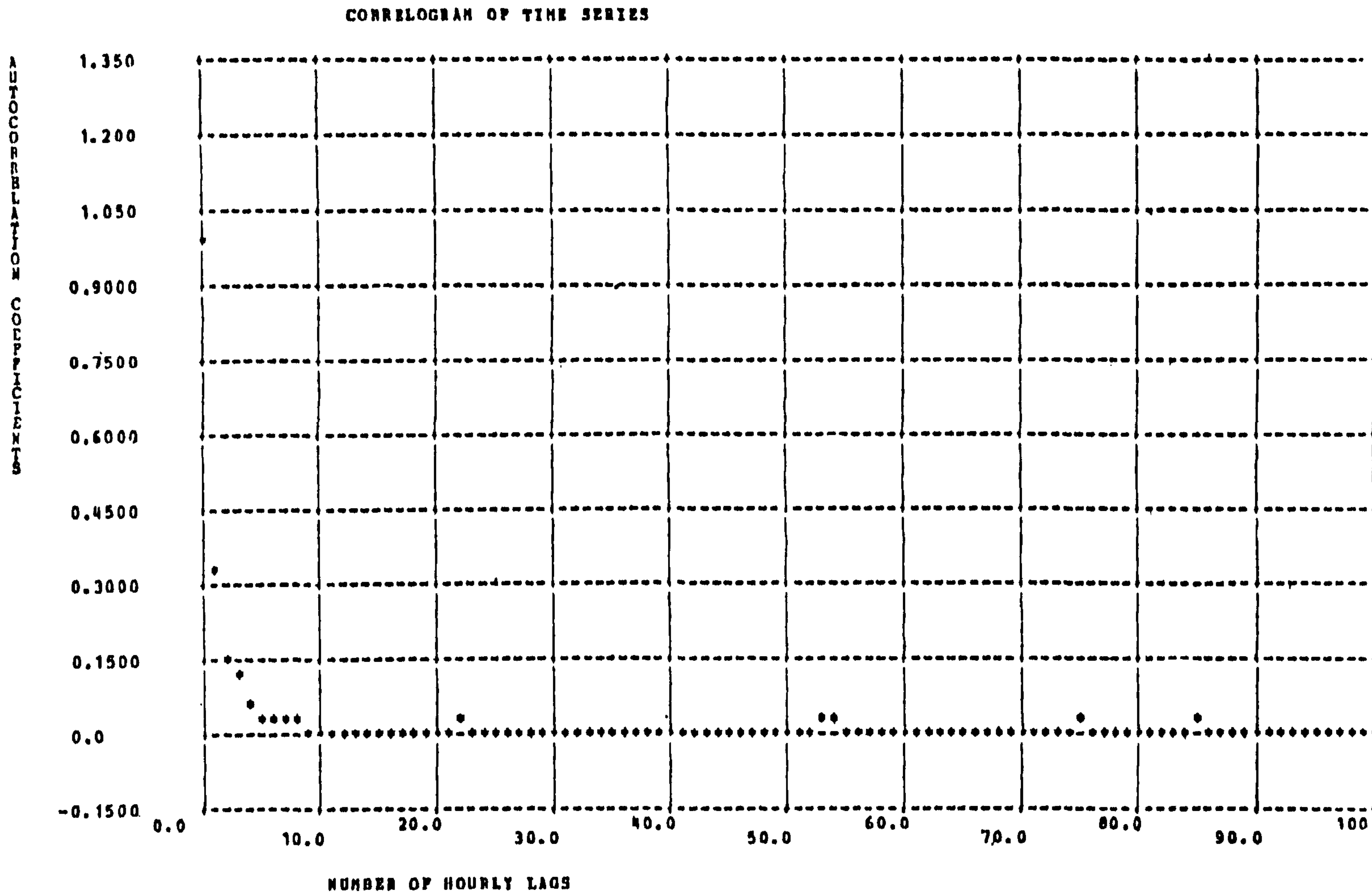


Figure VI-6. Sample Correlogram of the Hydrologic Time Series

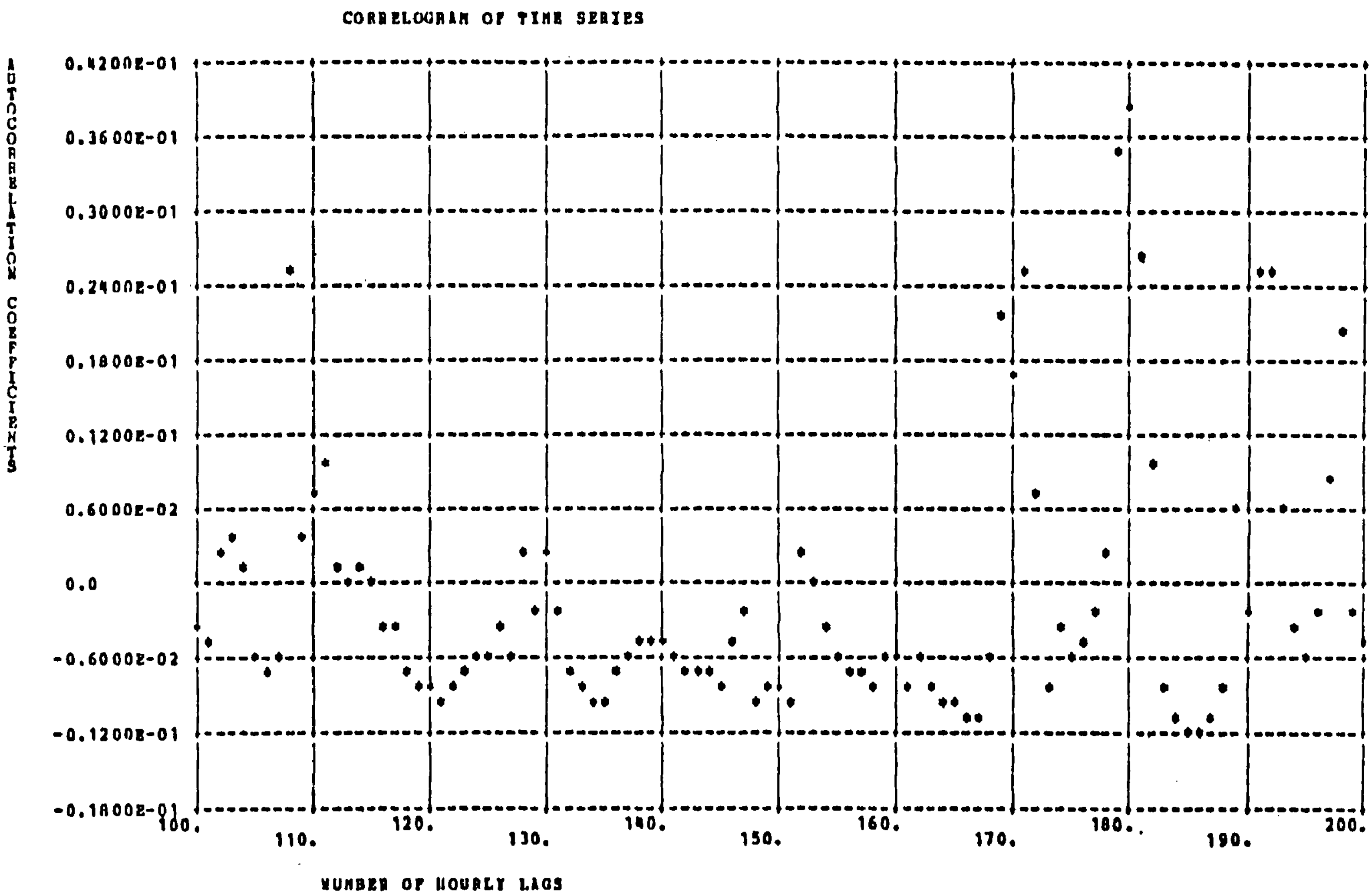


Figure VI-6. (Continued)

TABLE VI-7. SAMPLE DISPLAY OF SUBPROGRAM COMMON INPUT DATA

```
**********************************************************************************
**        COMMON INPUT DATA FOR WET-WEATHER FLOW AND DRY-WEATHER FLOW MODELS   **
**********************************************************************************

**********************************************************************************
** IWWFM=1      IDWFM=1                                                         **
** ATOT=   49000.0  ACRES   X=   29620.8  FEET   E=           180000.0  FT**2/HOUR **
** DX=       1.50      ITSAG=     1      IPR1=     2      IPR2=     3            **
** DWFX=            54.62  CFS    DWFLO=     325.06  MG/L   XK1MAX=0.0417  1/HOUR **
** PCTTRT=     0.30     0.85     0.95                        XK1MIN=0.0083 1/HOUR **
** RF=     0.0      0.25     1.00        GAMMA1= 0.990    GAMMA2=-0.280         **
** ALPHA1=1.300    ALPHA2=0.060    BETA1=0.200    BETA2=0.450                    **
**********************************************************************************


****************************************************************************************************
********       ANALYSIS OF CRITICAL DISSOLVED OXYGEN LEVELS IN THE                         ********
********       DES MOINES RIVER..DOWNSTREAM..FROM..DES MOINES,IOWA                         ********
****************************************************************************************************


*****************************************************************
** WET-WEATHER FLOW MODEL INPUT DATA                           **
*****************************************************************

*****************************************************************
** IPROG = 0     IFILE =  0     JNS =      0                   **
** ASEP=             45000.0 ACRES ** ACOM=          4000.0 ACRES **
** DWBODX=         3987.50 LBS/BOD/HR ** FFLBS=    13.84 LBS BOD-5/DWH**
** PCT=     0.0      0.25     0.75                             **
** ICALC=     0 ICALC1=     1 ICALC2=     1 ICALCX=     2      **
** IPR3=     1 IDISKW=     9 IPR4=     5                       **
*****************************************************************
```

TABLE VI-8. TYPICAL PRINTED OUTPUT FOR EACH WET-WEATHER EVENT

```
*****************************************
**** DATE  5/15/68 HOUR 16 DWH   37 ****
*****************************************
**** RUNOFF DURATION =   3 HOURS    ****
*****************************************
*************************
**** EVENT NO.= 14 *****
*************************


**UPSTREAM RIVER FLO=    660.00 CFS ** BOD =  11.00 MG/L ** TEMP.= 18.1 DEG.CENT. ** D.O.=  7.40 MG/L ***
** AVE. URBAN RUNOFF=  314.83  CFS *** BOD LOAD =   2505.3  LBS/HOUR *** BOD CONC.=     35.4  MG/L ***

**COMBINATION= 1  PCTTRT=0.85  RIVER FLOW FRACTN =1.00  PCTTRT RUNOFF =0.0    *** AVE. RIVER FLOW=    714.6 CFS ***
**AVE. UPSTREAM RIVERFLOW=    660.0 CFS *** ULTIMATE BOD=      14.0  MG/L *** DEPTH =  3.85  FEET ***
**CRITICAL DEFICIT=  2.71  MG/L   DOCONC=  6.67  MG/L   SAT DO=  9.38MG/L   INTEGRAL DEF EQN=  162.72  MG-HOUR/L ***
**D.O. DEFICIT=  2.41  MG/L *** D.O. @ X =  6.98  MG/L ***
** TC =  12.26 HOURS *** XC = 16.13   MI. *** TX =   4.27  HOURS *** DIST X =  5.61   MI. *** V = 1.93  FPS ***
**REAERATION COEFFICIENT(XK2T)=0.97203E-01  1/HOUR    DEOXYGENATION COEFFICIENT(XK1T)=0.25919E-01  1/HOUR

**COMBINATION= 2  PCTTRT=0.85  RIVER FLOW FRACTN =1.00  PCTTRT RUNOFF =0.0    *** AVE. RIVER FLOW=    888.1 CFS ***
**AVE. UPSTREAM RIVERFLOW=    660.0 CFS *** ULTIMATE BOD=      18.3  MG/L *** DEPTH =  4.24  FEET ***
**CRITICAL DEFICIT=  3.52  MG/L   DOCONC=  5.87  MG/L   SAT DO=  9.38MG/L   INTEGRAL DEF EQN=  229.22  MG-HOUR/L ***
**D.O. DEFICIT=  2.57  MG/L *** D.O. @ X =  6.82  MG/L ***
** TC =  16.58 HOURS *** XC = 22.09   MI. *** TX =   4.21  HOURS *** DIST X =  5.61   MI. *** V = 1.95  FPS ***
**REAERATION COEFFICIENT(XK2T)=0.86468E-01  1/HOUR    DEOXYGENATION COEFFICIENT(XK1T)=0.25219E-01  1/HOUR

**COMBINATION= 3  PCTTRT=0.85  RIVER FLOW FRACTN =1.00  PCTTRT RUNOFF =0.0    *** AVE. RIVER FLOW=    730.0 CFS ***
**AVE. UPSTREAM RIVERFLOW=    660.0 CFS *** ULTIMATE BOD=      16.2  MG/L *** DEPTH =  3.89  FEET ***
**CRITICAL DEFICIT=  3.07  MG/L   DOCONC=  6.32  MG/L   SAT DO=  9.38MG/L   INTEGRAL DEF EQN=  187.07  MG-HOUR/L ***
**D.O. DEFICIT=  2.57  MG/L *** D.O. @ X =  6.81  MG/L ***
** TC =  13.62 HOURS *** XC = 17.93   MI. *** TX =   4.26  HOURS *** DIST X =  5.61   MI. *** V = 1.93  FPS ***
**REAERATION COEFFICIENT(XK2T)=0.96092E-01  1/HOUR    DEOXYGENATION COEFFICIENT(XK1T)=0.25850E-01  1/HOUR

**COMBINATION= 4  PCTTRT=0.85  RIVER FLOW FRACTN =1.00  PCTTRT RUNOFF =0.0    *** AVE. RIVER FLOW=    848.9 CFS ***
**AVE. UPSTREAM RIVERFLOW=    660.0 CFS *** ULTIMATE BOD=      18.2  MG/L *** DEPTH =  4.16  FEET ***
**CRITICAL DEFICIT=  3.48  MG/L   DOCONC=  5.90  MG/L   SAT DO=  9.38MG/L   INTEGRAL DEF EQN=  224.06  MG-HOUR/L ***
**D.O. DEFICIT=  2.60  MG/L *** D.O. @ X =  6.78  MG/L ***
** TC =  16.06 HOURS *** XC = 21.34   MI. *** TX =   4.22  HOURS *** DIST X =  5.61   MI. *** V = 1.95  FPS ***
**REAERATION COEFFICIENT(XK2T)=0.88595E-01  1/HOUR    DEOXYGENATION COEFFICIENT(XK1T)=0.25363E-01  1/HOUR

**COMBINATION= 5  PCTTRT=0.85  RIVER FLOW FRACTN =1.00  PCTTRT RUNOFF =0.0    *** AVE. RIVER FLOW=    903.5 CFS ***
**AVE. UPSTREAM RIVERFLOW=    660.0 CFS *** ULTIMATE BOD=      20.0  MG/L *** DEPTH =  4.28  FEET ***
**CRITICAL DEFICIT=  3.83  MG/L   DOCONC=  5.56  MG/L   SAT DO=  9.38MG/L   INTEGRAL DEF EQN=  251.25  MG-HOUR/L ***
**D.O. DEFICIT=  2.69  MG/L *** D.O. @ X =  6.69  MG/L ***
** TC =  17.11 HOURS *** XC = 22.81   MI. *** TX =   4.21  HOURS *** DIST X =  5.61   MI. *** V = 1.96  FPS ***
**REAERATION COEFFICIENT(XK2T)=0.85670E-01  1/HOUR    DEOXYGENATION COEFFICIENT(XK1T)=0.25165E-01  1/HOUR
```

TABLE VI-8. (Continued)

```
****************************************************************************
**   DISSOLVED OXYGEN PROFILES FOR ALL WASTE INFLOW COMBINATIONS (M=1,5)   **
**       DISTANCE --> 100 INTERVALS, EACH INTERVAL =       1.50 MILES      **
**          EVENT NO.  14                         UNITS IN MG/L            **
****************************************************************************
```

COMBINATION 1:

7.55	7.36	7.19	7.06	6.95	6.87	6.80	6.75	6.71	6.69	6.67	6.67	6.68	6.69	6.71	6.74	6.77	6.80	6.84	6.88
6.92	6.97	7.01	7.06	7.11	7.16	7.21	7.26	7.31	7.36	7.41	7.46	7.50	7.55	7.60	7.64	7.69	7.74	7.78	7.82
7.86	7.91	7.95	7.99	8.02	8.06	8.10	8.13	8.17	8.20	8.24	8.27	8.30	8.33	8.36	8.39	8.42	8.45	8.47	8.50
8.53	8.55	8.57	8.60	8.62	8.64	8.66	8.68	8.70	8.72	8.74	8.76	8.78	8.80	8.81	8.83	8.85	8.86	8.88	8.89
8.91	8.92	8.93	8.95	8.96	8.97	8.98	9.00	9.01	9.02	9.03	9.04	9.05	9.06	9.07	9.08	9.09	9.10	9.10	9.11
9.12																			

COMBINATION 2:

7.91	7.56	7.25	6.99	6.76	6.57	6.41	6.27	6.16	6.07	6.00	5.95	5.91	5.88	5.87	5.87	5.88	5.89	5.91	5.94
5.98	6.02	6.06	6.11	6.16	6.21	6.26	6.32	6.37	6.43	6.49	6.55	6.61	6.67	6.73	6.79	6.85	6.91	6.97	7.03
7.08	7.14	7.19	7.25	7.30	7.36	7.41	7.46	7.51	7.56	7.60	7.65	7.70	7.74	7.78	7.83	7.87	7.91	7.95	7.99
8.03	8.06	8.10	8.13	8.17	8.20	8.23	8.26	8.30	8.32	8.35	8.38	8.41	8.44	8.46	8.49	8.51	8.54	8.56	8.58
8.61	8.63	8.65	8.67	8.69	8.71	8.73	8.74	8.76	8.78	8.80	8.81	8.83	8.84	8.86	8.87	8.89	8.90	8.92	8.93
8.94																			

COMBINATION 3:

7.59	7.33	7.11	6.93	6.77	6.65	6.55	6.47	6.41	6.37	6.34	6.32	6.32	6.32	6.34	6.36	6.39	6.42	6.46	6.50
6.54	6.59	6.64	6.69	6.74	6.80	6.85	6.91	6.96	7.02	7.07	7.13	7.18	7.24	7.29	7.34	7.40	7.45	7.50	7.55
7.60	7.64	7.69	7.74	7.78	7.82	7.87	7.91	7.95	7.99	8.03	8.07	8.10	8.14	8.17	8.21	8.24	8.27	8.31	8.34
8.37	8.39	8.42	8.45	8.48	8.50	8.53	8.55	8.58	8.60	8.62	8.64	8.66	8.69	8.71	8.73	8.74	8.76	8.78	8.80
8.81	8.83	8.85	8.86	8.88	8.89	8.91	8.92	8.93	8.95	8.96	8.97	8.98	8.99	9.01	9.02	9.03	9.04	9.05	9.06
9.07																			

COMBINATION 4:

7.84	7.50	7.20	6.94	6.73	6.54	6.39	6.26	6.16	6.07	6.01	5.96	5.93	5.91	5.90	5.91	5.92	5.94	5.96	6.00
6.03	6.08	6.12	6.17	6.22	6.28	6.33	6.39	6.45	6.51	6.57	6.63	6.69	6.75	6.81	6.87	6.93	6.98	7.04	7.10
7.16	7.21	7.27	7.32	7.37	7.42	7.48	7.53	7.57	7.62	7.67	7.71	7.76	7.80	7.84	7.89	7.93	7.97	8.01	8.04
8.08	8.12	8.15	8.18	8.22	8.25	8.28	8.31	8.34	8.37	8.40	8.43	8.45	8.48	8.50	8.53	8.55	8.57	8.60	8.62
8.64	8.66	8.68	8.70	8.72	8.74	8.76	8.77	8.79	8.81	8.82	8.84	8.86	8.87	8.88	8.90	8.91	8.93	8.94	8.95
8.96																			

COMBINATION 5:

7.93	7.53	7.19	6.88	6.63	6.40	6.22	6.06	5.93	5.82	5.73	5.67	5.62	5.59	5.57	5.56	5.56	5.57	5.59	5.62
5.66	5.70	5.74	5.79	5.84	5.90	5.95	6.01	6.07	6.14	6.20	6.26	6.33	6.39	6.46	6.52	6.59	6.65	6.72	6.78
6.84	6.90	6.96	7.02	7.08	7.14	7.20	7.25	7.31	7.36	7.41	7.46	7.51	7.56	7.61	7.66	7.70	7.75	7.79	7.83
7.88	7.92	7.96	7.99	8.03	8.07	8.10	8.14	8.17	8.21	8.24	8.27	8.30	8.33	8.36	8.39	8.41	8.44	8.47	8.49
8.52	8.54	8.56	8.59	8.61	8.63	8.65	8.67	8.69	8.71	8.73	8.75	8.76	8.78	8.80	8.81	8.83	8.85	8.86	8.88
8.89																			

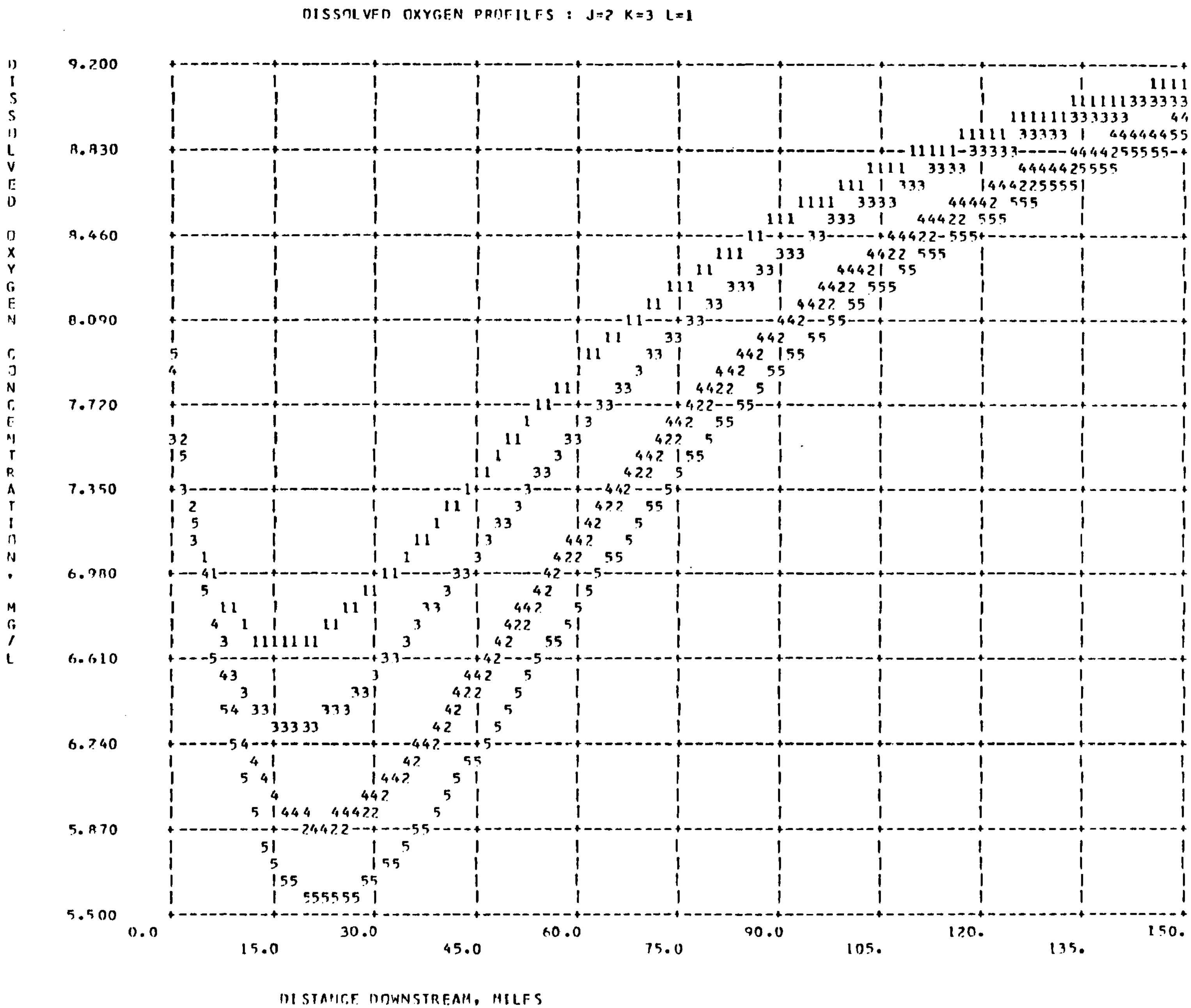


Figure VI-7. Spatial Distribution of DO for Event No. 14 for Various Waste Inflow Combinations

MAXIMUM = 16.00000
MINIMUM = 0.0

(OUTPUT SCALED BY: 1.0E 01)

0 + =====>

0.0 0.2 0.5 0.7 1.0 1.2 1.5 1.7 2.0 2.2 2.5

DO CONC	FREQ.*	CUM. FREQ.
0.0	1.600	1.600
0.500	0.400	2.000
1.00	0.200	2.200
1.50	0.500	2.700
2.00	0.400	3.100
2.50	0.200	3.300
3.00	0.500	3.800
3.50	0.100	3.900
4.00	0.200	4.100
4.50	0.500	4.600
5.00	0.100	4.700
5.50	0.100	4.800
6.00	0.200	5.000
6.50	0.100	5.100
7.00	0.0	5.100
7.50	0.0	5.100
8.00	0.100	5.200
8.50	0.100	5.300
9.00	0.200	5.500
9.50	0.0	5.500
10.0	0.100	5.600
10.5	0.100	5.700
11.0	0.100	5.800
11.5	0.0	5.800
12.0	0.0	5.800
12.5	0.0	5.800
13.0	0.0	5.800
13.5	0.0	5.800
14.0	0.0	5.800
14.5	0.0	5.800
15.0	0.0	5.800

*** CRITICAL D.O. HISTOGRAM ***
***M=2 ***J=1 ***K=1 ***L=2

NORMALIZING FACTOR= 58 EVENTS

Figure VI-8. Sample Output of Critical DO Frequency Histograms

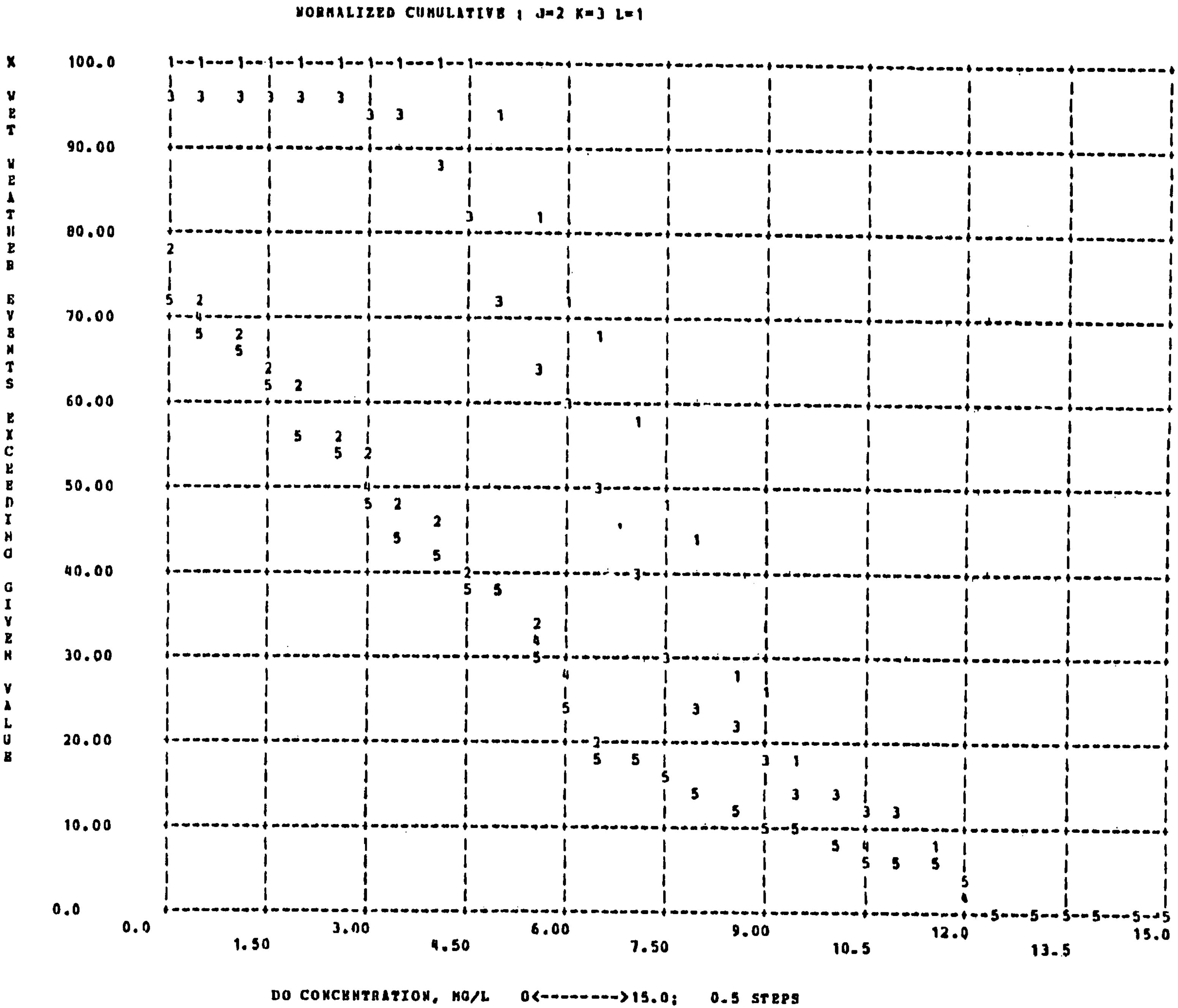


Figure VI-9. Sample Output of Critical DO Cumulative Frequency Curves

TABLE VI-9. CHRONOLOGICALLY SORTED WET AND DRY WEATHER EVENTS

LISTING OF COMPOSITE WET AND DRY WEATHER EVENTS AND CORRESPONDING D.O. VALUES AT X = 5.61 MILES DOWNSTREAM

EVENT NO.	DATE	D.O.
1.	3/ 6/68	9.19
2.	3/ 7/68	9.93
3.	3/ 8/68	7.33
4.	3/10/68	12.08
5.	3/12/68	13.31
6.	3/15/68	11.47
7.	3/18/68	7.86
8.	3/19/68	10.16
9.	3/28/68	9.95
10.	4/ 1/68	9.82
11.	4/ 3/68	5.82
12.	4/ 5/68	10.03
13.	4/10/68	9.80
14.	4/12/68	1.40
15.	4/14/68	5.81
16.	4/15/68	8.32
17.	4/16/68	7.10
18.	4/16/68	7.20
19.	4/17/68	8.36
20.	4/18/68	6.52
21.	4/19/68	8.61
22.	4/20/68	8.98
23.	4/22/68	9.32
24.	4/23/68	10.09
25.	4/24/68	9.43
26.	4/25/68	9.61
27.	5/ 1/68	8.42
28.	5/ 5/68	8.22
29.	5/ 6/68	8.21
30.	5/ 7/68	5.65
31.	5/ 8/68	7.93
32.	5/10/68	7.32
33.	5/11/68	7.12
34.	5/12/68	7.02
35.	5/14/68	3.94
36.	5/15/68	6.69
37.	5/17/68	7.57
38.	5/18/68	7.52
39.	5/20/68	8.44
40.	5/21/68	8.84
41.	5/22/68	6.16
42.	5/23/68	8.92
43.	5/26/68	7.61
44.	5/27/68	8.95
45.	5/28/68	7.08
46.	5/29/68	8.59
47.	5/30/68	8.22
48.	5/31/68	6.02
49.	6/ 4/68	6.25
50.	6/ 5/68	6.30
51.	6/10/68	2.89

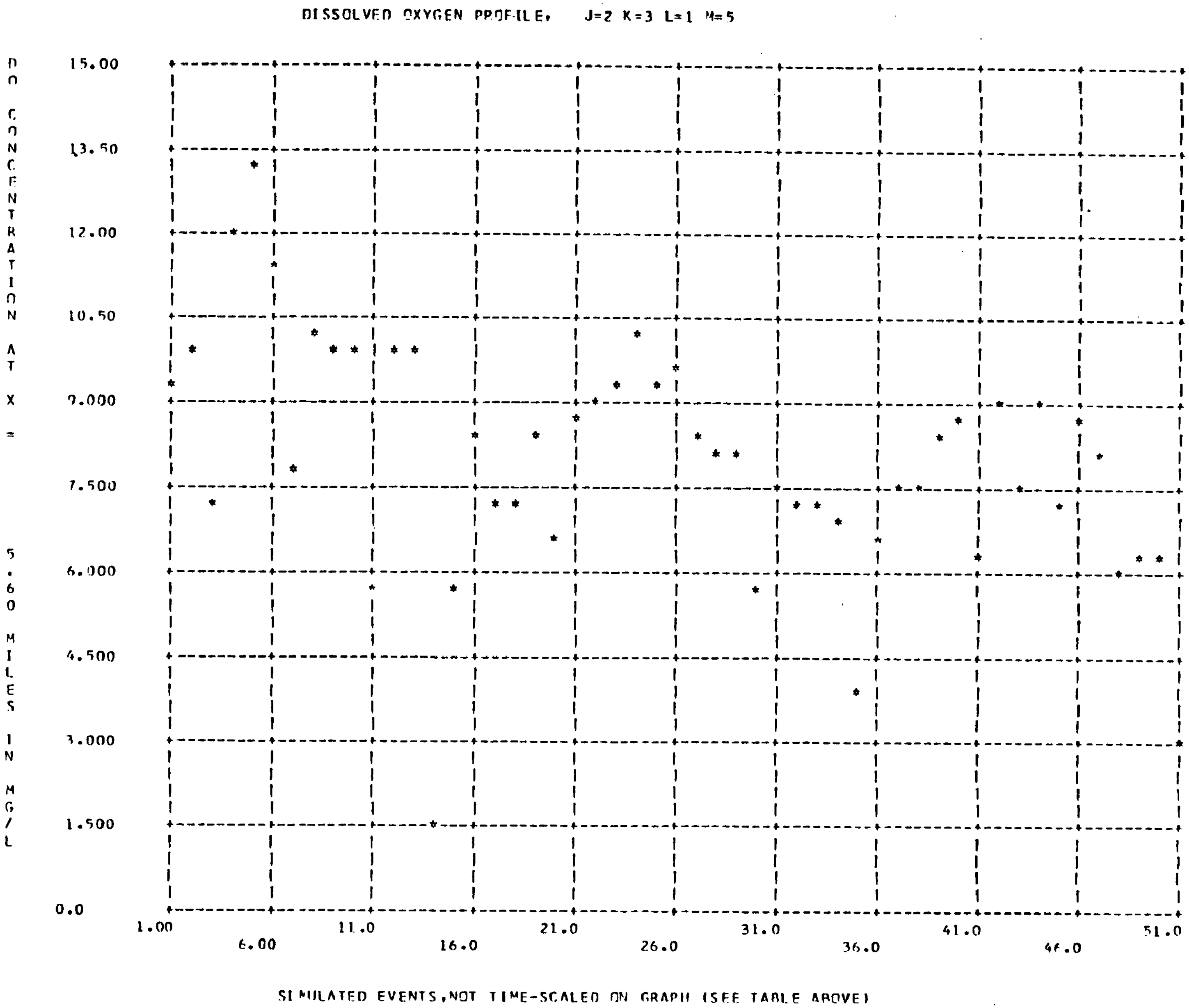


Figure VI-10. DO Distribution Per Event Number At a Specified Location Downstream of Level III-Receiving output.

A review of Table VI-2 is in order at this point. An analysis of the precipitation time series, depicted in Figure VI-4 earlier, results in the curve shown in Figure VI-11, which corresponds to the computer printout of Figure VI-6. At an hourly lag of zero, the correlation of the discrete open series is unity because this point on the curve represents the linear dependence of the data series on itself. The number of observations (including zero values) totals 7,344 consecutive values, and lags up to 800 hours were investigated. The first minimum of the autocorrelation function may be considered to occur at a lag of 10 hours, where the value of the function is significantly equal to zero at a 95 percent probability level. The physical interpretation is that periods without rainfall for at least 10 hours separate uncorrelated, and therefore independent, storm events. Actually any point of the autocorrelation function which lies outside of the 95 percent tolerance limits indicated suggests a significantly non-zero correlation between storm events at that particular time lag. The Des Moines rainfall record obviously exhibits nonrandom behavior at lags of 377 hours ($\sim$ 16 days) and 421 hours. ($\sim$ 18 days) in particular. Values of the autocorrelation function between lags of 100 to 300 hours and 500 to 720 hours fell between the 95 percent tolerance limits and are not shown.

Similarly, autocorrelation analysis was performed on the sequence of hourly runoff values generated by STORM from the rainfall input. The lag-k serial correlation coefficients, $r_Q(k)$, are plotted against the number of lags in Figure VI-12. The analytic technique established that the minimum interevent time of consecutive DWH that separate independent runoff events is 9 hours. The runoff time series is not purely random either. Linear dependence is observed at time lags of 377 hours ($\sim$ 16 days) and 436 hours ($\sim$ 18 days), as expected, because of the high correlation between rainfall and runoff processes. Thus, only one of either time series need be analyzed to determine a reasonable minimum interevent time. Based on NOAA records (Asheville, North Carolina, the total precipitation that fell over Des Moines, Iowa, during 1968 was 27.59 inches (701 mm). STORM computed a total runoff of 10.28 inches (261 mm) over a watershed area of 49,000 acres (19,600 ha), for an overall urban area runoff coefficient of 0.37. There were 65 days in the year during which rainfall was recorded, from which 58 wet-weather events were defined.

As a basis for comparison, it is appropriate to examine first the model estimates of DO concentration in the Des Moines River for conditions assumed to exist in 1968 <u>during periods of urban runoff</u>:

1. combination M = 5, all waste inputs;

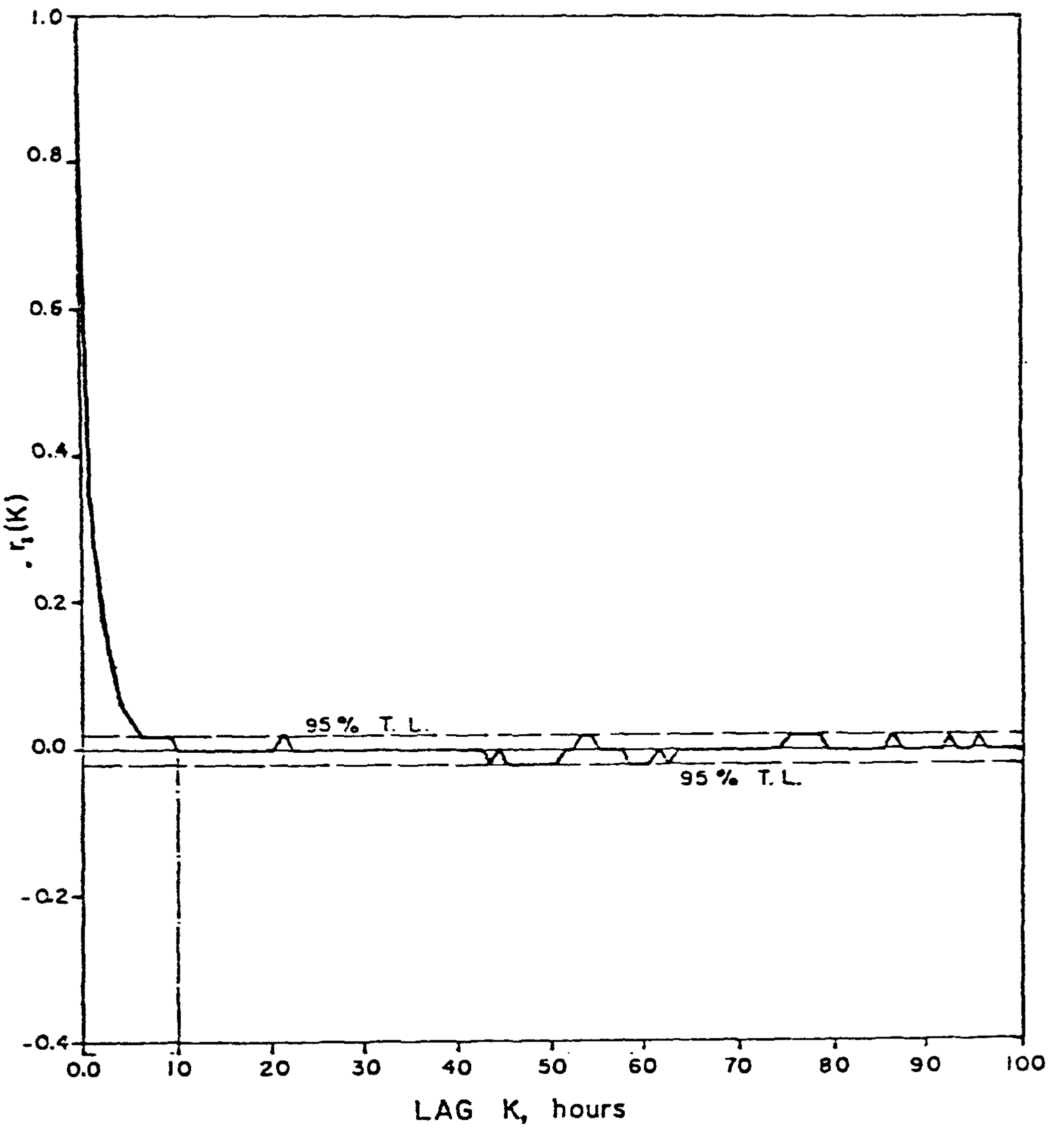


Figure VI-11. Lag-k Autocorrelation Function of Des Moines, Iowa, Hourly Rainfall, 1968.

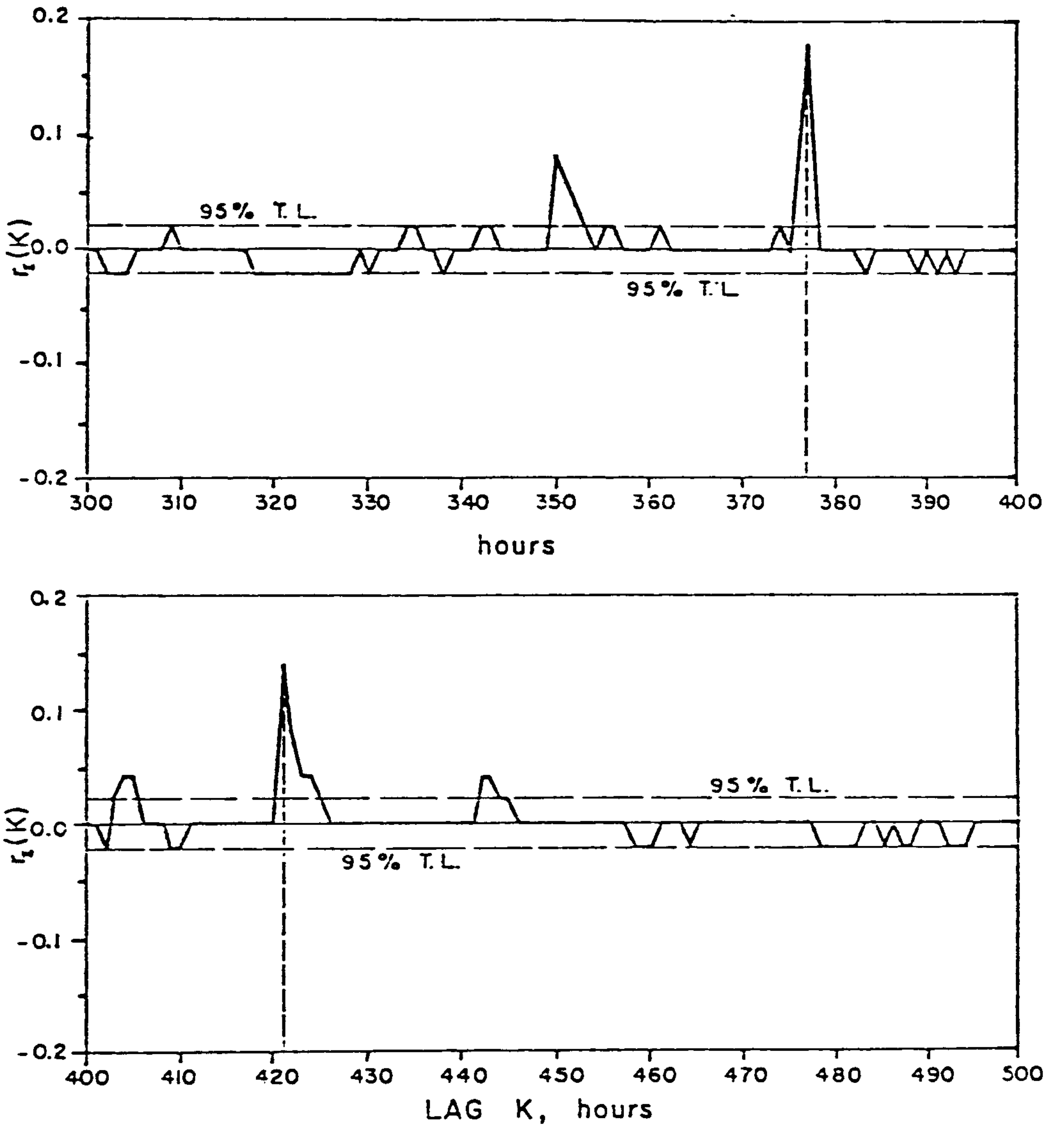


Figure VI-11. (Continued)

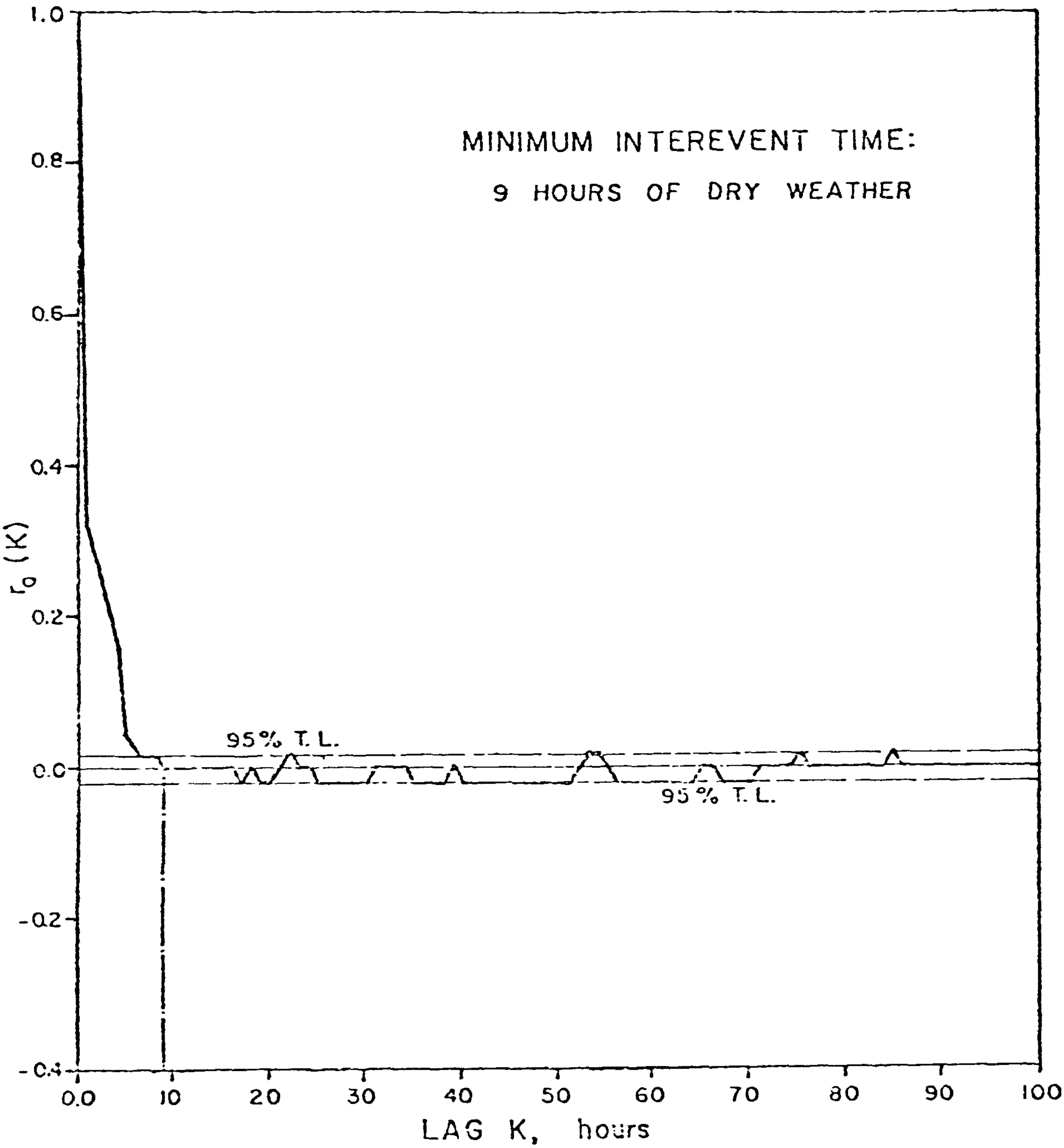


Figure VI-12. Autocorrelation Function of Hourly Urban Runoff for Des Moines, Iowa, 1968.

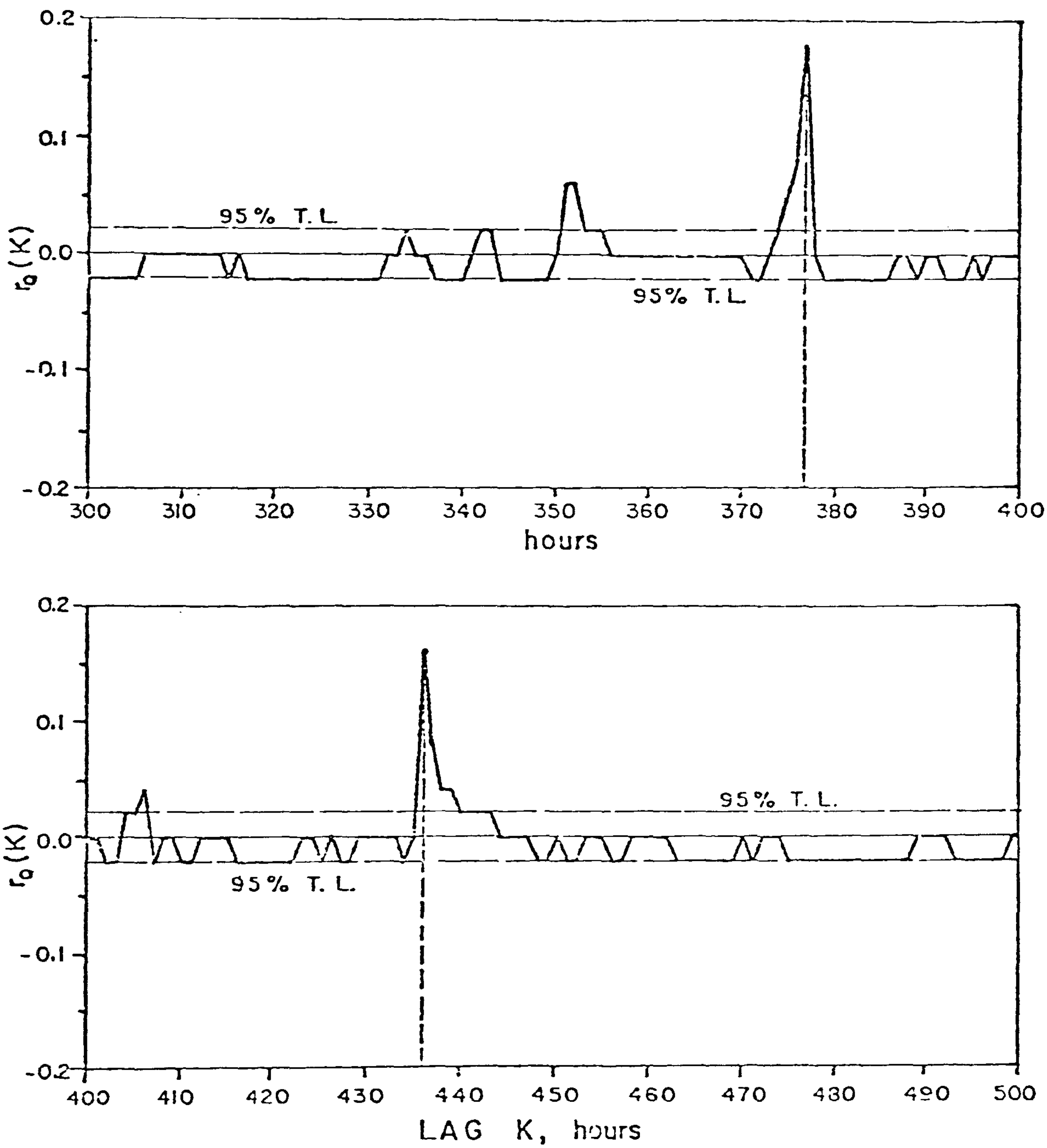


Figure VI-12. (Continued)

2. secondary treatment (85 percent BOD removal) of DWF, J = 2;

3. no stormwater treatment, L = 1;

4. river flow 100 percent of measured flow, K = 3; and

5. the fraction of combined area is 8.16 percent of the total urban area.

Figure VI-13 illustrates all waste inflow combinations. The curves indicate clearly that all combinations including a substantial amount of wet-weather flow (WWF) result in a drastic decrease in river minimum DO concentrations. For example, 42 percent of all the wet-weather events throughout the year produced conditions in the receiving water that caused minimum DO levels below 4.0 mg/l. Combined sewers contributed WWF from only 8 percent of the total urban area modeled, yet the BOD_C concentration was sufficiently high to inflict an appreciable reduction in DO levels when compared to DWF sources during periods of runoff.

Similar cumulative DO frequency curves are computed, for all possible combinations listed in Table VI-2, by the mathematical model. Figures VI-14 through VI-18 represent the results obtained by considering all waste inputs (combination M = 5, Table VI-2) while varying the other parameters. Figure VI-14 displays the minimum DO frequency curves obtained by varying the percent of the total urban area served by combined sewers. There is a substantial, but not drastic, decrease in water quality when the extreme conditions are compared: an area served only by separate sewers (0 percent combined) versus an area served exclusively by combined sewers. The curves support the theory that total separation of sewers is not the answer to the control of urban runoff pollution. The curves in this figure all represent secondary treatment of DWF, no urban runoff treatment, and full river flow. Figure VI-15 shows the relative effect of urban stormwater runoff in the upstream portions of the drainage basin. As explained earlier, this effect is modeled by reducing upstream river flow to three different fractions of its actual measured value. DWF is given secondary treatment (85 percent BOD removal), while WWF is untreated. Thus, the only flow in the river consists of DWF and urban runoff when modeling discharge into a dry river bed (K=1, Table VI-2). Variation of upstream river flow does not reveal large differences in receiving water quality, as might be expected, because of the relatively large volumes of stormwater runoff discharged by the urban area into the river:

1. for all of the precipitation events defined by the model, upstream river flow was on the average 50 percent of the total river flow; and

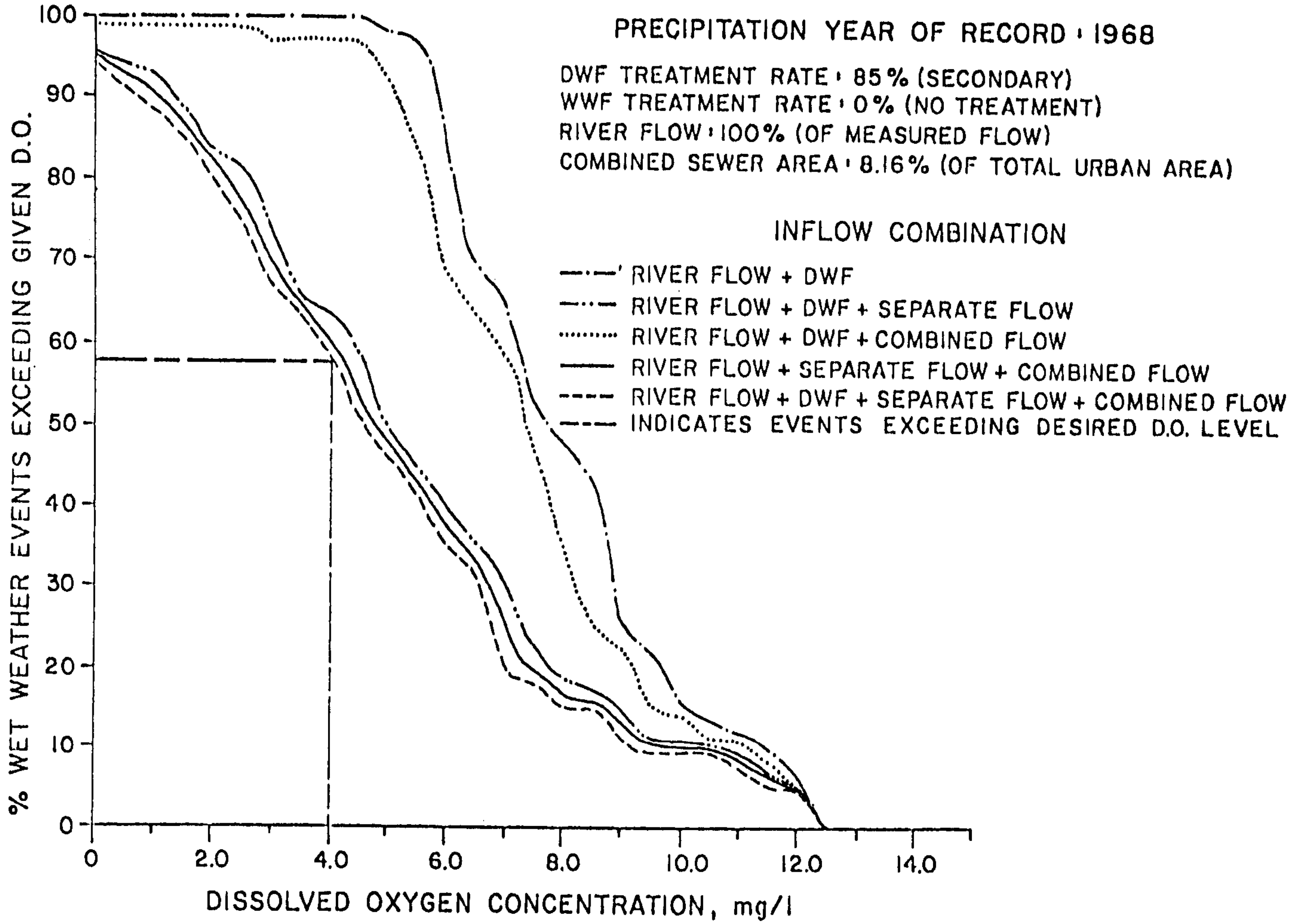


Figure VI-13. Minimum DO Frequency Curves for Existing Conditions in the Des Moines River

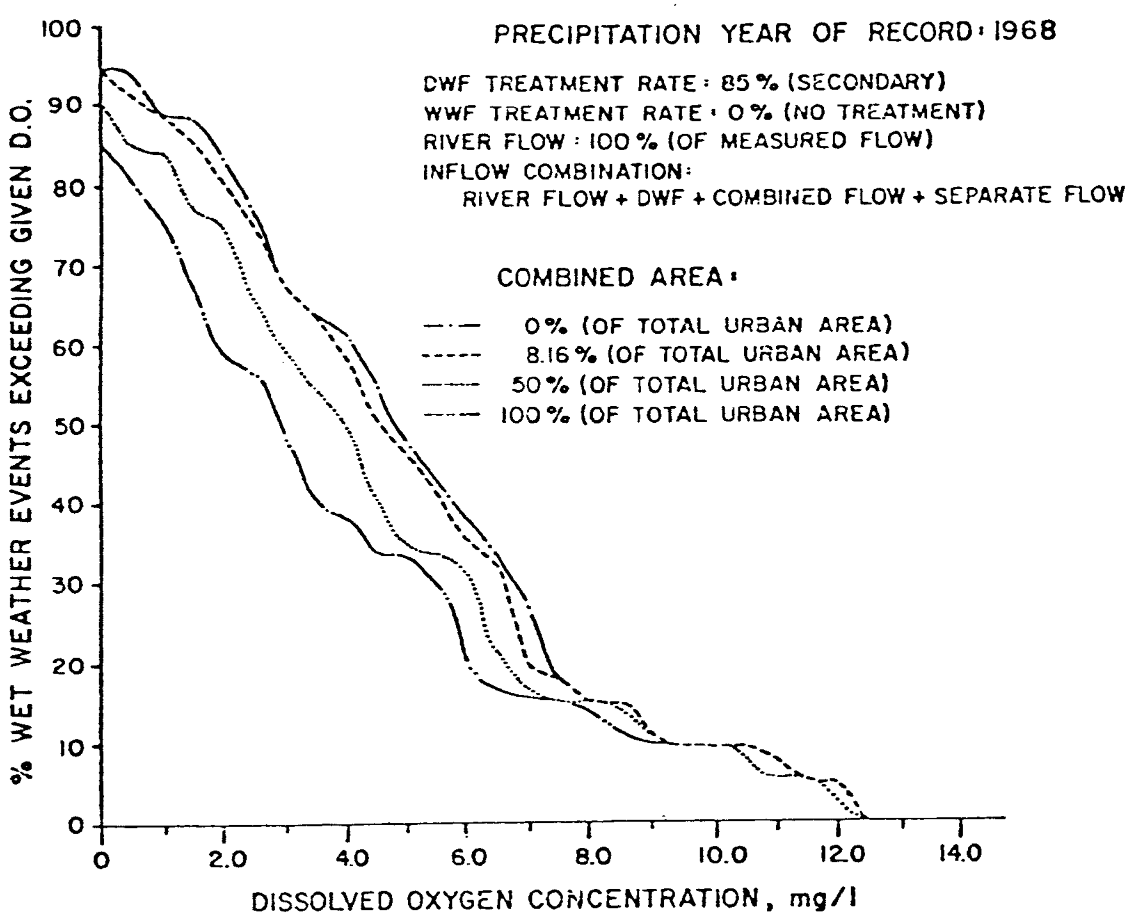


Figure VI-14. Minimum DO Frequency Curves for Varied Percent of Combined Sewer Area

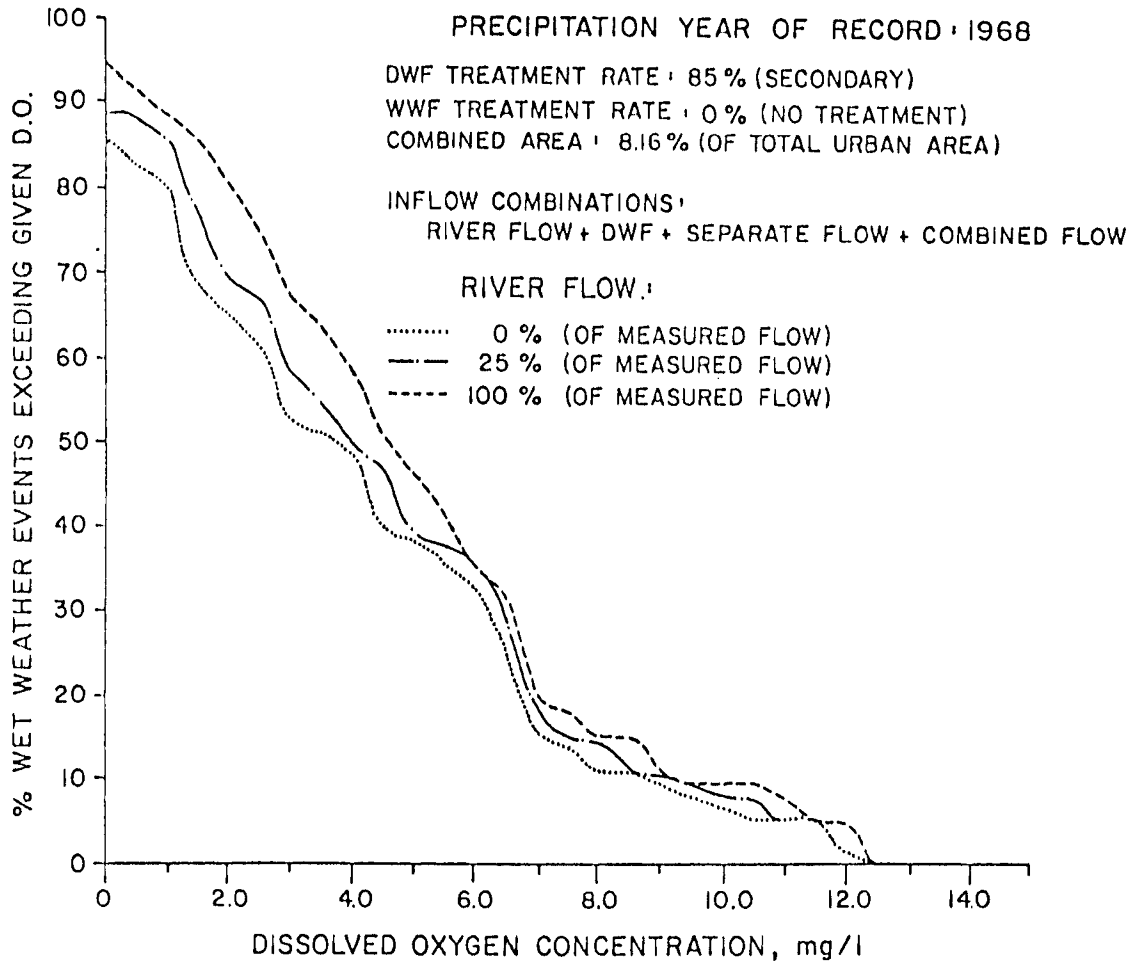


Figure VI-15. Minimum DO Frequency Curves for Varied Percent of Actual Measured Upstream River Flow

2. this percentage ranged from as low as 6 percent to as high as 97 percent of total river flow.

For the Des Moines application, and the particular rainfall year selected (1968), urban runoff seems to be the key factor in receiving water critical DO levels. However, an urban area located very far upstream in a river basin would have a more detrimental impact on water quality downstream from the urban area than if the same urban area was located on a higher order stream within the network.

Figure VI-16 shows the effect of varying the degree of treatment of DWF while holding the other parameters constant. It can be inferred that there is no significant improvement of stream water quality (DO) by upgrading DWF treatment from secondary to tertiary during periods of wet weather. However, it is clear that the improvement in minimum DO levels by upgrading DWF treatment from primary to secondary is probably worthwhile: 7 percent more wet-weather events would exceed a DO value of 4.0 mg/l. Examination of Figure VI-17 reveals that critical DO levels are improved appreciably with 25 percent treatment of WWF and markedly with 75 percent treatment of WWF, while providing secondary treatment of DWF. The minimum DO frequency curves in Figure VI-18 compare four treatment alternatives to reduce water pollution during periods of urban runoff:

1. 95 percent treatment of DWF and no treatment of urban runoff,

2. 85 percent treatment of DWF and 25 percent treatment (BOD removal) of WWF,

3. 85 percent treatment of DWF and 75 percent treatment of WWF, and

4. 85 percent treatment of DWF and no treatment or urban runoff.

The zero treatment and primary treatment curves are also shown for comparison, but are not considered acceptable alternatives. It appears that options 1 and 4 above result in comparable critical DO levels in the receiving stream. However, options 2 and 3 result in much more improved critical DO levels.

It is now appropriate to examine the results of applying the model to periods throughout the year during which <u>no urban runoff</u> was produced. Dry weather was experienced for approximately 300 days throughout 1968. The DWFM was applied to these periods, using a daily time step. This is certainly justified since conditions are more truly steady-state than during periods of precipitation and subsequent runoff: for example, waste

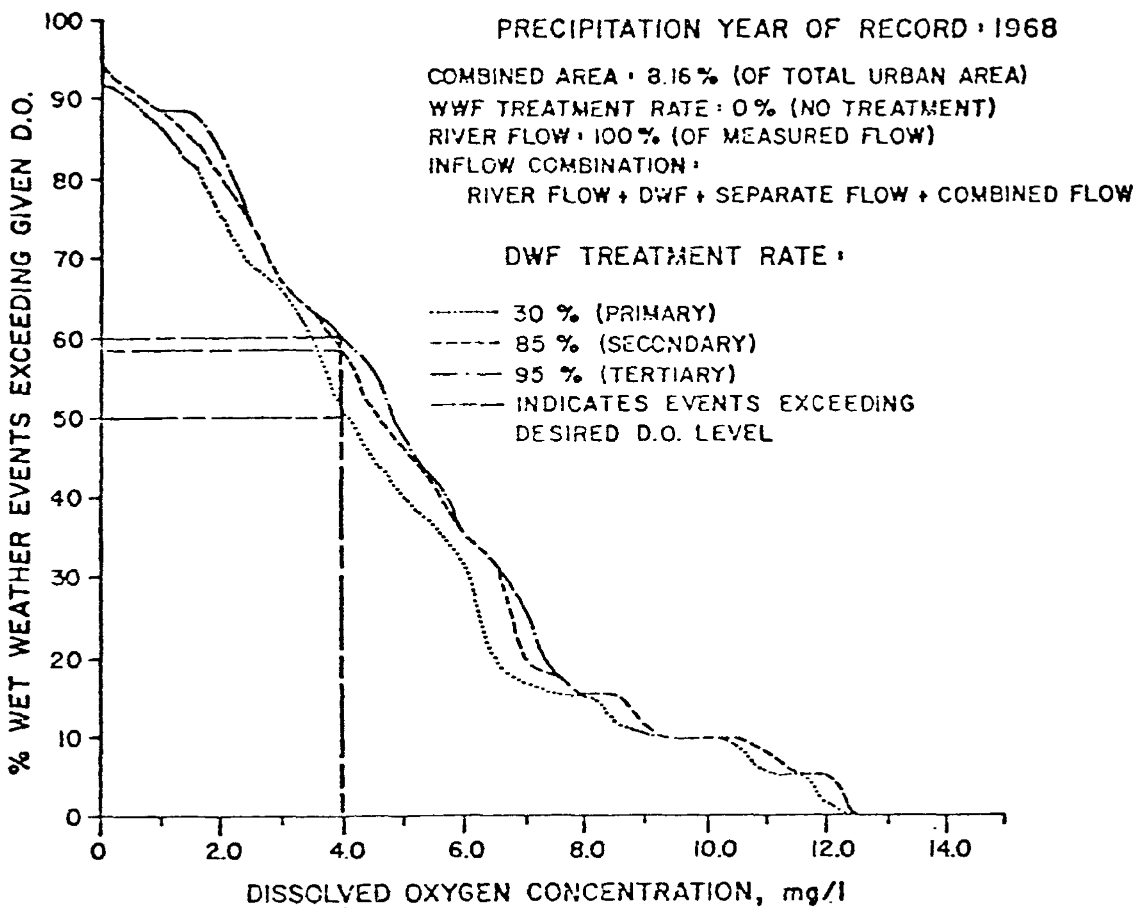


Figure VI-16. Minimum DO Frequency Curves for Varied DWF Treatment

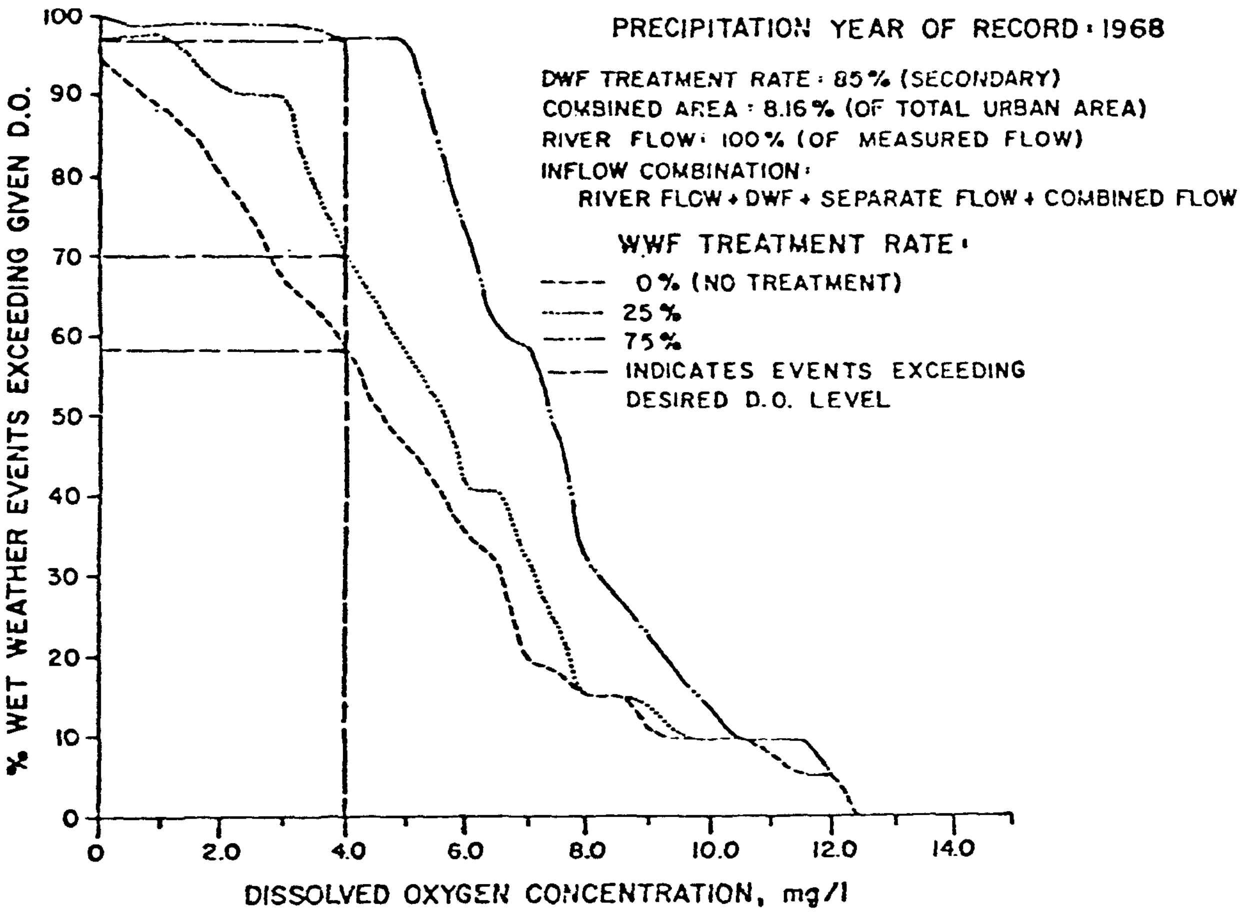


Figure VI-17. Minimum DO Frequency Curves for Varied WWF Treatment

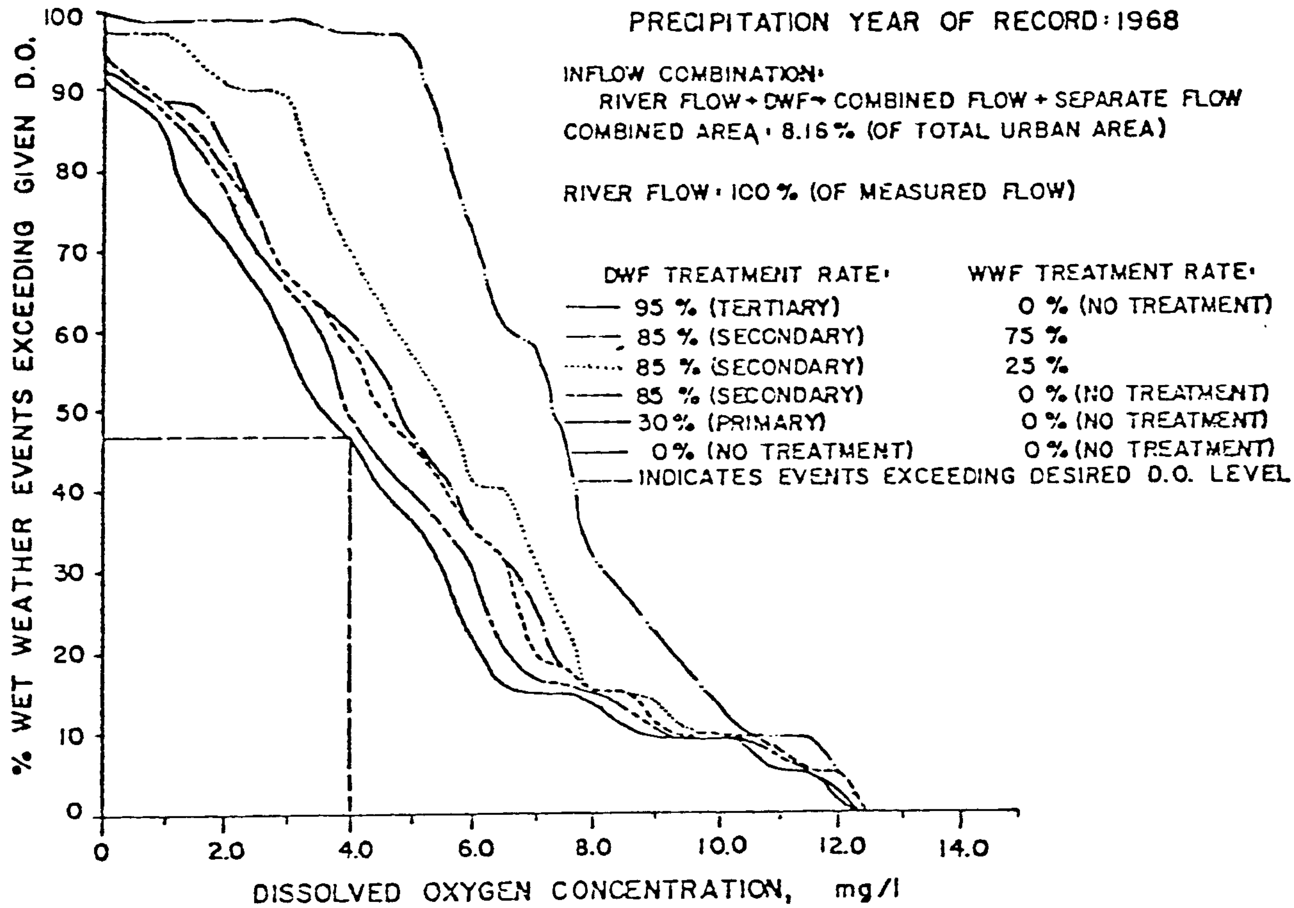


Figure VI-18. Minimum DO Frequency Curves for Varied Treatment Alternatives loadings (DWF treatment plant effluent) and river flow do not vary as much during the day. For the dry-weather simulation period, upstream river flow was on the average 94 percent of total river flow, ranging from 82 percent to 99.6 percent. The results are shown in Figure VI-19. A remarkable 97 percent of the dry-weather days exceed a minimum DO concentration of 4.0 mg/l. Upgrading of DWF treatment becomes meaningful only if stream DO standards are set higher than 4.0 mg/l. The Des Moines River carries a high BOD load upstream of the Des Moines urban area. This explains, why, even during dry-weather periods only, a significant increase in the DWF treatment rate does not result in a corresponding increase in the critical DO levels.

To maintain the proper perspective, it is desirable to view the effects of urban runoff on an annual basis, not just during periods of wet weather. The frequency curves shown in Figures VI-18 and VI-19 are combined by weighting on the basis of the number of rainfall days and dry-weather days in the year. The composite totals are presented in Figure VI-20. For example, a given stream standard of 4.0 mg/l is exceeded 90 percent of the time for existing conditions in Des Moines, Iowa, throughout the year 1968. A significant amount of treatment (75% BOD removal) of WWF in addition to secondary treatment of DWF results in critical DO levels such that the same stream standard is exceeded 97 percent of the days in the year. Annual DO duration curves tend to mask the impact of shock loads of organic pollutants discharged during periods of urban runoff. A few extended violations of stream DO standards may cause anaerobic conditions resulting in fish kills and proliferation of undesirable microorganisms.

The effect of individual storm events on receiving water quality may be viewed in terms of the more traditional dissolved oxygen sag curves. The spatial distributions of DO concentrations for a distance of 150 miles (240 km) downstream from the point of waste discharge are illustrated in Figures VI-21 and VI-22 for wet weather events No. 14 and No. 31, respectively. Each graph illustrates the curves which correspond to waste inflow combinations (M) described earlier in Table VI-2. Event No. 31 exhibits a more drastic difference in DO sag for those combinations which include significant amounts of urban runoff.

The integral of the DO deficit equation over all time, equations (IV-48) and (IV-49), has been suggested as a measure of the relative effect of one waste source versus another. Denoted at $\mathbf{V}$, the volume of DO deficit, this parameter is computed for each treatment option during both wet- and dry-weather periods. The average values obtained are given in Table VI-10. The results indicate the same ranking of the treatment alternatives as suggested by the curves in Figure VI-20, from a water quality viewpoint. This implies that the integrated DO deficit $\mathbf{V}$, may provide a simple method of comparing the impact upon

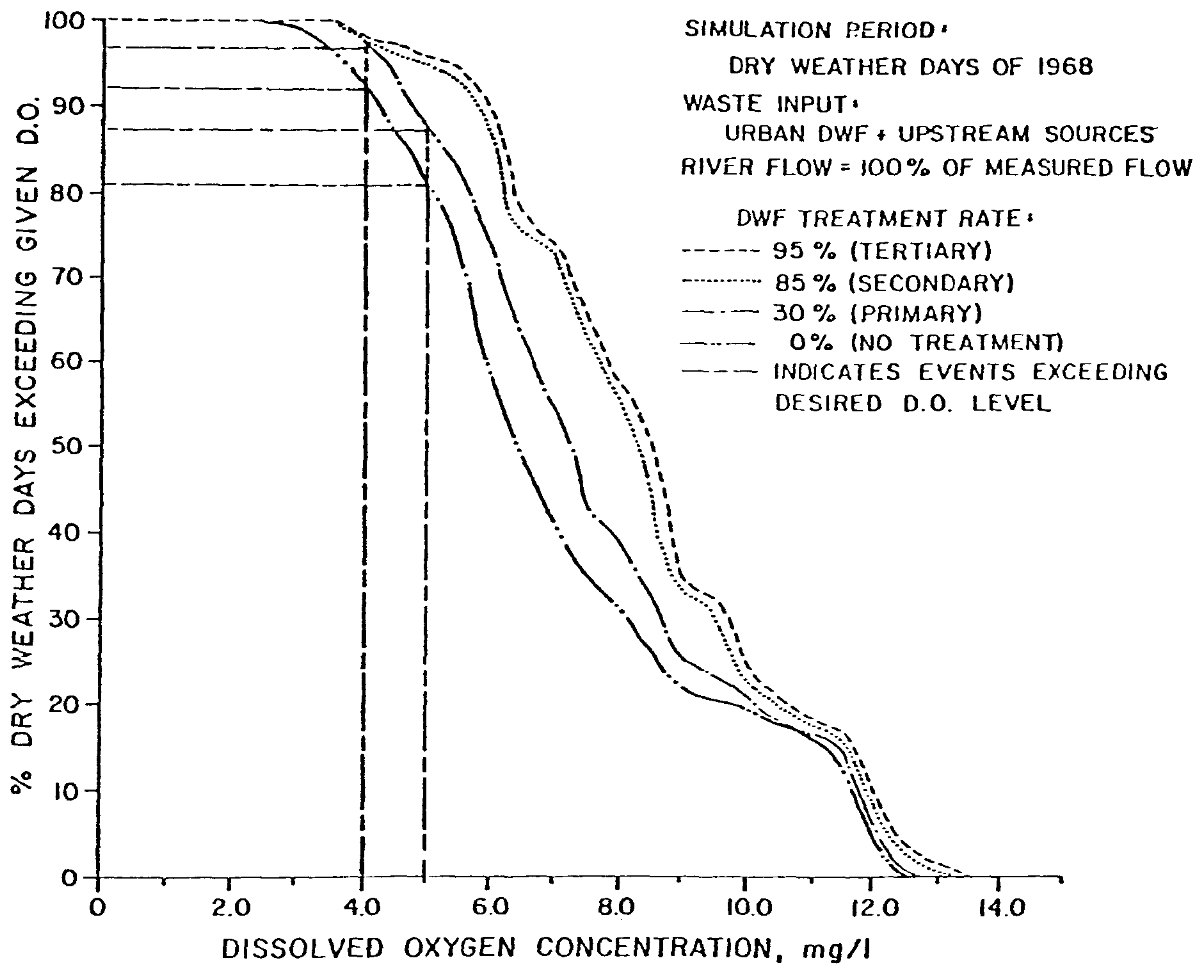


Figure VI-19. Dry-Weather Minimum DO Frequency Curves for Varied DWF Treatment Alternatives

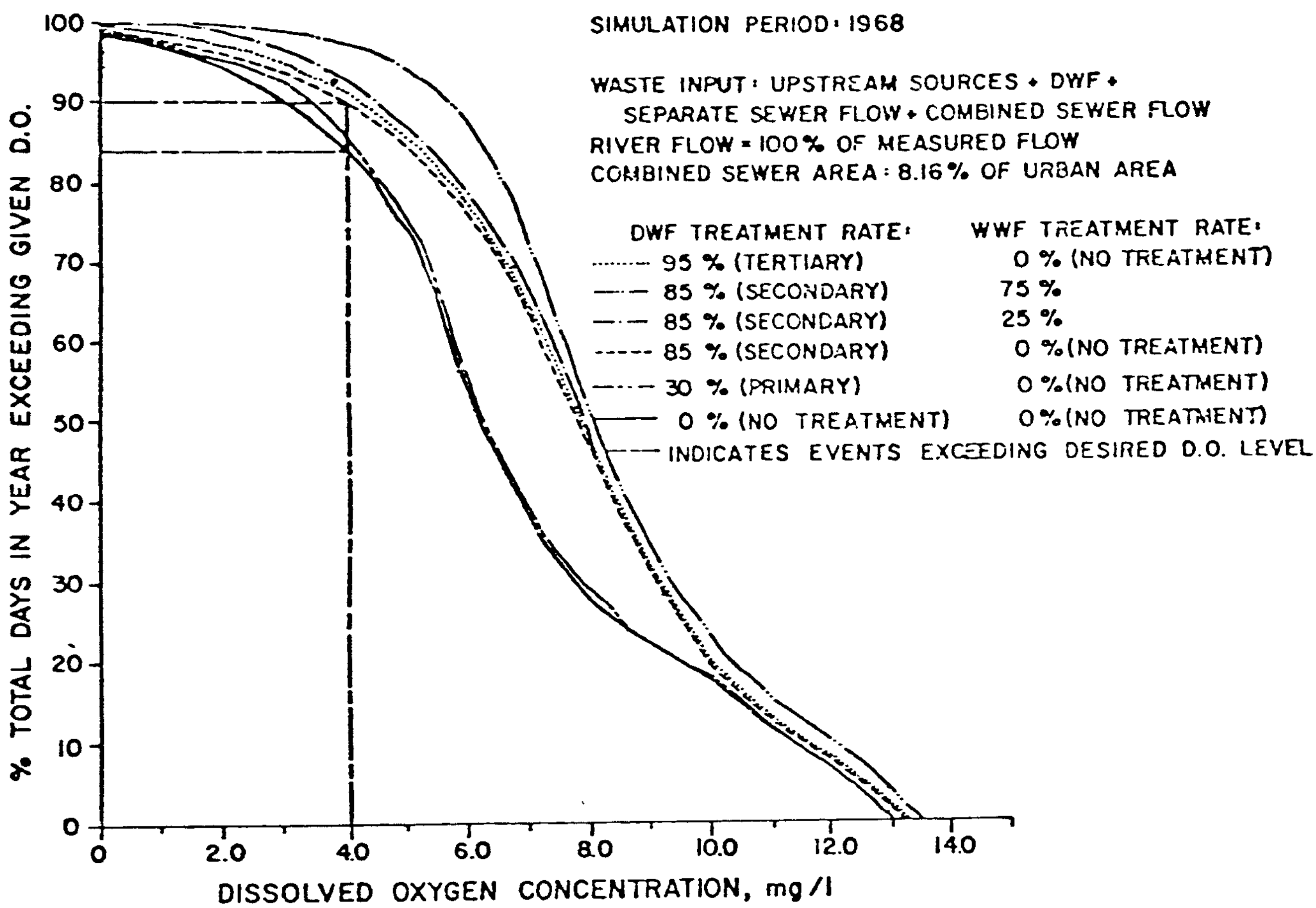


Figure VI-20. Annual Minimum DO Frequency Curves

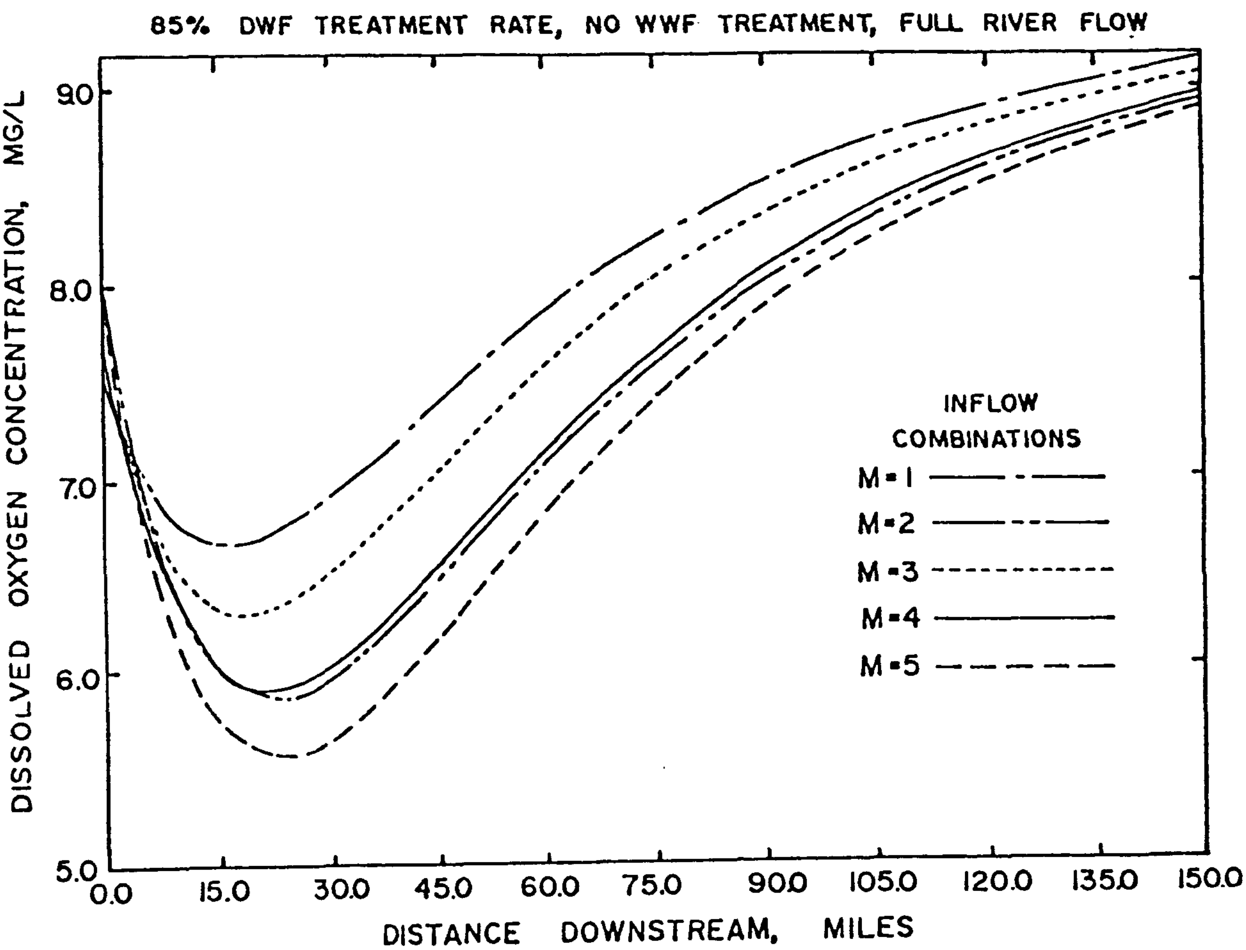


Figure VI-21. Spatial Distribution of Stream DO Concentrations for Event No. 14

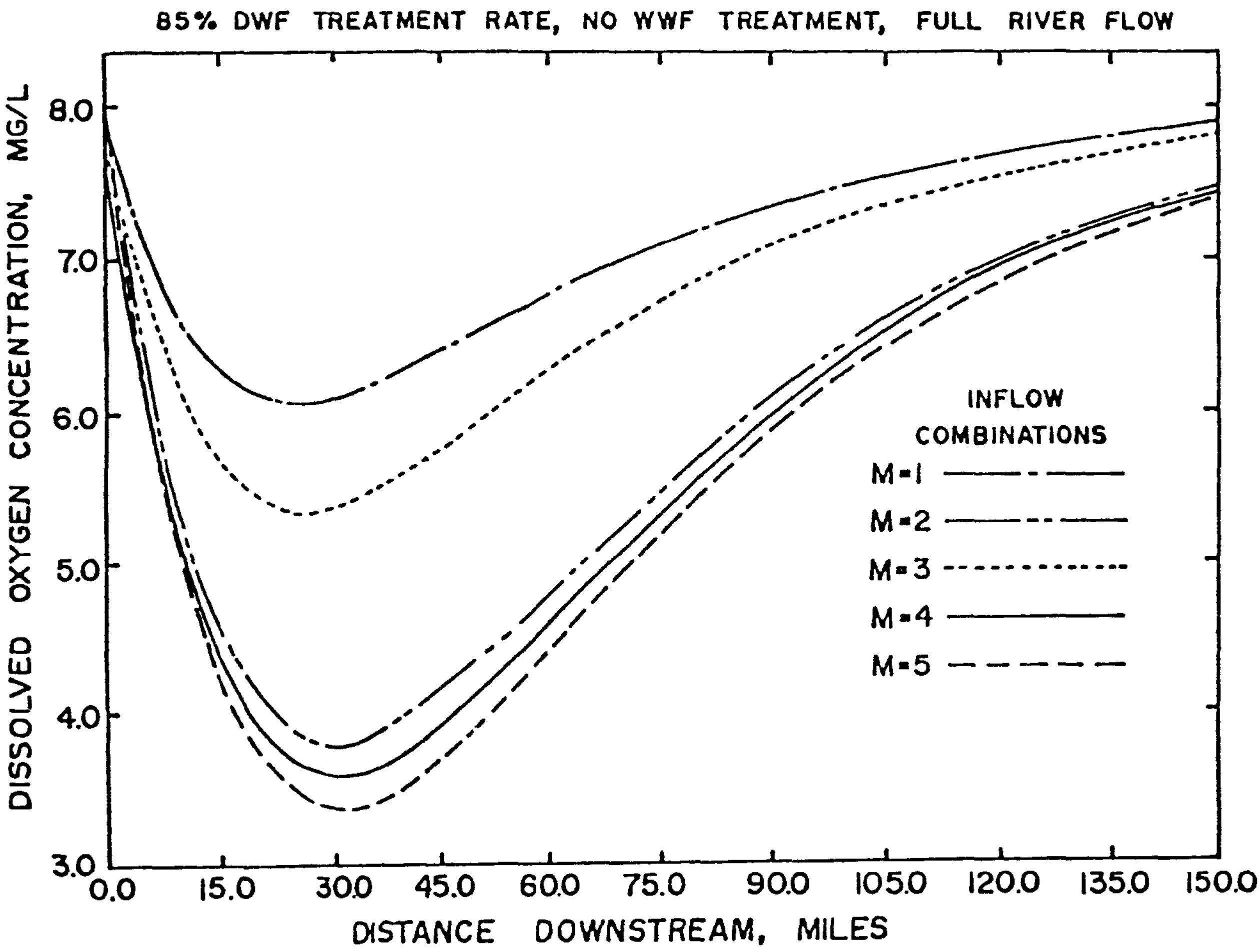


Figure VI-22. Spatial Distribution of Stream DO Concentrations for Event No. 31

TABLE VI-10. VOLUME OF DO DEFICIT

Option	DWF Treatment Rate (% BOD Removal)	WWF Treatment Rate (% BOD Removal)	Average ∀ for Wet Periods (mg-day/l)	Average ∀ for Dry Periods (mg-day/l)	Average ∀ Year (mg-day/l)
1	95 (Tertiary)	0 (No Treatment)	30.3	6.1	10.4
2	85 (Secondary)	75 (Biological, Physical, Chemical)	12.1	7.0	7.9
3	85 (Secondary)	25 (Physical)	24.6	7.0	10.1
4	85 (Secondary)	0 (No Treatment)	30.9	7.0	11.3
5	30 (Primary)	0 (No Treatment)	34.1	12.3	16.2
6	0 (No Treatment)	0 (No Treatment)	35.9	15.4	19.1

See equation (IV-48) when longitudinal dispersion coefficient $E > 0$, and equation (IV-49) when $E = 0$.

receiving waters of alternative input configurations.

MODEL UTILITY FOR AREAWIDE WATER QUALITY MANAGEMENT PLANS

Municipal water pollution control alternatives should be evaluated in terms of pollutant removal efficiency, receiving water impacts, and associated costs. The true cost-effectiveness of various treatment strategies can be determined realistically only by a continuous analysis of the frequency of violation of established water quality standards. Of course, in the selection of the best control strategy other factors may become important: 1) recovery of receiving waters from shock loads generated by urban runoff, 2) local and regional water quality goals in addition to established standards, 3) public willingness to pay the additional costs associated with increased control, and 4) dual use of WWF facilities, as DWF treatment units during periods of no runoff.

The cost figures shown in Table VI-11 represent the additional expense incurred in providing storage/treatment beyond that already available with secondary treatment of DWF and no control of urban runoff (existing conditions for Des Moines, Iowa). Details of the cost assessment for typical wet-weather and dry-weather control facilities have been presented in the nationwide study (Heaney, et al., 1977). The Des Moines River stretches for 200 mi (322 km) from the City of Des Moines to its junction with the Mississippi River and is generally wide and swift with a broad flood plain. Bottom material is composed of silt deposits, sand, gravel and rubble providing numerous habitats for fish and other aquatic life (State Hygienic Laboratory, 1974). The entire reach is classified by the Iowa Water Quality Standards such that the absolute minimum DO level must equal 4.0 mg/l, and 5.0 mg/l during at least 16 hours per day (State Hygienic Laboratory, 1970). The effects of various control strategies upon the critical (minimum) DO concentrations of the Des Moines River have been presented in Figures VI-18, VI-19, and VI-20. Thus, taking 4.0 mg/l as the standard or basis for water quality comparisons, the different control options may be judged by the following criteria:

1. total annual cost, and

2. violations of the minimum allowable dissolved oxygen level.

Table VI-12 summarizes control costs versus DO standard violations for two advanced waste treatment options, two wet-weather control options, and existing DWF secondary treatment facilities. For comparative purposes, two additional treatment conditions which are not presently acceptable by government

TABLE VI-11. DWF TERITARY TREATMENT vs. WWF CONTROL[1] (HEANEY, ET AL., 1977)

Options	Amortized Annual Capital Cost $ (20 yrs, 8%)	Operation Maintenance Cost ($/yr)	Total Annual Cost ($/yr)
1. DWF Complete Tertiary Treatment, No WWF Treatment	2,158,000	4,132,000	6,290,000
2. DWF Activated Sludge-Coagulation-Filtration, No WWF Treatment	- - -	- - -	1,664,000
3. WWF 75% BOD Removal, DWF Secondary Treatment	- - -	- - -	9,293,000
4. WWF 25% BOD Removal, DWF Secondary Treatment	- - -	- - -	816,000

[1]Based on 49,000 acres (19,600 ha) of developed urban area with population approximately 200,000. The total annual cost includes amortized capital cost (20 yrs, 8%) and operation and maintenance costs, 1975 dollars (ENR 2200); design flow of 35.3 mgd (134,000 cu m/day) for the DWF facility.

TABLE VI-12. COST-EFFECTIVENESS OF CONTROL OPTIONS (HEANEY, ET AL, 1977)

Options	% Wet-Weather Events[1] Violating Standard	% Dry Days in Year Violating Standard	Total Incremental Annual Cost[2] ($/yr)	Total No. of Days During Year that Standard is Violated[3]
1. DWF Complete Tertiary Treatment, No WWF Treatment	40	1.5	6,290,000	31
2. DWF Activated Sludge Coagulation-Filtration Treatment, No WWF Treatment	40	1.5	1,664,000	31
3. DWF Secondary Treatment WWF 75% BOD Removal	3	2.0	9,293,000	8
4. DWF Secondary Treatment, WWF 25% BOD Removal	30	2.0	816,000	26
5. DWF Secondary Treatment, No WWF Treatment	42	2.0	0	33
6. DWF Primary Treatment[4], No WWF Treatment	50	3.0	-1,438,000	42
7. No DWF Treatment[5], No WWF Treatment	53	7.0	-1,843,000	55

[1]Defined by a minimum interevent time of 9 DWH.

[2]In addition to control costs for existing conditions (option 5).

[3]Based on a minimum allowable DO concentration of 4.0 mg/l.

[4]Savings incurred by reducing DWF treatment of trickling filter plant of 35.3 mgd (1.55 cu m/sec).

[5]Savings by completely eliminating treatment.

regulation are present. Detailed process flow charts for the DWF facilities are included in the nationwide assessment (Heaney, *et al.*, 1977). Results of the simulation and the economic evaluation reveal that:

1. Since both types of tertiary treatment remove essentially the same amount of BOD_5, option 1 is justified over option 2 only when nutrient removal is necessary;

2. option 4 is preferred over any form of advanced waste treatment;

3. option 3 is attractive because it causes the least amount of damage to the receiving stream, but it is the most expensive alternative; and

4. any reduction in the degree of DWF treatment for existing conditions, option 5, results in a substantial deterioration to receiving water dissolved oxygen levels and must be weighed against the savings incurred.

Furthermore, the issue of shock load prevention seems to favor high levels of WWF control.

The user should be cautioned that the above results were derived from application of the model to a specific urban area for a historical record of storm events occurring during a particular year. However, the usefulness of the methodology applied should be clear. The success of its application still relies heavily on the quality of the field data available. Dissolved oxygen in the receiving water body has been used as the key indicator of water quality, yet other parameters may have to be considered depending upon water quality goals. Complex hydrodynamic conditions will require additional, more detailed modeling efforts. Engineering judgement must be exercised carefully in the interpretation of model output and the importance of verification procedures cannot be overemphasized. The model is a *user assistance tool* in the preparation of water quality management plans, not a decision-maker by itself.

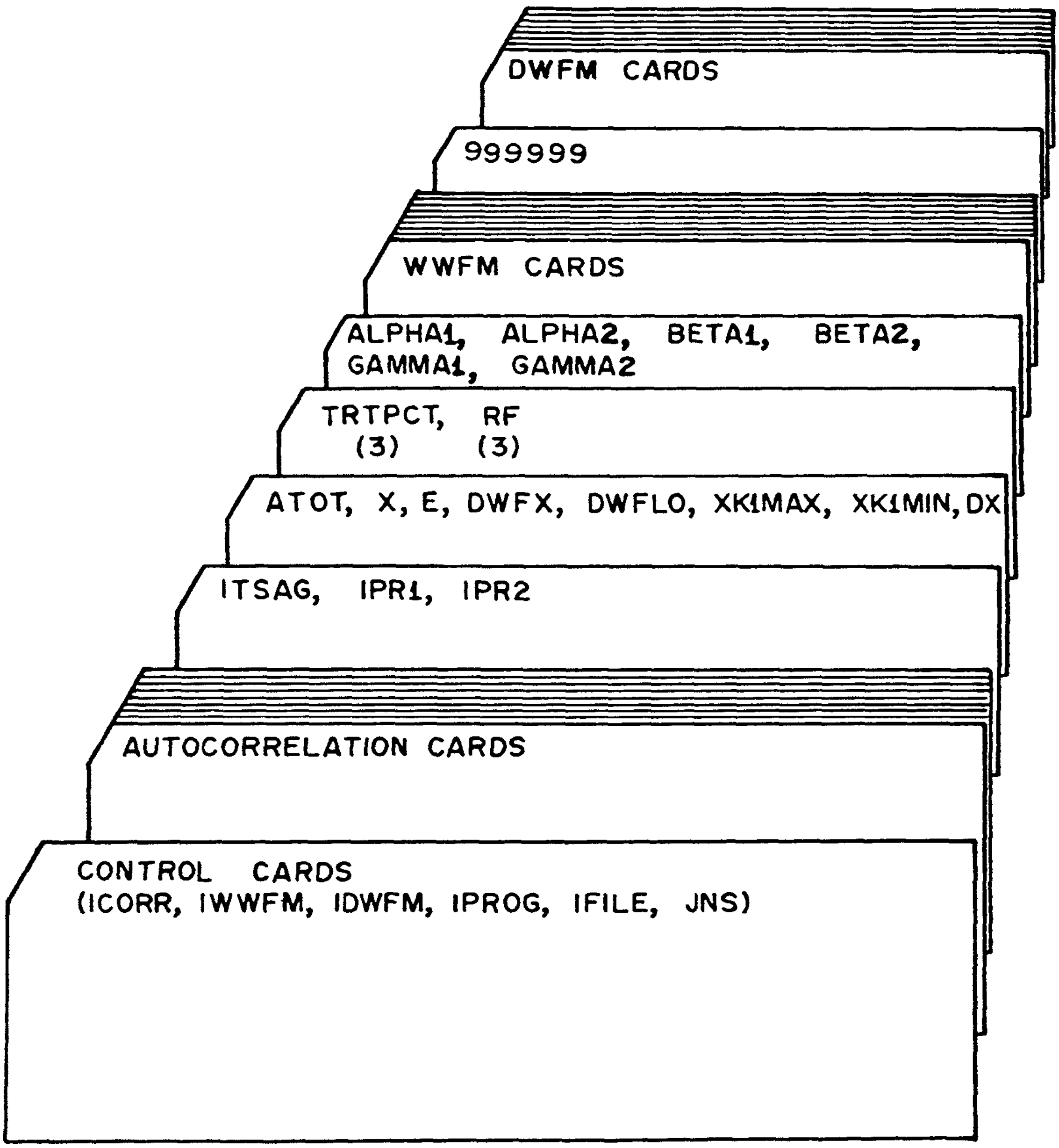


Figure VI-23. Input Data Card Deck for Level III-Receiving

TABLE VI-13. INSTRUCTIONS FOR DATA PREPARATION[1]

Card Group	Format	Card Columns	Description	Variable Name
I			Control card: one card, which indicates which subroutines are to be called and also specifies input data options.	
Card 1	6I5	1-5	Command to execute autocorrelation subroutine for event definition = 1; = 0, user must specify minimum interevent time (see Card 10).	ICORR
		6-10	Command to execute wet-weather flow model (main program) = 1; otherwise, = 0.	IWWFM
		11-15	Command to execute the dry weather flow model (subroutine DWFM) = 1; otherwise, = 0.	IDWFM

[1]Superscripts denote footnotes at the end of this table.

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
		16-20	Specifies input data options. = 0, input from cards only; = 1, input from cards and SWMM; = 2, input from cards and user-created data set, e.g. from STORM output.	IPROG
		21-25	Specifies data set unit number. = N, integer unit number required if IPROG > 0, set by user in accordance with computer system; = 0, no input from data set.	IFILE
		26-30	SWMM input junction number, required if IPROG = 1 (see Section V); = 0, otherwise.	JNS

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
II			Autocorrelation analysis of hydrologic time series, skipped if ICORR= 0; variable number of cards.	
Card 2	2I5			
		1-5	Total number of data points, equal to number of consecutive hours within specified simulation time period, maximum value = 8760. If > 8760, user must re-dimension array X in subroutine CORREL.	N
		6-10	Number of hourly lags, usually 10% of value for N above, maximum value = 800. The MIT is well-defined for this value even if N is increased.	NLAGS
Card 3	A1	1	Key indicating wet or dry weather hours; = W if wet weather data typed on rest of card; = D if dry weather hours follow.	IKEY

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
	15F5.0	6-10 11-15 16-20 : 76-80	If IKEY = W, type up to 15 consecutive hourly wet weather rainfall or runoff values. Units may be arbitrarily chosen by user; for example, hundredths of an inch. If there are more than 15 consecutive wet weather hours, repeat the wet-weather format of this card until all hourly values have been listed. If IKEY = D, then type the number of consecutive dry-weather hours in columns 6-10, leaving the rest of the card blank. NOTE: Card 3 may be repeated until all dry and wet weather events have been listed chronologically, with each dry-weather card being separated by one or more wet-weather cards.	DUMMY(J)

(<u>Blank</u> card is required to end Card Group II)

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
III			Input data common to both wet-weather and dry-weather flow models; four cards. Group is skipped if both IWWFM and IDWFM = 0.	
Card 4	3I5	1-5	Command to plot composite event DO profile at end of program. = 1, if plot desired. = 0, otherwise.	ITSAG
		6-10	Command to select DWF treatment rate combination (subscript J in MAIN) to be printed: must be either 1, 2, or 3. Example: = 1, primary; = 2, secondary; = 3, tertiary treatment rate.	IPR1
		11-15	Command to select upstream river flow fraction combination (subscript K in MAIN) to be printed: must be 1, 2, or 3.	IPR2
Card 5	F10.0	1-10	Total area of urban catchment, acres.	ATOT

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
	F10.2	11-20	Any distance downstream for which dissolved oxygen concentrations are to be computed, miles.	X
	F15.0	21-35	Longitudinal dispersion coefficient, $ft.^2/hour.^2$	E
	4F10.0	36-45	Average wastewater (DWF) treatment plant flow rate, cfs.	DWFX
		46-55	Wastewater treatment plant BOD influent concentration, mg/l.	DWFLO
		56-65	Upper bound for deoxygenation rate constant of carbonaceous BOD_5 @ 20°C, $hour^{-1}$.	XK1MAX
		66-75	Lower bound for deoxygenation rate constant of carbonaceous BOD_5 @ 20°C, $hour^{-1}$.	XK1MIN
	F5.2	76-80	Spatial increment (100 segments of length DX) at which DO concentrations are computed in	DX

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			receiving body of water per event, miles. NOTE: This parameter should be used if either or both ICALCX on Card 10 or ICALCD on Card 14 are greater than 0. If both of these parameters are 0, then leave DX blank.	
Card 6	6F5.0			
		1-5 6-10 11-15	Three values of BOD_5 <u>fraction</u> removed by DWF wastewater treatment facility, dimensionless. Example: 0.85 for 85% BOD removal.	TRTPCT
		16-20 21-25 26-30	Three <u>fractions</u> of measured upstream flow, dimensionless. Example: 0.50 for upstream flow which is 50% of actual measured value.	RF

TABLE VI-13. (Continued)

Card Groups	Format	Card Columns	Description	Variable Name
Card 7	6F6.0			
		1-6	Regression coefficient, dimensionless.[3]	ALPHA1
		7-12	Regression coefficient, dimensionless.[3]	ALPHA2
		13-18	Regression coefficient, dimensionless.[4]	BETA1
		19-24	Regression coefficient, dimensionless.[4]	BETA2
		25-30	Regression coefficient, dimensionless.[5]	GAMMA1
		31-36	Regression coefficient, dimensionless.[5]	GAMMA2
IV			Wet-weather flow model data requirements; variable number of cards. Group is skipped if IWWFM = 0.	

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
Card 8	20A4 20A4	1-80 1-80	Two title cards which print desired heading, such as urban catchment identification, on wet-weather flow model output; if none, insert two blank cards.	HEADNG
Card 9	4F10.0	1-10	Urban area served by separate sewers, acres.	ASEP
		11-20	Urban area served by combined sewers, acres.	ACOM
		21-30	Total hourly BOD load from municipal (DWF) wastewater, lbs BOD/hour.	DWBODX
		31-40	First flush factor, lbs BOD/DWH preceding first hour of runoff of each wet weather event.[6]	FFLBS
	3F5.0	41-45 46-50 51-55	Three fractions of BOD_5 removed by WWF treatment facility, dimensionless. Example: 0.75	TPCT

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			for 75% removal of BOD_5.	
Card 10	8I5	1-5	Minimum interevent time, hours. (not required if ICORR = 1)	MXT
		6-10	Control option command which identifies whether urban runoff BOD washoff values are supplied to the model as concentration or mass rate. = 1, BOD concentration. mg/l = 0, BOD mass rate, lbs/hour.	ICALC
		11-15	Control option command for DO frequency histogram (subroutine PLOT). = 0, no plot; = 1, critical DO frequency histogram is plotted; = 2, DO frequency histogram (at distance X downstream) is	ICALC1

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			plotted.	
		16-20	Control option command to plot cumulative DO frequency curves. = 1, subroutine MGRAPH called; = 0, no plot.	ICALC2
		21-25	Command to select WWF treatment rate combination (subscript L) to be printed. (value must be either 1,2, or 3)	IPR3
		26-30	Command to print matrices and plot DO concentration for each wet-weather event at 100 increments of DX miles downstream (see variable DX on Card 5): = 0, no plot; = 1, print matrices of 100 DO values for all 5 inflow combinations (subscript M): = 2, print matrices and plot profile of 100 values for all 5 inflow combinations;	ICALCX

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			= 3, print all matrices, but plot only DO profile for combination M = 1;	
			= 4, print all matrices, but plot only DO profile for combination M = 2;	
			= 5, print all matrices, but plot only DO profile for combination M = 3;	
			= 6, print all matrices, but plot only DO profile for combination M = 4;	
			= 7, print all matrices, but plot only DO profile for combination M = 5.	
		31-35	FORTRAN unit number for wet-weather scratch data set, needed only if ITSAG = 1; must be matched in the job control cards by	IDISKW

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			the corresponding file specification for the user's computer system.	
		36-40	Command to select one of 5 inflow combinations (subscript M) to be printed out on composite DO profile; needed only if ITSAG = 1; must be 1, 2, 3, 4, or 5.	IPR4
Card 11			This card is read if IPROG = 0, input from the cards only. The program interpolates linearly between the values on successive cards of Card Type 11. Repeat Card 11, if data is available, for each hourly urban runoff event.	
	I6	1-6	Six-digit integer number identifying month/day/year corresponding to input data on card. Example: 083168 refers to August 31, 1968.	IDATE

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
	2I5	11-15	Time of day (24 hour clock) identifying hour of the day corresponding to input data on card. Example: 13 refers to 1:00 P.M.	IHOUR
		16-20	Number of dry-weather hours (DWH) preceding an event.	IDWHX
	3F10.0	21-30	Stormwater runoff from urban catchment, cfs.	WWFX
		31-40	Urban runoff BOD_5 IF ICALC = 1 (see Card 10), expressed as concentration, mg/l. If ICALC = 0, expressed as mass rate, lbs/hour.	URBOD
		41-50	Receiving water discharge (streamflow), cfs.	QX
	3F5.0	51-55	Initial receiving water BOD_5 concentration, mg/l.	BODX

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
		56-60	Receiving water temperature, °C.	T
		61-65	Initial receiving water dissolved oxygen concentration, mg/l.	C
Card 12			This card is read if IPROG = 1, input from cards and SWMM tape.[7]	
	I6	1-6	Same as in Card 11.	IDATE
	2I5	11-15	Same as in Card 11.	IHOUR
		16-20	Dummy variable, the dry weather hours preceding an event are determined from continuous SWMM input tape. (No card input required for this variable)	IDUMMY
	3F10.0	21-30	Dummy variable, stormwater runoff if obtained directly from SWMM input tape. (No card input required for this variable)	DUM
		31-40	Dummy variable, BOD_5 mass rates or concentrations are read from SWMM input tape. (No card input required for	DUM

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			this variable)	
		41-50	Same as in Card 11.	QX
	3F5.0	51-55	Same as in Card 11.	BODX
		56-60	Same as in Card 11.	T
		61-65	Same as in Card 11.	C
Card 13			This card is read if IPROG = 2, input from cards and user-created data set.[8]	
	I6	1-6	Same as in Card 11.	IDATE
	2I5	11-15	Same as in Card 11.	IHOUR
		16-20	Same as in Card 11.	IDWHX
	3F10.0	21-30	Dummy variable, stormwater runoff read from user-created data set. (No card input required for this variable)	DUM
		31-40	Dummy variable, BOD_5 mass rates or concentrations read from user-created data set. (No card input required for this variable)	DUM

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
		41-50	Same as in Card 11.	QX
	3F5.0	51-55	Same as in Card 11.	BODX
		56-60	Same as in Card 11.	T
		61-65	Same as in Card 11.	C
	I6	1-6	Sentinel value, required as last card in group. = 999999	IDATEF
V			Dry-weather flow model data requirements: variable number of cards. Model operates on a daily (24-hour) time step.	
Card 14	6I5			
		1-5	Number of dry days to be simulated.	ND
		6-10	Control option command for DO frequency histogram (subroutine PLOT). = 0, no plot; = 1, critical DO	ICALC3

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			frequency histogram plotted; = 2, DO frequency histogram (at distance X downstream) plotted.	
		11-15	Control option command to plot cumulative DO frequency curves. = 1, subroutine MGRAPH executed; = 0, no plot.	ICALC4
		16-20	Command to print matrices and plot DO concentration for each dry-weather event at 100 increments of DX miles downstream (see variable DX on Card 5): = 0, no plot; = 1, print matrices of 100 DO values for all 3 DWF treatment rates (subscript J); = 2, print matrices and plot profile of 100 values for all 3 DWF treatment rates;	ICALCD

TABLE VI-13. (Continued)

Card Groups	Format	Card Columns	Description	Variable Name
			= 3, print all matrices, but plot only DO profile for treatment rate J = 1; = 4, print all matrices, but plot only DO profile for treatment rate J = 2; = 5, print all matrices, but plot only DO profile for treatment rate J = 3;	
		21-25	Command to select upstream river flow fraction (subscript K) to be printed with D.O. profile downstream; needed only if ICALCD = 0. (Value equals 1, 2, or 3.	IPRD
		26-30	FORTRAN unit number for dry-weather scratch data set; needed only if ITSAG = 1; must be matched in the job control cards by the corresponding file specification	IDISKD

TABLE VI-13. (Continued)

Card Group	Format	Card Columns	Description	Variable Name
			for the user's computer system.	
Card 15			Receiving water quantity and quality parameters.	
	I6	1-6	Six-digit integer number identifying month/day/year corresponding to input data on card.	IDATE
	4F10.0	11-20	Receiving water flow (upstream), cfs.	RFLOW
		21-30	Initial receiving water BOD_5 concentration, mg/l.	RBOD
		31-40	Receiving water temperature, °C	RTEMP
		41-50	Initial DO concentration upstream from waste source, mg/l.	RDO
			NOTE: Repeat Card 15 according to the number of dry days (ND) specified by the user in Card 14.	

Table VI-13. (Continued)

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[2]See Table VI-2 for typical range of values, from streams to tidal rivers and estuaries.

[3]User may determine these coefficients from available data, or assume reasonable values and adjust during the calibration process. The coefficients are related to velocity and discharge by:

$$U = \alpha_1 \, Q^{\alpha_2} \qquad \text{(IV-40)}$$

[4]Determined as above, these coefficients are related to depth and discharge by:

$$H = \beta_1 \, Q^{\beta_2} \qquad \text{(IV-41)}$$

[5]Determined as above, these coefficients are related to deoxygenation rate constant carbonaceous BOD_5 @ 20°C and depth by:

$$K_1 = \gamma_1 \, H^{\gamma_2} \qquad \text{(IV-37)}$$

[6]An example calculation for this factor is provided in Section VI.

[7]Interfacing of this model with continuous SWMM is discussed in further detail in Section V.

[8]When IPROG > 0, IFILE is required and specifies the input device number. The data read from the data set correspond

Table VI-13. (Continued)

to WWFX (stormwater runoff, cfs) and URBOD (either BOD_5 mass rate in lbs/hour or concentration in mg/l), respectively: using a FORMAT (F8.1, 2X, F10.1) specification. Refer to program statements MAIN3390 and MAIN3400, Appendix B.

NOTE: The user must insure that program statements MAIN0390 and MAIN0400 (corresponding to FORTRAN statement numbers 1 and 2, respectively) identify the appropriate reference numbers for card input (INPT) and printer output (IOUT). For operation through the Triangle Universities Computation Center (TUCC) and the Duke University Computation Center (DUCC), they are:

INPT = 1

IOUT = 3

Other installations often use:

INPT = 5

IOUT = 6

SECTION VII

ABBREVIATIONS AND SYMBOLS

A_c	Area served by combined sewers, acres
A_s	Area served by separate sewers, acres
A_s	Mean water surface area between Y_1 and Y_t
A_t	Total area of catchment, acres
AR_u	Urban area runoff, inches per hour
α	Infiltration decay coefficient
α_d	Infiltration decay coefficient for the recovery curve
α_1, α_2	Regression coefficients
B	Benthal demand of bottom deposits, mg per 1-hour
BOD	Biochemical oxygen demand, mg/l
BOD_c	Mixed BOD concentration in the combined sewer, mg/l
BOD_d	BOD concentration of wet-weather flow treatment facility effluent, mg/l
BOD_f	BOD concentration of municipal sewage, mg/l
BOD_m	Mixed BOD concentration in receiving water, mg/l
BOD_s	BOD concentration of urban stormwater runoff, mg/l
BOD_t	Hourly BOD concentration of total urban runoff, mg/l
BOD_u	Mixed BOD concentration from sources upstream of urban area, mg/l
BOD_w	BOD concentration of treated wet-weather effluent, mg/l

BOD_5	Standard BOD test, 5 days at 68°F (20°C), mg/l
β_1, β_2	Regression coefficients
C	Concentration of water quality parameter, M/L^3
C	Concentration of dissolved oxygen (DO) in the stream, mg/l
C_{min}	Concentration of DO at maximum deficit, mg/l
C_s	Saturation concentration of DO, mg/l
CBOD	Carbonaceous biochemical oxygen demand
CR_u	Composite runoff coefficient dependent on urban land use
C_1	Conversion factor, pounds per hour to mg/l · cfs
D	Dissolved oxygen deficit = C_s - C, mg/l
D_c	Critical (maximum) deficit, mg/l
D_d	Detention depth
D_o	Initial DO deficit, mg/l
D_t	Water depth at time t
D_u	DO deficit in receiving waters upstream of inflow point, mg/l
DO	Dissolved oxygen
DWF	Dry-weather flow, cfs
DWFCMB	DWF contribution from combined sewer area, cfs
DWFSEP	Dry-weather flow contribution from separate sewer area, cfs
DWH	Number of dry-weather hours preceding each runoff event
D_1	Water depth after rainfall
D_2	Depth after infiltration
Δt	Time interval

E	Longitudinal dispersion coefficient, $feet^2$ per second
f	Self-purification ratio, K_2/K_1
f_{cap}	Infiltration capacity into soil
$\bar{f}_{cap}$	Average infiltration capacity over time interval Δt
f_{∞}	Minimum or ultimate value of infiltration capacity (at $t = \infty$)
f_o	Maximum or initial value of infiltration capacity (at $t = 0$)
f_u	Available urban depression storage, inches
FF	First flush BOD load, pounds per hour
FFLBS	First flush factor, pounds/hour per DWH
$F_X(x_i)$	Cumulative distribution function (CDF)
$f_X(x)$	Probability density function (PDF)
$G_X(x)$	Complement of the cumulative distribution function, expected number of occurrences greater than or equal to given magnitude
γ_1, γ_2	Regression coefficients
H	Stream depth, feet
$\bar{I}$	Average rainfall intensity over the time step
$\bar{I}_t$	Average actual infiltration over the time step
k	Number of hourly lags
k	Pollutant decay constant, directly proportional to the rate of runoff
K_n	Oxidation coefficient of nitrogenous BOD, $hours^{-1}$
K_1	Deoxygenation constant of carbonaceous BOD, $hours^{-1}$

K_2	Atmospheric reaeration coefficient, $hours^{-1}$
L	Remaining carbonaceous BOD concentration, mg/l
L_o	Mixed BOD concentration in the river, mg/l
$(L_o)_c$	Ultimate first-stage BOD demand, mg/l
$M(t_p)$	Cumulative infiltration at time t_p
n	Total number of data points or observations of a hydrologic process
n	Manning's Coefficient
N	Remaining nitrogenous BOD concentration, mg/l
N	Total number of observations of event X
n_i	Cumulative frequency of occurrence (successive partial sums) in class interval i
n_1	Number of occurrences of event of magnitude x_1
N_o	Magnitude of nitrogenous demand
NBOD	Nitrogenous biochemical oxygen demand
P	Pollutant after time t, mg
P	Oxygen production rate by algal photosynthesis, mg/l-hour
P_o	Pollutant originally on ground, mg
P_u	Hourly rainfall-snowmelt in inches over the urban area
$P_X(x_i)$	Probability mass function (PMF)
Q	Streamflow, cfs
Q_c	Combined sewer flow, cfs
Q_d	DWF treated effluent, cfs
Q_{in}	Gutter inflow

Q_s	Urban runoff carried by the separate storm sewer, cfs
Q_t	Total (storm plus combined) urban runoff, cfs
Q_u	Upstream flow, cfs
Q_w	Wet-weather flow (WWF) treated effluent, cfs
Q_w	Subcatchment outflow
R	Hydraulic radius
R_d	Fraction removal of BOD achieved by the DWF treatment facility
R_e	Algal respiration rate, mg/l-hour
$r_I(k)$	Sample estimate of lag-k autocorrelation coefficient for rainfall
R_o	Deficit load ratio = D_o/L_o
$r_Q(k)$	Sample estimate of lag-k autocorrelation coefficient for runoff
R_w	Fraction removal of BOD achieved by the WWF treatment facility
S	Sources and sinks of the substance C, M/L^3T
S	Ground slope
S_i	Invert slope
T	Stream temperature, °C
TKN	Total Kjeldahl nitrogen
t	Time, hours or days
t_c	Elapsed time at which critical deficit occurs, hours or days
t_w	Hypothetical projected time at which $f_{cap} = f_\infty$ on the recovery curve
TL $[r_I(k)]$	Tolerance limits at a 95 percent probability level
U	Flow velocity in stream, feet per second

u	Dummy variable of integration
V	Subcatchment velocity of flow
$\forall$	Volume of DO deficit, mg-hours/l or mg-day/l
WWF	Wet-weather flow, cfs
x	Distance downstream, feet or miles
x	Magnitude of hydrologic event
x_i	Discrete data series (observations) of a hydrologic process
X	A hydrologic event
Y_l, Y_t	Water depths in gutter

SECTION VIII

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SECTION IX

GLOSSARY

Antecedent conditions: Initial conditions in catchment as determined from hydrologic events prior to storm.

Biological treatment processes: Means of treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Trickling filters, activated sludge processes and lagoons are examples.

Catchment: Surface drainage area.

Combined sewage: Sewage containing both domestic sewage and surface water or stormwater, with or without industrial wastes. Includes flow in heavily infiltrated sanitary sewer systems as well as combined sewer systems.

Combined sewer: A sewer receiving both intercepted surface runoff and municipal sewage.

Combined sewer overflow: Flow from a combined sewer in excess of the interceptor capacity that is discharged into a receiving water.

Conservative: Non-interacting substance, undergoing no kinetic reaction; examples are salinity, total dissolved solids, total nitrogen, total phosphorus.

Depression Storage: Amount of precipitation which can fall on an area without causing runoff.

Detention: The slowing, dampening, or attenuating of flows either entering the sewer system or within the sewer system by temporarily holding the water on a surface area, in a storage basin, or within the sewer itself.

Domestic sewage: Sewage derived principally from dwellings, business buildings, institutions, and the like. It may not contain groundwater.

First flush: The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

Frequency diagram: Curve which relates the number of occurrences of events to their magnitude.

Initial abstraction: Initial precipitation loss including interception and depression storage.

In-system: Within the physical confines of the sewer pipe network.

Interception: Initial loss of precipitation due to vegetation.

Non-conservative: Substance undergoing kinetic interaction, assumed to be a first-order reaction; examples are biochemical oxygen demand (BOD), coliform bacteria, dissolved oxygen (DO).

Physical-chemical treatment processes: Means of treatment in which the removal of pollutants is brought about primarily by chemical clarification in conjunction with physical processes. The process string generally includes preliminary treatment, chemical clarification, filtration, carbon adsorption, and disinfection.

Pollutant: Any harmful or objectionable material in, or change in, physical characteristic of water or sewage.

Precipitation event: A precipitation event terminates if zero rainfall has been recorded for the previous specified time interval.

Primary treatment: Process which removes about 30% of the biochemical oxygen demand of the waste.

Retention: The prevention of runoff from entering the sewer system by storing on a surface area or in a storage basin.

Runoff coefficient: Fraction of rainfall that appears as runoff after subtracting depression storage and interception. Typically accounts for infiltration into ground and evaporation.

Sanitary sewer: A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with relatively low quantities of ground, storm, and surface waters that are not admitted intentionally.

Secondary treatment: Process which removes about 85% of the biochemical oxygen demand of the waste.

Sewer: A pipe or conduit generally closed, but normally not flowing full, for carrying sewage or other waste liquids.

Sewerage: System of piping, with appurtenances, for collecting and conveying wastewaters from source to discharge.

Storm flow: Overland flow, sewer flow, or receiving stream flow caused totally or partially by surface runoff or snowmelt.

Storm sewer: A sewer that carries intercepted surface runoff, street wash and other wash waters, or drainage, but excludes domestic sewage and industrial wastes.

Storm sewer discharge: Flow from a storm sewer that is discharged into a receiving water.

Stormwater: Water resulting from precipitation which either percolates into the soil, runs off freely from the surface, or is captured by storm sewer, combined sewer, and to a limited degree, sanitary sewer facilities.

Surface runoff: Precipitation that falls onto the surfaces of roofs, streets, ground, etc., and is not absorbed or retained by that surface, thereby collecting and running off.

Tertiary treatment: Process which removes about 95% of the biochemical oxygen demand of the waste.

Urbanized area: Central city, or cities, and surrounding closely settled territory, which has a population of 50,000 or more. Peripheral areas with population density of 1,000 persons per acre or more are included.

Urban runoff: Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Wastewater: The spent water of a community.

APPENDIX A

STORM Input Data and Load Module Job Control Language

```
//STORM   JOB   DU.D06.AT4119,MEDINA,T=1,P=50,M=1,R=300K,PRTY=2
//    EXEC    PGM=STORM
//STEPLIB  DD   DSN=DU.D06.AT4096.MEDINA.STORM1,DISP=SHR,UNIT=DISK,
//    VOL=SER=DUK8BB
//G.FT06F001   DD   SYSOUT=A
//G.FT11F001   DD   UNIT=SYSDA,SPACE=(CYL,(2,1),RLSE)
//G.FT12F001   DD   UNIT=SYSDA,SPACE=(CYL,(2,1),RLSE)
//G.FT13F001   DD   SYSOUT=A,DCB=(RECFM=FA,LRECL=133,BLKSIZE=133)
//G.FT14F001   DD   SYSOUT=A,DCB=(RECFM=FA,LRECL=133,BLKSIZE=133)
//G.FT15F001   DD   SYSOUT=A,DCB=(RECFM=FA,LRECL=133,BLKSIZE=133)
//G.FT05F001   DD   *
A1                               STORM
A2                 STORM RUN ON ENTIRE AREA OF DES MOINES
A3                        DES MOINES,IOWA
B1     1       0       0       1       1
B2    42       3       1 680112
C1 DES MOINES                          5          680308              1
C2680308        2  6  7 29  9 12  6  2
C2680319              6  3  1
C2680403                10 14        1              4
C2680412                                                    22
C2680414  7 12  6  6  2
C2680416                       2                                   2  1  2
C2680418        8  8 22  4
C2680419                             4  7    13  3  5  3  3  6 12 24  1  5  6  1
C2680422           16  2                                3  1  1  4 10 18 20 14 14
C2680423 11  5  2  9  4  3  7 10  8  9  7  2  4
C2680507                             2  4  2  1  2       17
C2680513                                                    17 29
C2680514 12  2
C2680515                                                4        2  1
C2680518                                             1     2              2  2
C2680522                                                         1  1  6
C2680525  4  1                          6  2  3  6  2     1  2              16
C2680526 12  5           3
C2680528                                                   6 13
C2680531                            11 21  9  7  2             3 11  1
C2680610                                             6  9 31 50 13 15  7     4
C2680613                                                                        9
C2680623                                                               2  6
C2680624                                       1      59
C2680625                                                      3  3  1  2  1  2
C2680629           46 12 16 16
C2680706                                              32 28 21
C2680708                                                              20 38 47
C2680716                       1    10 20  7  3  1
C2680717           2  4  5
C2680723                                      133  2  1 21        2  2  2
C2680727       13  1  1
C2680731 16  5  3
C2680804                    1        7
C2680807                    3 11 13  1
C2680808                 54116  5     1  2
C2680815                      16  5
C2680816        2  2     2 12
C2680818                          2  1  1  1  2  8
C2680826                               112 11 22 16 13  3  1
C2680830        1  6  1  2        6  9  6  2              5  6  5
C2680831                                                         5
C2680903                                                   4             14    14
C2680904 43 13  4 16  2           1     1
C2680905                                      3  2  1  1             10 20  4  1
C2680916                                                1 20  9
C2680920
C2680928           2  3  2
C2680929     19 14 18  4
C2681005                       1     1        1  4  8  5  3  3  6  7  6  4  3  4
C2681008                                      1  6  1              1
C2681009 20  5  5  9 18  3
C2681017    18  4                                                 1  1     1  2  3  2
C2681105
C2681106  1  2        1  2  1              1
```

```
C2681110  6  6  6  6  7  6 12 12 12 12 12 11  4  4  4  4  4  3  1  1  1  1  1  1
C2681114                                                        1  4  3  5
C2681116                    2  3  3  5  3  1        1
C2681218                             1                 12 29 33 11
C2681219  1     1  2  1  1  2  2  2
C2681221                                                  2  2  1  1  2  2  1  1
C2681222  2  3  3  2  2  1                             1              1
C2681227           1  2  2  1  1  1           2  1  1  1  2     1  1     1  1  2
C2681230              1  1  1        2  2
C2
E1 DES MOINES          5     4.6    0.70
E2 49000      1.
E3   0.0     0.0    0.01    0.06    0.12    0.17    0.21     0.0     0.0     0.0
E3  0.18    0.12
E4     1     .15      .9     .01
F1SINGLE    34.6    25.9     119      55
F2  1.71      48      42   4.400    0.87    0.16
F1MULTPL    16.1    27.6     161      50
F2  1.84      49      41   4.600    0.81    0.16
F1COMMCL    16.3    29.6     201      45
F2  1.91      50      41   4.800    0.76    0.16
F1INDSTL    17.1    35.4     288      40
F2  2.04      53      39   5.200    0.62    0.15
F1OPEN      16.0    41.7     347      37
F2  1.98      54      39   5.200    0.56    0.15
T1     1
T2   0.0       1      20       0       3                                       1
T3   0.0
T4    41      42      43      44      45      46      47      48      49      50
T4    51      52      53      54      55      56      57      58      59      60
/*
//*PW=IMPACT1
//
T2   0.0       1       6       0       3                       1
T4     1       2       3       4       5       6       7       8       9      10
T4    11      12      13      14      15      16      17      18      19      20
T4    21      22      23      24      25      26      27      28      29      30
T4    31      32      33      34      35      36      37      38      39      40
T4    61      62      63      64      65      66      67      68      69      70
T4    71      72      73      74      75      76      77      78      79      80
T4    81      82      83      84      85      86
```

```
      COMMON INPT,IOUT
      COMMON/SET1/ MIT
      COMMON/SET2/ATOT,DWFX,PCTTRT(3),DWFLO,X,E,ALPHA1,ALPHA2,BETA1,
     1 BETA2,RF(3),DX,TRTPCT(3),ITSAG,IDISKW,IDISKD,IPR1,IPR2,IPR3,IPR4,
     2 XK1MAX,XK1MIN,GAMMA1,GAMMA2
      COMMON/SET3/ DATA1(31,5,3,3,3),HEADNG(40),PCT(3),FLO(5,3),FL(5,3),
     1 XK2T(5,3),QU(3),DO(5,3),U(5,3),F(5,3),V(5,3),TF(5,3),TPCT(3),
     2 ULTLO(5,3,3,3),XG(5,3),POLL2(3,50),PCTG(5,31),CG(31),
     3 QQ2(50),JINNS(50),CCDIST(5),F1(5,3),F2(5,3),XM1(5,3),XM2(5,3),
     4 XJ(5,3),XDG(101),XD,TX,DTX,DTXCN,DOXDX(5,101),DOXDX1(101),
     5 XM12(5,3),H(5,3),DENOM(5,3),XK1T(5,3),DUMMY(3971)
      DIMENSION MONTH(12),JKEY(3),KKEY(3),LKEY(3)
      INTEGER STITLE(20),COMKEY(5),TITLE1(20),YTITL1(51),LABEL1(20),
     1        HEADNG
      DATA COMKEY/'1','2','3','4','5'/
      DATA STITLE/'DISS','OLVE','D OX','YGEN',' PRO','FILE',
     1 ' :  ','J=1 ','K=1 ','L=1 ','    ','COMB','INAT','ION ',
     2 '1   ',5*'    '/
      DATA TITLE1/'DISS','OLVE','D OX','YGEN',' PRO','FILE','S : ',
     1 'J=1 ','K=1 ','L=1 ',10*'    '/
      DATA YTITL1/'D','I','S','S','O','L','V','E','D',' ','O',
     1 'X','Y','G','E','N',' ','C','O','N','C','E','N','T','R',
     2 'A','T','I','O','N',',',' ','M','G','/','L',15*' '/
      DATA LABEL1/'DIST','ANCE',' DOW','NSTR','EAM,',' MIL',
     1 'ES  ',13*'    '/
      INTEGER FREQ(31),TITLE(20),YTITLE(51),LABEL(20)
      DATA MONTH/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA JKEY/'J=1 ','J=2 ','J=3 '/,KKEY/'K=1 ','K=2 ','K=3 '/,
     1 LKEY/'L=1 ','L=2 ','L=3 '/
      DATA TITLE/'NORM','ALIZ','ED C','UMUL','ATIV','E : ',
     1 'J=1 ','K=1 ','L=1 ',11*'    '/
      DATA YTITLE/'%',' ','W','E','T',' ','W','E','A','T','H','E',
     1 'R',' ','E','V','E','N','T','S',' ','E','X','C','E','E',
     2 'D','I','N','G',' ','G','I','V','E','N',' ','V','A','L',
     3 'U','E',9*' '/
      DATA LABEL/'DO C','ONCE','NTRA','TION',', MG','/L  ',' 0<-',
     1 '----','--->','15.0',':   ','0.5 ','STEP','S   ',6*'    '/
C
    1 INPT=1
    2 IOUT=3
C
      IDISKW=0
      IDISKD=0
      WRITE(IOUT,410)
  410 FORMAT(/////////////)
      WRITE(IOUT,412)
  412 FORMAT(1H0,25(1H.),10X,52H *        *****  *    *  *****  *         ***
     . *** ***      ,10X,25(1H.)/1X,25(1H.),10X,52H *        *       *    *  *
     .        *          *   *    *          ,10X,25(1H.)/1X,25(1H.),10X,52H *
     .  ***     *     *  ***      *          *    *    *  ***,10X,25(1H.)/1X,25(1
```

```
     .H.),10X,52H *        *         * *    *        *          *    *    *       ,10
     .X,25(1H.)/1X,25(1H.),10X,52H *****   *****      *     *****  *****     *
     .** *** ***       ,10X,25(1H.)/1X,25(1H.),72X,25(1H.)/1X,25(1H.),7X,58
     .H ****     *****   *****   *****   ***   *    *   ***   *    *  *****,7X,25(
     .1H.)/1X,25(1H.),7X,58H *    *   *      *       *        *    *    *    *
     .   **   *   *      ,7X,25(1H.)/1X,25(1H.),7X,58H ****    ***       *       *
     .**        *     *     *     *     * * *  *   **,7X,25(1H.)/1X,25(1H.),7X,58H *
     .   *     *        *        *          *      * *      *    *   **   *    *,7X,25(1H.
     .)/1X,25(1H.),7X,58H *    *  *****  *****  *****  ***      *     ***   *
     .     *   *****,7X,25(1H.)///////)
      WRITE(IOUT,415)
  415 FORMAT(35X,55H *******************************************************
     .***/35X,55H **         FOR INFORMATION AND ASSISTANCE:                **
     ./35X,55H **         DR. MIGUEL A. MEDINA,JR.                  **/35
     .X,55H ** DEPT. OF CIVIL ENGINEERING, DUKE UNIVERSITY        **/35X,5
     .5H ** DURHAM,N.C.    TELEPHONE:  919-684-2434, EXT. 46   **/35X,
     .55H **                         -OR-                         **/35X,55H
     . **                 DR. WAYNE C. HUBER                   **/
     .35X,55H **  DEP'T. OF ENV. ENG. SCIENCES, UNIV. OF FLORIDA  **/
     .35X,55H **  GAINESVILLE, FLA.      TELEPHONE: 904-392-0846  **/
     .35X,55H *******************************************************,
     .//////)
      WRITE(IOUT,416)
  416 FORMAT(' ',47X,30('*')/' ',47X,'**',26X,'**'/' ',47X,
     1 '** VERSION: SEPTEMBER, 1978 **',/' ',47X,'**',26X,'**'/' ',
     2 47X,30('*'))
C
C
C         IPROG   =0= INPUT FROM CARDS ONLY.
C                 =1= INPUT FROM CARDS AND SWMM.
C                 =2= INPUT FROM CARDS AND USER CREATED DATA SET.
C
C         IFILE   =0= NO INPUT FROM DATA SET.
C                 =N= DATA SET UNIT NUMBER "N". (REQUIRED IF IPROG.GT.0).
C
C         JNS     =   INPUT JUNCTION NUMBER. (REQUIRED IF IPROG = 1).
C
C
C>>>>>>>> READ CARD TYPE  1 <<<<<<<<
C
      READ(INPT,420) ICORR,IWWFM,IDWFM,IPROG,IFILE,JNS
  420 FORMAT(6I5)
C
      IF (ICORR.EQ.1) CALL CORREL
C***********************************************************************
C
      IF(ICORR.EQ.1.AND.IWWFM.EQ.0.AND.IDWFM.EQ.0)  GO TO 9999
C
C
C>>>>>>>> READ CARD TYPE 4 <<<<<<<<
```

```
C
      READ(INPT,422) ITSAG,IPR1,IPR2
  422 FORMAT(3I5)
C
C>>>>>>>> READ CARD TYPE  5 <<<<<<<<
C
      READ(INPT,425) ATOT,X,E,DWFX,DWFLC,XK1MAX,XK1MIN,DX
  425 FORMAT(F10.0,F10.2,F15.0,4F10.0,F5.2)
C
C          CONVERSION FROM MILES TO FEET
C
      X=X*5280.0
C
C
C>>>>>>>> READ CARD TYPE  6 <<<<<<<<
C
      READ(INPT,430) TRTPCT,RF
  430 FORMAT(6F5.0)
      DO 431 J=1,3
         PCTTRT(J)=1.-TRTPCT(J)
  431 CONTINUE
C
C
C>>>>>>>> READ CARD TYPE  7 <<<<<<<<
C
      READ(INPT,435) ALPHA1,ALPHA2,BETA1,BETA2,GAMMA1,GAMMA2
  435 FORMAT(6F6.0)
C
      WRITE(IOUT,440)
  440 FORMAT(1H1)
      WRITE(IOUT,443)
  443 FORMAT(1H ,87(1H*))
      WRITE(IOUT,445)
  445 FORMAT(' **        COMMON INPUT DATA FOR WET-WEATHER ',
     1 'FLOW AND DRY-WEATHER FLOW MODELS              **')
      WRITE(IOUT,447)
  447 FORMAT(1H ,87(1H*),//,1H ,87(1H*))
      WRITE(IOUT,450)      IWWFM,IDWFM
  450 FORMAT(10H ** IWWFM=,I1,11H      IDWFM=,I1,62X,3H **)
      WRITE(IOUT,455)ATOT,X,E
  455 FORMAT(9H ** ATOT=,F10.1,12H  ACRES    X=,F10.1,11H  FEET    E=,
     .F20.1,16H  FT**2/HOUR  **)
      WRITE(IOUT,457) DX,ITSAG,IPR1,IPR2
  457 FORMAT(' ** DX=',F10.2,5X,'ITSAG=',I5,5X,'IPR1=',I5,5X,'IPR2=',
     1 I5,T87,'**')
      WRITE(IOUT,460)DWFX,DWFLO,XK1MAX
  460 FORMAT(9H ** DWFX=,F15.2,14H  CFS    DWFLC=,F10.2,16H  MG/L    XK1MA
     .X=,F6.4,18H  1/HOUR        **)
      WRITE(IOUT,465)TRTPCT,XK1MIN
  465 FORMAT(11H ** PCTTRT=,3F8.2,21X,8H XK1MIN=,F6.4,7H 1/HOUR,9X,2H**)
```

```
      WRITE(IOUT,470)RF,GAMMA1,GAMMA2
  470 FORMAT(7H ** RF=,3F8.2,5X,8H GAMMA1=,F6.3,11H    GAMMA2=,F6.3,18X,
     13H **)
      WRITE(IOUT,477)ALPHA1,ALPHA2,BETA1,BETA2
  477 FORMAT(11H ** ALPHA1=,F5.3,10H    ALPHA2=,F5.3,9H    BETA1=,F5.3,9H
     .   BETA2=,F5.3,26X,3H **)
      WRITE(IOUT,443)
C
      IF(IWWFM.NE.1) GO TO 750
C
C******** WET WEATHER FLOW MODEL
C
C
C>>>>>>>> READ CARD TYPE  8 <<<<<<<<
C
      READ(INPT,500) (HEADNG(I),I=1,40)
  500 FORMAT(20A4)
C
C
C>>>>>>>> READ CARD TYPE  9 <<<<<<<<
C
      READ(INPT,505) ASEP,ACOM,DWBODX,FFLBS,TPCT
  505 FORMAT(4F10.0,3F5.0)
      DO 506 L=1,3
           PCT(L)=1.-TPCT(L)
  506 CONTINUE
C
C
C>>>>>>>> READ CARD TYPE 10 <<<<<<<<
C
      READ(INPT,510) MXT,ICALC,ICALC1,ICALC2,IPR3,ICALCX,IDISKW,IPR4
  510 FORMAT(8I5)
      IF (IDISKW.GT.0) REWIND IDISKW
      IF(ICORR.NE.1) MIT = MXT
      TITLE1(8)=JKEY(IPR1)
      STITLE(8)=JKEY(IPR1)
      TITLE1(9)=KKEY(IPR2)
      STITLE(9)=KKEY(IPR2)
      TITLE1(10)=LKEY(IPR3)
      STITLE(10)=LKEY(IPR3)
C
      DO 560 M=1,5
      DCDIST(M)=0.0
  560 CONTINUE
      DO 566 II=1,31
      DO 566 M=1,5
      DO 566 J=1,3
      DO 566 K=1,3
      DO 566 L=1,3
      DATA1(II,M,J,K,L) = 0.0
```

```
  566 CONTINUE
C
      JNSS = JNS
C
      IF(IPROG.NE.1) GO TO 568
C
C********* SWMM INPUT
C
      IF(IFILE.EQ.0) GO TO 9999
      JNS = 0
      REWIND IFILE
      READ(IFILE) (HEADNG(I),I=1,40)
      READ(IFILE) NDT,NOUTS,NPOLL,DTT,TZERC,TRIBA
      READ(IFILE) (JINNS(I),I=1,NOUTS)
      DO 567 I = 1,NOUTS
      IF(JNSS.NE.JINNS(I)) GO TO 567
      JNS = I
      GO TO 568
  567 CONTINUE
C
      IF(JNS.EQ.0) GO TO 9999
C
  568 WRITE(IOUT,600)
  600 FORMAT(//////////,1H ,100(1H*))
      WRITE(IOUT,610) (HEADNG(I),I=1,40)
  610 FORMAT(9H ********,2X,20A4,10H  ********)
      WRITE(IOUT,615)
  615 FORMAT(1H ,100(1H*))
      WRITE(IOUT,635)
  635 FORMAT(////,1H ,72(1H*))
      WRITE(IOUT,640)
  640 FORMAT(37H ** WET-WEATHER FLOW MODEL INPUT DATA,33X,3H **)
      WRITE(IOUT,643)
  643 FORMAT(1H ,72(1H*),// ,1H ,72(1H*))
      WRITE(IOUT,644) IPRCG,IFILE,JNSS
  644 FORMAT(11H ** IPROG =,I2,3X,8H IFILF =,I3,3X,6H JNS =,I5,30X,2H**)
      WRITE(IOUT,645)ASEP,ACOM
  645 FORMAT(9H ** ASEP=,F20.1,15H ACRES ** ACON=,F20.1,9H ACRES **)
      WRITE(IOUT,650)DWBODX,FFLBS
  650 FORMAT(11H ** DWBODX=,F15.2,21H LBS/BOD/HR ** FFLBS=,F10.2,16H LBS
     . BOD-5/DWH**)
      WRITE(IOUT,652) TPCT
  652 FORMAT(8H ** PCT=,3F8.2,38X,3H **)
      IF(ICORR.NE.1) WRITE(IOUT,656) MIT
  656 FORMAT(35H ** MIT OR MINIMUM INTEPEVENT TIME=,I4,6H HOURS,25X,3H *
     .*)
      WRITE(IOUT,660)ICALC,ICALC1,ICALC2,ICALCX
  660 FORMAT(10H ** ICALC=,I5,8H ICALC1=,I5,8H ICALC2=,I5,8H ICALCX=,
     1   I5,17X,2H**)
      WRITE(IOUT,665)           IPR3,IDISKW,IPR4
```

```
  665 FORMAT(' ** IPR3=',I5,' IDISKW=',I5,' IPR4=',I5,T72,'**')
      WRITE(IOUT,670)
  670 FORMAT(1H ,72(1H*),/////)
C
C
      IC=0
      ID=0
      IL=0
      IDWH = 0
      IDWHX = 0
      IDWH1 = 0
      IJUMP = 0
      ITIME = 0
      ITIMEX = 0
      IDATE8 = 0
      IDATE9 = 0
      IDWHXF = 0
      IDWHRS = 0
      IDWHXP = 0
      IHOURF = 0
      IHOURX = 0
      ISTART = 0
      Q=0.0
      RC=0.0
      RT=0.0
      DWF=0.0
      WWF=0.0
      RBOD=0.0
      TIME = 0.0
      ASUM1=0.0
      ASUM2=0.0
      ASUM7=0.0
      DWBOD=0.0
      URLBS=0.0
      ABODCB=0.0
      ABODSP=0.0
      AFLCMB=0.0
      AFLSEP=0.0
      ANAVFL=0.0
      SUMCMB=0.0
      CKQ = 0.0
      CKRC = 0.0
      CKRT = 0.0
      CKDWB = 0.0
      CKDWF = 0.0
      CKWWF = 0.0
      CKRBOD = 0.0
      CKURLB = 0.0
      Z=3600.0
      D=X/5280.
```

```
C
C
C>>>>>>>> READ CARD TYPE 11 <<<<<<<<
C
      IF(IPROG.EQ.0) READ(INPT,515) IDATE,IHOUR,IDWHX,WWFX,URBOD,OX,
     1 BODX,T,C
  515 FORMAT(I6,4X,2I5,3F10.0,3F5.0)
C
C
C>>>>>>>> READ CARD TYPE 12 <<<<<<<<
C
      IF(IPROG.EQ.2) READ(INPT,515) IDATE,IHOUR,IDWHX,DUM,DUM,OX,
     1 BODX,T,C
C
      IF(IPROG.NE.1) GO TO 14
C
C******** SWMM INPUT
C
C
C>>>>>>>> READ CARD TYPE 13 <<<<<<<<
C
      READ(INPT,515) IDATE,IHOUR,IDUMMY,DUM,DUM,OX,BODX,T,C
C
      ITIME = IHOUR
      IHOURP = IHOUR
      IDATEF = IDATE
      IDATE8 = IDATE
      IDATE9 = IDATE
C
      READ(IFILE,END=9999) TIME,(QQ2(J),J=1,NOUTS),((POLL2(K,J),
     1K=1,NPOLL),J=1,NOUTS)
      WWFX = QQ2(JNS)
      URBOD = POLL2(1,JNS) * 60.0
      IF(WWFX.EQ.0.0) IDWHRS = 1
      IDWHXP = IDWHRS
      IDWH1 = IDWHXP
C
   14 IF (IPROG.EQ.2) READ(IFILE,571) WWFX,URBOD
  571 FORMAT(F8.1,2X,F10.1)
C
      NEVT= 999999
      IEND = 0
      ISKIP = 0
C
C  ****************************************
C  ***                                  ***
C  ***        MAJOR EVENT LOOP          ***
C  ***                                  ***
C  ****************************************
C
```

```
      DO 999 I = 1,NEVT
   15 IF(IEND.EQ.1) GO TO 9998
C
      IL = IL + 1
C
      IF(ISKIP.EQ.0) GO TO 39
      ITIME = ITIMEX
      IDATE8 = IDATE9
      WWFX = WWFXF
      URBOD = URBODF
C
      IF(IPROG.EQ.1.AND.(IDATEF.NE.IDATE8.OR.IHCURF.GT.ITIME)) GO TO 39
      IF(IPROG.EQ.1) GO TO 38
C
      IHOUR = IHOURF
      IDATE = IDATEF
      IDWHX = IDWHXF
   38 C = CF
      T = TF
      QX = QXF
      BODX = BODXF
C
   39 ISKIP = 1
      DCNCTX = 0.0
      IF(ICALC.EQ.1) DCNCTX = URBOD
      IF(ICALC.EQ.0.AND.WWFX.NE.0.0) DCNCTX = URBOD * 4.4491 / WWFX
      DURBOD = URBOD
      IF(ICALC.EQ.1) DURBOD = URBOD * WWFX / 4.4491
C
C
C>>>>>>>> READ CARD TYPE 11 <<<<<<<<
C
      IF(IPROG.EQ.0)READ(INPT,515,END=45) IDATEF,IHOURF,IDWHXF,WWFXF,
     1 URBODF,QXF,BODXF,TF,CF
C
      IF(IPROG.EQ.0) GO TO 47
C
C
C>>>>>>>> READ CARD TYPE 12 <<<<<<<<
C
      IF(IPROG.EQ.1.AND.IDATEF.EQ.IDATE8.AND.IHCURF.LE.ITIME)
     1READ(INPT,515,END=45)  IDATEF,IHOURF,IDUMMY,DUMF,DUMF,QXF,BODXF,
     2 TF,CF
C
C
C>>>>>>>> READ CARD TYPE 13 <<<<<<<<
C
      IF(IPROG.EQ.2) READ(INPT,515) IDATEF,IHOURF,IDWHXF,DUM,DUM,QXF,
     1 BODXF,TF,CF
C
```

```
      IF(IDATEF.EQ.999999) GO TO 45
C
      IF(IPROG.NE.1) GO TO 43
C
C******** SWMM INPUT
C
      ITIMEX = ITIME + 1
      IDATE9 = IDATE8
      IF(ITIMEX.LE.24) GO TO 42
      ITIMEX = 1
      MON = IDATE9 / 10000
      IDAY = (IDATE9 - MON * 10000) / 100
      IYR = (IDATE9 - MON * 10000 - IDAY * 100)
      IDAY = IDAY + 1
      MONTH(2) = 28
      LEAP = IYR / 4 * 4
      IF(LEAP.EQ.IYR) MONTH(2) = 29
      IF(IDAY.LE.MONTH(MON)) GO TO 40
      IDAY = 1
      MON = MON + 1
      IF(MON.LE.12) GO TO 40
      MON = 1
      IYR = IYR + 1
   40 IDATE9 = MON * 10000 + IDAY * 100 + IYR
C
   42 READ(IFILE,END=45)   TIME,(QQ2(J),J=1,NCUTS),((POLL2(K,J),
     1K=1,NPOLL),J=1,NCUTS)
      WWFXF = QQ2(JNS)
      URBODF = POLL2(1,JNS) * 60.0
      IF(ISTART.EQ.0.AND.WWFXF.GT.0.0) GO TO 2000
      IF(WWFXF.EQ.0.0) GO TO 2004
      GO TO 2002
 2000 IDATEP = IDATE9
      IDWH1 = IDWHRS
      IDWHXP = IDWHRS
      IHOURP = ITIMEX
      IC = 0
      ISTART = 1
 2002 IDWHRS = 0
      GO TO 47
 2004 IDWHRS = IDWHRS + 1
      IF(IDWHRS.LE.MIT.OR.ISTART.EQ.0) GO TO 47
 2006 IF(IEND.NE.1) IC = IC - MIT
      IJUMP = 1
      Q = Q - CKQ
      RC = RC - CKRC
      RT = RT - CKRT
      DWF = DWF - CKDWF
      WWF = WWF - CKWWF
      RBOD = RBOD - CKRBOD
```

```
      DWBOD = DWBOD - CKDWB
      URLBS = URLBS - CKURLB
      IF(IEND.EQ.1) GO TO 50
      GO TO 47
C
   43 IF(IPROG.EQ.2) READ(IFILE,571,END=45) WWFXF,URBODF
      GO TO 47
C
   45 IEND = 1
      IF(IPROG.EQ.1) GO TO 9998
      GO TO 50
C
   47 IF(IDATEF.EQ.999999) GO TO 45
      IF(IPROG.NE.1) GO TO 7000
C
      IHOURX = IHOURF
      IF(IDATE8.EQ.IDATEF) GO TO 6000
      MON1 = IDATE8 / 10000
      MON2 = IDATEF / 10000
      IDAY1 = (IDATE8 - MON1 * 10000) / 100
      IDAY2 = (IDATEF - MON2 * 10000) / 100
      IYR1 = (IDATE8 - MON1 * 10000 - IDAY1 * 100)
      IYR2 = (IDATEF - MON2 * 10000 - IDAY2 * 100)
      IF(IYR1.NE.IYR2) GO TO 5000
      IF(MON1.NE.MON2) GO TO 4000
      IDAY3 = IDAY2 - IDAY1 - 1
 3000 IHOURX = 24 - IHOUR + IHOURF + IDAY3 * 24
      GO TO 6000
 4000 NFMON = MON1 + 1
      NLMON = MON2 - 1
      IDAY3 = 0
 4200 LEAP = IYR1 / 4 * 4
      MONTH(2) = 28
      IF(LEAP.EQ.IYR1) MONTH(2) = 29
      DO 4400 NN = NFMON,NLMON
 4400 IDAY3 = IDAY3 + MONTH(NN)
      IDAY3 = IDAY3 + MONTH(MON1) - IDAY1 + IDAY2 - 1
      GO TO 3000
 5000 NLMON = 12
      NFMON = MON1 + 1
      IDAY3 = 0
      IYR4 = IYR1
      IYR3 = IYR2 - IYR1
      DO 5500 NN = 1,IYR3
      IYR4 = IYR4 + 1
      LEAP = IYR4 / 4 * 4
      MONTH(2) = 28
      IF(LEAP.EQ.IYR4) MONTH(2) = 29
      IF(NN.EQ.IYR3) GO TO 5300
      DO 5200 INN = 1,12
```

```
 5200 IDAY3 = IDAY3 + MONTH(INN)
      GO TO 5500
 5300 IF(MON2.EQ.1) GO TO 4200
      NLLMON = MON2 - 1
      DO 5400 INN = 1,NLLMON
 5400 IDAY3 = IDAY3 + MONTH(INN)
 5500 CONTINUE
      GO TO 4200
C
 6000 IHOUR = ITIMEX - 1
      IF(IHOUR.EQ.IHOURX.AND.IDAY1.EQ.IDAY2) IHOURX = IHOURX + 1
      IF(IHOUR.EQ.IHOURX.AND.IDAY1.NE.IDAY2) IHOURX = IHOURX + 24
      IF(IHOUR.GT.IHOURX) IHOURX = IHOURX + 24
      QX = QX + (ITIMEX- IHOUR) * (QXF - QX) / (IHOURX - IHOUR)
      BODX = BODX + (ITIMEX- IHOUR) * (BODXF - BODX) / (IHOURX - IHOUR)
      T = T + (ITIMEX- IHOUR) * (TF - T) / (IHOURX - IHOUR)
      C = C + (ITIMEX- IHOUR) * (CF - C) / (IHOURX - IHOUR)
      IHOUR = ITIMEX
      IDATE8 = IDATE9
C
      IF(IL.EQ.1.AND.IDWHXF.LT.MIT) GO TO 50
      IF(IPROG.EQ.1) GO TO 50
 7000 IF(MIT.EQ.0)  GO TO 99
      IF(IDWHX.GT.MIT.AND.IDWHXF.GT.MIT) GO TO 99
   50 IC=IC+1
      IF(IPROG.EQ.1) GO TO 62
      IDWH=IDWH+IDWHX
      IF(IC.NE.1)  GO TO 60
      IHOURP = IHOUR
      IDWHXP = IDWHX
      IDWH1=IDWHX
      IDWHX = 0
   60 ID=ID+IDWHX
   62 IF(IPROG.EQ.1.AND.ISTART.EQ.0) GO TO 66
      Q = Q + QX * (1 + IDWHX)
      RC = RC + C * QX * (1 + IDWHX)
      RT = RT + T * (1 + IDWHX)
      DWF=DWF+DWFX*(1+IDWHX)
      WWF=WWF+WWFX
      RBOD = RBOD + BODX * QX * (1 + IDWHX)
      DWBOD=DWBOD+DWBODX*(1+IDWHX)
      URLBS=URLBS+DURBOD
      IF(IPROG.NE.1) GO TO 66
      IF(WWFX.EQ.0.0) GO TO 64
      CKQ = 0.0
      CKRC = 0.0
      CKRT = 0.0
      CKDWB = 0.0
      CKDWF = 0.0
      CKWWF = 0.0
```

```
      CKRBOD = 0.0
      CKURLB = 0.0
C
   64 CKQ = CKQ + QX * (1 + IDWHX)
      CKRC = CKRC + C * QX * (1 + IDWHX)
      CKRT = CKRT + T * (1 + IDWHX)
      CKDWB = CKDWB + DWBODX * (1 + IDWHX)
      CKDWF = CKDWF + DWFX * (1 + IDWHX)
      CKWWF = CKWWF + WWFX
      CKRBOD = CKRBOD + BODX * QX * (1 + IDWHX)
      CKURLB = CKURLB + DURBOD
C
   66 CONCT = 0.0
      IF(WWF.NE.0.0) CONCT = URLBS * 4.4491 / WWF
      IF(IEND.EQ.1) GO TO 100
      IF(IJUMP.EQ.1) GO TO 100
      IF(IPROG.EQ.1) GO TO 15
      IF(IC.EQ.1) IDWHX = IDWH1
      IF(IDWHX.LT.MIT.AND.IDWHXF.GT.MIT) GO TO 100
      GO TO 15
C
C******** COMPUTE OUTPUT FOR ONE EVENT
C
   99 IHOURP = IHOUR
      IDWHXP = IDWHX
      IC=1
      ID=0
      Q=QX
      DWF=DWFX
      WWF=WWFX
      IDWH=IDWHX
      DWBOD=DWBODX
      URLBS = DURBOD
      CONCT = DCNCTX
      RT = T
      RC = C * QX
      RBOD = BODX * QX
C
  100 C = RC / Q
      BODX = RBOD / Q
      T = RT / (IC + ID)
      DFSEP=ASEP*DWF/ATOT
      DFCOMB=ACOM*DWF/ATOT
      QSEP=ASEP*WWF/ATOT
      QCOMB=ACOM*WWF/ATOT
      CSFLO=QCOMB+DFCOMB
      BODSEP=ASEP*URLBS/ATOT
      SEPLO=CONCT
      IF(ASEP.EQ.0.0) SEPLO=0.0
      BODCOM=CONCT*QCOMB*0.2248+ACOM*DWBOD/ATOT
```

```
      FF=0.0
      CCOMB=0.0
      IF(CSFLO.NE.0.0.AND.IPROG.NE.1) FF = FFLBS * IDWH
      IF(CSFLO.NE.0.0)  CCOMB=(BODCOM+FF)/((QCOMB+DFCOMB)*3600.0)
      COMBLO=CCOMB*16016.60
      CS=14.652-0.41022 * T + 0.0079910 * (T**2.)- 0.000077774 *(T
     /**3.)
      CO=CS-C
      IF(CS.LT.C) CO = 0.0
      WWFA=WWF/IC
      URLBA=URLBS/IC
      XNUM=7.5999*(1.024**(T - 20.0))* (ALPHA1/BETA1**1.33)/24.0
C
      DO 110 K=1,3
      QU(K)=Q*RF(K)/(IC+ID)
      FLO(1,K)=Q*RF(K)+CWF
      FLO(2,K)=Q*RF(K)+CWF+QSEP
      FLO(3,K)=Q*RF(K)+CWF+QCOMB
      FLO(4,K)=Q*RF(K)+QSEP+QCOMB
      FLO(5,K)=Q*RF(K)+CWF+QSEP+QCOMB
C
      DO 110 M=1,5
      FL(M,K)=FLO(M,K)/(IC+ID)
      H(M,K)=BETA1*FL(M,K)**BETA2
      XK1=GAMMA1*H(M,K)**GAMMA2/24.0
      IF(XK1.GT.XK1MAX) XK1=XK1MAX
      IF(XK1.LT.XK1MIN) XK1=XK1MIN
      XK1T(M,K)=XK1*1.047**(T-20.0)
      DENOM(M,K)=(1.-EXP(-5.*24.*XK1T(M,K)))/(0.02*T+0.6)
      XK2T(M,K)=XNUM*(FL(M,K)**(ALPHA2-1.33*BETA2))
      DO(M,K)=QU(K)*CC/FL(M,K)
      U(M,K)=(ALPHA1*Z)*(FL(M,K))**ALPHA2
      F(M,K)=XK2T(M,K)/XK1T(M,K)
      V(M,K)=U(M,K)/3600.0
      F1(M,K)=F(M,K)-1.
      F2(M,K)=XK2T(M,K)-XK1T(M,K)
      TE(M,K)=0.0
      IF(U(M,K).GT.0.0)  TE(M,K)=X/U(M,K)
      XM1(M,K)=SQRT(1.0+(4.0*XK1T(M,K)*E)/U(M,K)**2.)
      XM2(M,K)=SQRT(1.0+(4.0*XK2T(M,K)*E)/U(M,K)**2.)
      XM12(M,K)=XM1(M,K)-XM2(M,K)
      XJ(M,K)=0.0
      XG(M,K)=0.0
      IF(E.NE.0.0)  XJ(M,K)=U(M,K)**2.*(1.0-XM1(M,K))/(2.0*E)
      IF(E.NE.0.0)  XG(M,K)=U(M,K)**2.*(1.0-XM2(M,K))/(2.0*E)
  110 CONTINUE
C
      DO 120 J=1,3
      DO 120 K=1,3
      DO 120 L=1,3
```

```
      ULTLO(1,J,K,L)=((Q*RF(K) * BODX + DWF*PCTTRT(J)*DWFLO)/FLO(1,K))/
     /DENOM(1,K)
      ULTLO(2,J,K,L)=((Q*RF(K) * BODX + DWF*PCTTRT(J)*DWFLO+QSEP*SEPLO*
     /PCT(L))/FLO(2,K))/DENOM(2,K)
      ULTLO(3,J,K,L)=((Q*RF(K) * BODX + DFSEP*PCTTRT(J)*DWFLO+DFCOMB*
     /PCTTRT(J)*COMBLO+QCOMB*COMBLO*PCT(L))/FLO(3,K))/DENOM(3,K)
      ULTLO(4,J,K,L)=((Q*RF(K) * BODX + QSEP*SEPLO*PCT(L)+QCOMB*COMBLO*
     /PCT(L))/FLO(4,K))/DENOM(4,K)
      ULTLO(5,J,K,L)=((Q*RF(K) * BODX + DFSEP*PCTTRT(J)*DWFLO+DFCOMB*
     /PCTTRT(J)*COMBLO+QSEP*SEPLO*PCT(L)+QCOMB*COMBLO*PCT(L))/FLO(5,K))/
     /DENOM(5,K)
  120 CONTINUE
C
      IF(IPROG.NE.1) IDATEP = IDATE
      IDATE1 = IDATEP/ 10000
      IDATE2 = (IDATEP- IDATE1 * 10000) / 100
      IDATE3 = (IDATEP- IDATE1 * 10000 - IDATE2 * 100)
C
      WRITE(IOUT,190)
  190 FORMAT(1H1)
      WRITE(IOUT,200)
  200 FORMAT(1H ,40(1H*))
      WRITE(IOUT,210)IDATE1,IDATE2,IDATE3,IHOURP,IDWHXP
  210 FORMAT(11H **** DATE ,I2,1H/,I2,1H/,I2,6H HOUR ,I2,5H DWH ,I4,5H *
     /***)
      WRITE(IOUT,200)
      WRITE(IOUT,230) IC
  230 FORMAT(23H **** RUNOFF DURATION =,I4,14H HOURS     ****)
      WRITE(IOUT,200)
      WRITE(IOUT,250)
  250 FORMAT(1H ,24(1H*))
      WRITE(IOUT,260) I
  260 FORMAT(16H **** EVENT NO.=,I3,6H *****)
      WRITE(IOUT,250)
      WRITE(IOUT,280) QX,BODX,T,C
  280 FORMAT(///22H **UPSTREAM RIVER FLO=,F10.2,13H CFS ** BOD =,F7.2,
     /15H MG/L ** TEMP.=,F5.1,19H DEG.CENT. ** D.O.=,F6.2,9H MG/L ***)
      WRITE(IOUT,290)WWFA,URLBA,CONCT
  290 FORMAT(22H ** AVE. URBAN RUNOFF=,F9.2,20H  CFS *** BOD LOAD =,
     /F9.1,25H  LBS/HOUR *** BOD CONC.=,F9.1,10H  MG/L ***)
C
      DO 400 M=1,5
      DO 400 J=1,3
      TITLE1(8)=JKEY(IPR1)
      DO 400 K=1,3
      DO 400 L=1,3
      TC = 0.0
      XC = 0.0
      IF (ULTLO(M,J,K,L).NE.0.0)  RO=DO(M,K)/ULTLO(M,J,K,L)
      IF(F1(M,K).NE.0.0.AND.XM12(M,K).NE.0.0)  GO TO 310
```

```
      DC =         ULTLO(M,J,K,L)*EXP(DO(M,K)/ULTLO(M,J,K,L)-1.0)
      GO TO 350
  310 IF (ULTLO(M,J,K,L).NE.0.0) GO TO 320
      DC = DO(M,K)
      GO TO 350
  320 IF (RO.GE.0.0.AND.RO.LE.(1./F(M,K)))  GO TO 330
      DC = DO(M,K)
      GO TO 350
  330 TC =         (ALOG(F(M,K)*(1.-F1(M,K)*DO(M,K)/ULTLO(M,J,K,L))))/(XK
     .1T(M,K)*F1(M,K))
      DC =(XK1T(M,K)*ULTLO(M,J,K,L)/XK2T(M,K))*EXP(-XK1T(M,K)*TC)
      IF(E.EQ.0.) GO TO 340
      TC =         ALOG(((XM1(M,K)/XM2(M,K))-RO*F(M,K)+RO)*XG(M,K)/XJ(M,K
     .))/(XJ(M,K)-XG(M,K))
      DC =         (ULTLO(M,J,K,L)*XK1T(M,K))/F2(M,K)*(EXP(XJ(M,K)*TC)
     1 -(XM1(M,K)/XM2(M,K))*EXP(XG(M,K)*TC)) +        DO(M,K)*EXP(XG(M,K
     2)*TC)
  340 XC = U(M,K) * TC / 5280.0
  350 DOCONC = CS - DC
      IF(DC.GT.CS) DOCONC = 0.0
      IF (DC.GT.CS) DC=CS
      IF(F2(M,K).NE.0.0)  GO TO 360
      DT=XK1T(M,K)*ULTLO(M,J,K,L)*TE(M,K)*EXP(-XK1T(M,K)*TE(M,K))+DO(M,K
     1)*EXP(-XK2T(M,K)*TE(M,K))
      GO TO 370
  360 DT=(EXP(-XK1T(M,K)*TE(M,K))-EXP(-XK2T(M,K)*TE(M,K)))*XK1T(M,K)*ULT
     1LO(M,J,K,L)/F2(M,K)+DO(M,K)*EXP(-XK2T(M,K)*TE(M,K))
      IF(E.EQ.0.) GO TO 370
      DT =    (ULTLO(M,J,K,L)*XK1T(M,K))/F2(M,K)*(EXP(XJ(M,K)*TE(M,K))-(X
     .M1(M,K)/XM2(M,K))*EXP(XG(M,K)*TE(M,K)))+DO(M,K)*EXP(XG(M,K)*TE(M,K
     .))
  370 DXCONC = CS - DT
      IF(DT.GT.CS) DXCONC = 0.0
      IF (DT.GT.CS) DT=CS
C     METHOD OF INTEGRATING DEFICIT EQUATION
      XIDE =        (ULTLO(M,J,K,L)+DO(M,K))/XK2T(M,K)
      IF (E.NE.0.0) XIDE=ULTLO(M,J,K,L)*XK1T(M,K)/(XK2T(M,K)-XK1T(M,K))*
     1 (XM1(M,K)/(XM2(M,K)*XG(M,K))-1./XJ(M,K))-DO(M,K)/XG(M,K)
C
      NG1 = 1
      IF(ICALC1.EQ.1 .OR. ICALC2.EQ.1) NG1 = 1.0 + DOCONC * 2.0
      IF(ICALC1.EQ.2 .OR. ICALC2.EQ.2) NG1 = 1.0 + DXCONC * 2.0
      IF(NG1.LT.1) NG1 = 1
      IF(NG1.GT.31) NG1 = 31
      DATA1(NG1,M,J,K,L) = DATA1(NG1,M,J,K,L) + 1.0
C
      IF(J.EQ.IPR1.AND.K.EQ.IPR2.AND.L.EQ.IPR3) GO TO 380
      GO TO 400
C
  380 WRITE(IOUT,382) M,TRTPCT(J),RF(K),TPCT(L),FL(M,K)
```

```
 382 FORMAT(//15H **COMBINATION=,I2,9H  PCTTRT=,F4.2,21H  RIVER FLOW FR
    /ACTN =,F4.2,17H  PCTTRT RUNOFF =,F4.2,23H    *** AVE. RIVER FLOW=
    /,F9.1,8H CFS ***)
     WRITE(IOUT,384)QU(K),ULTLO(M,J,K,L),H(M,K)
 384 FORMAT(27H **AVE. UPSTREAM RIVERFLOW=,F9.1,22H CFS *** ULTIMATE BO
    /D=,F10.1,18H  MG/L *** DEPTH =,F6.2,10H  FEET ***)
     WRITE(IOUT,386) DC,DOCONC,CS,XIDE
 386 FORMAT(20H **CRITICAL DEFICIT=,F6.2,16H  MG/L   DOCONC=,F6.2,
    /16H  MG/L   SAT DO=,F6.2,24HMG/L   INTEGRAL DEF EQN=,F8.2,15H  MG-
    /HOUR/L ***)
     WRITE(IOUT,388) DT,DXCONC
 388 FORMAT(16H **D.O. DEFICIT=,F6.2,21H  MG/L *** D.O. @ X =,F6.2,
    /10H  MG/L ***)
     WRITE(IOUT,390) TC,XC,TE(M,K),D,V(M,K)
 390 FORMAT(8H ** TC =,F7.2,15H HOURS *** XC =,F6.2,15H   MI. *** TX =,
    /F7.2,20H  HOURS *** DIST X =,F6.2,14H   MI. *** V =,F5.2,
    /9H  FPS ***)
     WRITE(IOUT,392) XK2T(M,K), XK1T(M,K)
 392 FORMAT(32H **REAERATION COEFFICIENT(XK2T)=,E11.5,44H  1/HOUR    DE
    /OXYGENATION COEFFICIENT(XK1T)=,E11.5,8H  1/HOUR)
C
     DCDIST(M)=DCDIST(M)+XC
     IF (ITSAG.EQ.1.AND.J.EQ.IPR1.AND.K.EQ.IPR2.AND.L.EQ.IPR3.
    1 AND.M.EQ.IPR4) WRITE(IDISKW) IDATE1,IDATE2,IDATE3,DXCONC
C
 400 CONTINUE
C
C <<<<<<<<<<     D.O. PROFILE CALCULATIONS      >>>>>>>>>>
C
      IF (ICALCX.EQ.0) GO TO 9050
      DO 8040 IDX=1,101
         XDG(IDX)=(IDX-1)*DX
         XD=XDG(IDX)*5280.0
         DO 8040 M=1,5
            TX=XD/U(M,IPR2)
            IF (F2(M,IPR2).NE.0.0.AND.XM12(M,IPR2).NE.0.0) GO TO 8000
            DTX=XK1T(M,IPR2)*ULTLO(M,IPR1,IPR2,IPR3)*TX*
    1 EXP(-XK1T(M,IPR2)*TX)+DO(M,IPR2)*EXP(-XK2T(M,IPR2)*TX)
            GO TO 8010
 8000       DTX=XK1T(M,IPR2)*ULTLO(M,IPR1,IPR2,IPR3)*(EXP(-XK1T(M,IPR2)*
    1             TX)-EXP(-XK2T(M,IPR2)*TX))/F2(M,IPR2)+DO(M,IPR2)*
    2             EXP(-XK2T(M,IPR2)*TX)
            IF (E.EQ.0.0) GO TO 8010
            DTX=(ULTLO(M,IPR1,IPR2,IPR3)*XK1T(M,IPR2))/F2(M,IPR2)*
    1             (EXP(XJ(M,IPR2)*TX)-(XM1(M,IPR2)/XM2(M,IPR2))*
    2             EXP(XG(M,IPR2)*TX))+DO(M,IPR2)*EXP(XG(M,IPR2)*TX)
 8010       DTXCN=CS-DTX
            IF (DTX.GT.CS) DTXCN=0.0
            IF (DTX.GT.CS) DTX=CS
            DOXDX(M,IDX)=DTXCN
```

```
 8040    CONTINUE
C
C <<<<<<<<<<     END OF D.O. PROFILE CALCULATIONS     >>>>>>>>>>
C
C
C <<<<<<<<<<     PRINT OUT MATRIX OF D.O. PROFILE VALUES     >>>>>>>>>>
C
      WRITE(IOUT,8050) DX,I
 8050 FORMAT('1',///,78('*'),
     1    /' **    DISSOLVED OXYGEN PROFILES FOR ALL WASTE INFLOW ',
     2 'COMBINATIONS (M=1,5)     **',/' **',7X,'DISTANCE --> 100 ',
     3 'INTERVALS, EACH INTERVAL = ',F10.2,' MILES',6X,'**',/
     4 ' **',10X,'EVENT NO. ',I3,28X,'UNITS IN MG/L',9X,'**'/
     5 ' ',77('*'))
      DO 8060 M=1,5
         WRITE(IOUT,8052) M,(DOXDX(M,IDX),IDX=1,101)
 8052    FORMAT(///' COMBINATION ',I1,':',6(/10X,20F6.2))
 8060    CONTINUE
      IF (ICALCX.EQ.1) GO TO 9050
      IF (ICALCX.EQ.2) CALL MGRAPH(XDG,DOXDX,101,5,TITLE1,YTITL1,LABEL1)
      IF (ICALCX.LT.3) GO TO 9050
      ICOMB=ICALCX-2
      DO 8070 IDX=1,101
         DOXDX1(IDX)=DOXDX(ICOMB,IDX)
         STITLE(15)=COMKEY(ICOMB)
 8070    CONTINUE
      CALL MGRAPH(XDG,DOXDX1,101,1,STITLE,YTITL1,LABEL1)
 9050 CONTINUE
      ANAVFL=ANAVFL+FL(5,3)
      ASUM1=ASUM1+SEPLO*WWF
      ASUM2=ASUM2+WWF
      ABODSP=ABODSP+BODSEP
      ABODCB=ABODCB+BODCOM+FF
      SUMCMB=SUMCMB+CCMBLC*CSFLO
      ASUM7=ASUM7+CSFLO
      AFLSEP=AFLSEP+QSEP*3600.0
      AFLCMB=AFLCMB+CSFLO*3600.0
      IC=0
      ID=0
      IL = 0
      IDWH=0
      IJUMP = 0
      ISTART = 0
      Q=0.0
      RC=0.0
      RT=0.0
      DWF=0.0
      WWF=0.0
      RBOD=0.0
      DWBOD=0.0
```

```
      URLBS=0.0
      CKQ = 0.0
      CKRC = 0.0
      CKRT = 0.0
      CKDWB = 0.0
      CKDWF = 0.0
      CKWWF = 0.0
      CKRBOD = 0.0
      CKURLB = 0.0
      NEVNTS = I
  999 CONTINUE
C
C  *********************************************
C  ***                                       ***
C  ***       END OF MAJOR EVENT LOOP         ***
C  ***                                       ***
C  *********************************************
C
 9998 ANAVFL=ANAVFL/FLOAT(NEVNTS)
      ACOMBL=0.0
      IF(ASUM7.NE.0.0) ACOMBL=SUMCMB/ASUM7
      ASEPLD=ASUM1/ASUM2
C
      WRITE(IOUT,905)
  905 FORMAT(1H1)
      WRITE(IOUT,910)
  910 FORMAT(///,1H ,54(1H*))
      WRITE(IOUT,915)
  915 FORMAT(55H ************ DURING WET WEATHER PERIODS *************)
      WRITE(IOUT,920) ANAVFL
  920 FORMAT(37H ** ANNUAL AVE. EVNT TOT.RIVER FLOW =,F7.1,11H   CFS ***
     /*)
      WRITE(IOUT,925)
  925 FORMAT(1H ,54(1H*))
      WRITE(IOUT,930) AFLSEP
  930 FORMAT(21H ** ANNUAL FLOW SEP =,E9.2,12H   CF/YR ***)
      WRITE(IOUT,935)
  935 FORMAT(1H ,41(1H*))
      WRITE(IOUT,940) AFLCMB
  940 FORMAT(21H ** ANNUAL FLOW COMB=,E9.2,12H   CF/YR ***)
      WRITE(IOUT,935)
      WRITE(IOUT,620)
  620 FORMAT(/////,1H ,32(1H*))
      WRITE(IOUT,625) NEVNTS
  625 FORMAT(25H *** WET WEATHER EVENTS =,I4,4H ***)
      WRITE(IOUT,630)
  630 FORMAT(1H ,32(1H*))
      WRITE(IOUT,950)
  950 FORMAT(1H1)
      WRITE(IOUT,955)
```

```
  955 FORMAT(1H ,44(1H*))                                                  MAIN9050
      WRITE(IOUT,960)                                                      MAIN9060
  960 FORMAT(45H ** ANN. BOD LOADS AND AVE. CONCENTRATIONS **)             MAIN9070
      WRITE(IOUT,955)                                                      MAIN9080
      WRITE(IOUT,970) ABODSP,ASEPLD                                        MAIN9090
  970 FORMAT(////19H *** ANN.BOD  SEP.=,F9.0,22H  LBS/YR *** ANN.AVE.=,FMAIN9100
     /6.1,    9H MG/L ***)                                                 MAIN9110
      WRITE(IOUT,975) ABODCB,ACOMBL                                        MAIN9120
  975 FORMAT(19H *** ANN.BOD COMB.=,F9.0,22H  LBS/YR *** ANN.AVE.=,F6.1,MAIN9130
     /    9H MG/L ***)                                                     MAIN9140
C                                                                          MAIN9150
      DO 990 M=1,5                                                         MAIN9160
      DCDIST(M) = DCDIST(M) / FLOAT(NEVNTS)                                MAIN9170
      WRITE(IOUT,985) M,DCDIST(M)                                          MAIN9180
 985  FORMAT(///42H *** AVERAGE DIST. TO CRITICAL D.O. FOR M=,I2,5H IS =MAIN9190
     /,F6.1,10H MILES ***)                                                 MAIN9200
 990  CONTINUE                                                             MAIN9210
C                                                                          MAIN9220
C******** FREQUENCY ANALYSIS OF DISSOLVED OXYGEN CONCENTRATIONS            MAIN9230
C                                                                          MAIN9240
      DO 700 I=1,31                                                        MAIN9250
 700  CG(I)=(I-1)*0.5                                                      MAIN9260
C                                                                          MAIN9270
      DO 720 J=1,3                                                         MAIN9280
      TITLE(7)=JKEY(J)                                                     MAIN9290
      DO 720 K=1,3                                                         MAIN9300
      TITLE(8)=KKEY(K)                                                     MAIN9310
      DO 720 L=1,3                                                         MAIN9320
      TITLE(9)=LKEY(L)                                                     MAIN9330
      DO 716 M=1,5                                                         MAIN9340
      DO 705 I=1,31                                                        MAIN9350
  705 FREQ(I) = DATA1(I,M,J,K,L)                                           MAIN9360
C                                                                          MAIN9370
C                                                                          MAIN9380
      IF(ICALC1.EQ.0) GO TO 715                                            MAIN9390
C                                                                          MAIN9400
      CALL PLOT(CG,FREQ,31,NEVNTS)                                         MAIN9410
C*************************************************************************MAIN9420
C                                                                          MAIN9430
      IF(ICALC1.EQ.1)  WRITE(IOUT,711)                                     MAIN9440
  711 FORMAT(//32H *** CRITICAL D.O. HISTOGRAM ***)                        MAIN9450
      IF(ICALC1.EQ.2)  WRITE(IOUT,712)                                     MAIN9460
  712 FORMAT(//33H *** CRIT. D.O. HISTOGRAM @ X ***)                       MAIN9470
      WRITE(IOUT,713) M,J,K,L                                              MAIN9480
  713 FORMAT(6H ***M=,I1,6H ***J=,I1,6H ***K=,I1,6H ***L=,I1)              MAIN9490
      WRITE(IOUT,714) NEVNTS                                               MAIN9500
  714 FORMAT(/////20H NORMALIZING FACTOR=,I4,7H EVENTS)                    MAIN9510
C                                                                          MAIN9520
  715 N1 = 0                                                               MAIN9530
      DO 716 I=1,31                                                        MAIN9540
```

```
      N1=N1+FREQ(I)                                                     MAIN9550
  716 PCTG(M,I) = (100.0 * (FLOAT(NEVNTS) - N1)) / FLOAT(NEVNTS)        MAIN9560
C                                                                       MAIN9570
      IF (ICALC2.GE.1) CALL MGRAPH(CG,PCTG,31,5,TITLE,YTITLE,LABEL)     MAIN9580
C***********************************************************************MAIN9590
C                                                                       MAIN9600
  720 CONTINUE                                                          MAIN9610
C                                                                       MAIN9620
  750 IF (IDWFM.EQ.1) CALL DWFM(ND)                                     MAIN9630
C***********************************************************************MAIN9640
      IF (IDWFM.NE.1) ND=0                                              MAIN9650
      IF (IWWFM.NE.1) NEVNTS=0                                          MAIN9660
C                                                                       MAIN9670
      IF (ITSAG.NE.1.OR.(IWWFM.NE.1.AND.IDWFM.NE.1)) GO TO 9999         MAIN9680
      CALL DOSAG(NEVNTS,ND)                                             MAIN9690
C                                                                       MAIN9700
 9999 STOP                                                              MAIN9710
      END                                                               MAIN9720
      SUBROUTINE CORREL                                                 CORL0010
C                                                                       CORL0020
C******** AUTOCORRELATION ANALYSIS OF TIME SERIES                       CORL0030
C                                                                       CORL0040
      DIMENSION DUMMY(15)                                               CORL0050
      COMMON INPT,IOUT                                                  CORL0060
      COMMON/SET1/ MIT                                                  CORL0070
      COMMON/SET3/ X(8760),RK(800),RK1(101),XAG1(101)                   CORL0080
      INTEGER TITLE(20),YTITLE(51),LABEL(20),POINTS                     CORL0090
      DATA TITLE/'CORR','ELOG','RAM ','OF T','IME ','SERI',             CORL0100
     1 'ES  ',13*'    '/                                                CORL0110
      DATA YTITLE/'A','U','T','O','C','O','R','R','E','L','A','T',      CORL0120
     1 'I','O','N',' ','C','O','E','F','F','I','C','I','E','N',         CORL0130
     2 'T','S',23*' '/                                                  CORL0140
      DATA LABEL/'NUMB','ER O','F HO','URLY',' LAG','S   ',             CORL0150
     1 14*'    '/                                                       CORL0160
      DATA IW,IBLANK/'W   ','    '/                                     CORL0170
C                                                                       CORL0180
C******** READ NUMBER OF DATA POINTS AND NUMBER OF LAGS.                CORL0190
C                                                                       CORL0200
C                                                                       CORL0210
C>>>>>>>> READ CARD TYPE  2 <<<<<<<<                                    CORL0220
C                                                                       CORL0230
      READ(INPT,99) N,NLAGS                                             CORL0240
 99   FORMAT(2I5)                                                       CORL0250
      IF (N.GE.NLAGS) GO TO 75                                          CORL0260
         WRITE(IOUT,71) N,NLAGS                                         CORL0270
   71    FORMAT(' VALUE N = ',I5,' IS LESS THAN NLAGS = ',I5)           CORL0280
         GO TO 999                                                      CORL0300
   75 IF (N.LE.8760) GO TO 80                                           CORL0310
         WRITE(IOUT,76) N                                               CORL0320
   76    FORMAT(' VALUE N = ',I5,' IS GREATER THAN 8760.  ',            CORL0330
```

```
     1        'REDIMENSION ARRAY X IN SUBROUTINE CORREL')
          GO TO 999
   80 IF (NLAGS.LE.800) GO TO 90
      WRITE(IOUT,81) NLAGS
   81 FORMAT(' NLAGS = ',I5,' IS GREATER THAN THE UPPER LIMIT OF 800.',
     1 '  IT WILL BE SET EQUAL TO 800.')
      NLAGS=800
C
C
C>>>>>>>> READ CARD TYPE  3 <<<<<<<<
C
   90 I=0
      DO 400 I2=1,N
         READ(INPT,401) IKEY,DUMMY
  401    FORMAT(A4,1X,15F5.0)
         IF (IKEY.EQ.IBLANK) GO TO 410
         IF (IKEY.NE.IW) GO TO 407
         DO 404 J=1,15
            IF (DUMMY(J).EQ.0.0) GO TO 405
            I=I+1
            X(I)=DUMMY(J)
  404       CONTINUE
  405    GO TO 400
  407    K=IFIX(DUMMY(1))
         DO 408 J=1,K
            I=I+1
            X(I)=0.0
  408       CONTINUE
  400    CONTINUE
  410 IF (I.EQ.N) GO TO 412
      WRITE(IOUT,411) I,N
  411 FORMAT(//' TOTAL NUMBER OF DATA POINTS INPUT',I5,
     1 ' IS NOT EQUAL TO THE VALUE INPUT FOR THE VARIABLE ''N''=',I5)
      STOP
C
  412 XN=N
      NLAGS=NLAGS+1
      XR=0.
      XTL=0.
      MIT=0
      MRK=0
C
C     CORRELOGRAM
C
      DO 15 J=1,NLAGS
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      SUM5=0.
```

```
      M=N-J-1
      XDIF=M
      DO 5 JJ=J,N
      SUM1=SUM1+X(JJ)
    5 SUM4=SUM4+X(JJ)*X(JJ)
      DO 10 I=1,M
      SUM2=SUM2+X(I)
      SUM3=SUM3+X(I)*X(I+J-1)
   10 SUM5=SUM5+X(I)*X(I)
      SS1=SUM5-(SUM2**2)/XDIF
      SS2=SUM4-(SUM1**2)/XDIF
      RK(J)=0.
      TLP = 0.0
      IF(SS1.EQ.0.0.OR.SS2.EQ.0.0) GO TO 12
      RK(J)=(SUM3-SUM2*SUM1/XDIF)/(SQRT(SS1)*SQRT(SS2))
   12 TLA=1.645*((N-J-1)**0.5)
      TLP =   (-1.+TLA)/(N-J)
      IF(XTL.NE.0.0.OR.RK(J).GT.TLP) GO TO 14
      MIT = J
      XTL=1.0
   14 IF(XR.NE.0.0.OR.RK(J).GT.0.0) GO TO 15
      MRK = J
      XR=1.0
   15 CONTINUE
      WRITE(IOUT,9999)
 9999 FORMAT(1H1)
      WRITE(IOUT,101)
  101 FORMAT(/////,1H ,38(1H*))
      WRITE(IOUT,102)
  102 FORMAT(39H ***** CORRELOGRAM OF TIME SERIES *****)
      WRITE(IOUT,103)
  103 FORMAT(1H ,38(1H*))
      WRITE(IOUT,9999)
      WRITE(IOUT,110)
  110 FORMAT(1H ,37(1H*))
      WRITE(IOUT,111)
  111 FORMAT(38H ********** DISCRETE VALUES **********)
      WRITE(IOUT,110)
      NLAGS1=NLAGS/2
      NLAGS2=NLAGS-NLAGS1
      WRITE(IOUT,120) (RK(I),I=1,NLAGS1)
  120 FORMAT(10F8.2)
      WRITE(IOUT,9999)
      WRITE(IOUT,125) (RK(I),I=1,NLAGS2)
  125 FORMAT(10F8.2)
      WRITE(IOUT,9999)
      WRITE(IOUT,53)
   53 FORMAT(10X,31(1H*))
      WRITE(IOUT,54) MIT
   54 FORMAT(10X,23H*****           MIT = ,I2,6H *****)
```

```
      WRITE(IOUT,57) MRK                                                CORL1290
   57 FORMAT(10X,23H*****    RK =0 @ LAG = ,I2,6H *****)                CORL1300
      WRITE(IOUT,53)                                                    CORL1310
      N = -101                                                          CORL1320
      NN = -100                                                         CORL1330
      POINTS=101                                                        CORL1331
      LIM=(NLAGS-2)/100+1                                               CORL1332
      DO 140 J = 1,LIM                                                  CORL1340
      N = N + 100                                                       CORL1350
      NN = NN + 100                                                     CORL1360
      DO 130 I = 1,101                                                  CORL1370
      XAG1(I) = I + N                                                   CORL1380
      RK1(I) = RK(I+NN)                                                 CORL1390
  130 CONTINUE                                                          CORL1400
C                                                                       CORL1410
      IF (J.EQ.LIM) POINTS=NLAGS-((LIM-1)*100)                          CORL1411
      CALL MGRAPH(XAG1,RK1,POINTS,1,TITLE,YTITLE,LABEL)                 CORL1420
C***********************************************************************CORL1430
C                                                                       CORL1440
  140 CONTINUE                                                          CORL1450
  999 RETURN                                                            CORL1460
      END                                                               CORL1470
      SUBROUTINE PLOT(T,F,N,NTOT)                                       PLOT0010
C                                                                       PLOT0020
C******** PLOTTING FREQUENCY HISTOGRAMS                                 PLOT0030
C                                                                       PLOT0040
      COMMON IREAD,IWRITE                                               PLOT0050
      DIMENSION T(N),F(N),DISP(3),DY(11),SCALF(3),SFRCT(5)              PLOT0060
      INTEGER PLINE(61),ASTRX,AXIS,BLANK,PLUS,VDASH,F                   PLOT0070
      DATA ASTRX,AXIS,BLANK,PLUS,VDASH/'*','I',' ','+','|'/             PLOT0080
      DATA SFRCT/1.,2.5,5.,7.5,10./,DISP/1.5,61.5,31.5/,SCALE/2*60.,30./PLOT0090
C                                                                       PLOT0100
C    NORMALIZATION SCHEME.                                              PLOT0110
C                                                                       PLOT0120
      FMAX=F(1)                                                         PLOT0130
      FMIN=F(1)                                                         PLOT0140
      DO 4 I=1,N                                                        PLOT0150
      IF(F(I)-FMAX)2,2,1                                                PLOT0160
    1 FMAX=F(I)                                                         PLOT0170
    2 IF(F(I)-FMIN)3,4,4                                                PLOT0180
    3 FMIN=F(I)                                                         PLOT0190
    4 CONTINUE                                                          PLOT0200
      IF(ABS(FMAX)-ABS(FMIN))6,5,5                                      PLOT0210
    5 DIV=ABS(FMAX)                                                     PLOT0220
      GO TO 7                                                           PLOT0230
    6 DIV=ABS(FMIN)                                                     PLOT0240
    7 NEXP=IFIX(ALOG(DIV)/ALOG(10.))                                    PLOT0250
      IF(DIV.LT.1.)NEXP=NEXP-1                                          PLOT0260
      PP=10.**NEXP                                                      PLOT0270
      P=10.**(-NEXP)                                                    PLOT0280
```

```
      FRACT=DIV*P
      DO 8 I=1,5
      DIV=SFRCT(I)*PP
      IF(FRACT-SFRCT(I))9,9,8
    8 CONTINUE
    9 WRITE(IWRITE,10)FMAX,FMIN
   10 FORMAT('1'/' MAXIMUM = ',G15.7/' MINIMUM = ',G15.7/)
C
C     INDEX THE APPROPRIATE PLOTTER SUBSECTION.
C
      WRITE(IWRITE,11)PP
   11 FORMAT(T38,'(OUTPUT SCALED BY: ',1PF7.1,')')
      IF(FMIN)12,20,20
   12 IF(FMAX)25,25,30
   20 INDEX=1
      DY(1)=0.
      YINC=DIV/10.
      WRITE(IWRITE,21)
   21 FORMAT(T21,'0 + =====>')
      GO TO 100
   25 INDEX=2
      DY(1)=-DIV*P
      YINC=DIV/10.
      WRITE(IWRITE,26)
   26 FORMAT(T72,'<===== - 0')
      GO TO 100
   30 INDEX=3
      DY(1)=-DIV*P
      YINC=DIV/5.
      WRITE(IWRITE,31)
   31 FORMAT(T42,'<===== - 0 + =====>')
  100 DO 110 I=2,11
  110 DY(I)=DY(I-1)+YINC*P
      WRITE(IWRITE,120)DY
  120 FORMAT(16X,11F6.1)
      WRITE(IWRITE,125)
  125 FORMAT('    DO CONC    FREQ.*',T21,'+',10('-----+'),2X,'CUM. FREQ.',
     1 2X,'% EXCEEDING')
      XFP=0.0
      XNTOT=FLOAT(NTOT)*P
      DO 190 J=1,N
      I=IFIX((F(J)/DIV)*SCALE(INDEX)+DISP(INDEX))
      DO 135 L=1,60,6
      DO 130 K=1,5
  130 PLINE(L+K)=BLANK
  135 PLINE(L)=VDASH
      PLINE(61)=VDASH
C
C     BRANCH TO APPROPRIATE SUBSECTION.
C
```

```
      GO TO (140,150,160),INDEX                                         PLOT0770
  140 DO 145 L=1,I                                                      PLOT0780
  145 PLINE(L)=ASTRX                                                    PLOT0790
      PLINE(1)=AXIS                                                     PLOT0800
      GO TO 170                                                         PLOT0810
  150 DO 155 L=1,60                                                     PLOT0820
  155 PLINE(L)=ASTRX                                                    PLOT0830
      PLINE(61)=AXIS                                                    PLOT0840
      GO TO 170                                                         PLOT0850
  160 IF(I-31)165,169,167                                               PLOT0860
  165 DO 166 L=I,30                                                     PLOT0870
  166 PLINE(L)=ASTRX                                                    PLOT0880
      GO TO 169                                                         PLOT0890
  167 DO 168 L=32,I                                                     PLOT0900
  168 PLINE(L)=ASTRX                                                    PLOT0910
  169 PLINE(31)=AXIS                                                    PLOT0920
  170 PLINE(I)=PLUS                                                     PLOT0930
      FP=F(J)*P                                                         PLOT0940
      XFP=XFP+FP                                                        PLOT0950
      PX=100.0*(1.0-XFP/XNTOT)                                          PLOT0955
      WRITE(IWRITE,180)T(J),FP,PLINE,XFP,PX                             PLOT0960
  180 FORMAT(' ',G10.3,1X,F7.3,1X,61A1,1X,F10.3,5X,F6.2)                PLOT0970
  190 CONTINUE                                                          PLOT0980
      WRITE(IWRITE,195)                                                 PLOT0990
  195 FORMAT(20X,'|',10('_____|'))                                      PLOT1000
      RETURN                                                            PLOT1010
      END                                                               PLOT1020
      SUBROUTINE MGRAPH(X,Y,NPTS,NPL,TITLE,YTITLE,LABEL)                MGRP0010
C                                                                       MGRP0020
C******** PLOTTING OF CUMULATIVE FREQUENCIES,D.C. PROFILES *****         MGRP0030
C                                                                       MGRP0040
      COMMON INPT,IOUT                                                  MGRP0050
      DIMENSION X(NPTS),Y(NPL,NPTS),XSC(11)                             MGRP0060
      INTEGER TITLE(20),YTITLE(51),LABEL(20)                            MGRP0070
      LOGICAL*1 SP,SPACE,DIV,BAR,MINUS,PLUS,$PT,LINE(101),              MGRP0080
     .          SYMB(9), SYMB1                                          MGRP0090
      DATA SPACE/' '/,BAR/'|'/,MINUS/'-'/,PLUS/'+'/,                    MGRP0100
     .          SYMB/'1','2','3','4','5','6','7','8','9'/,              MGRP0110
     .          SYMB1/'*'/                                              MGRP0120
C                                                                       MGRP0130
      XMAX = X(1)                                                       MGRP0140
      XMIN = X(1)                                                       MGRP0150
      YMAX1 = Y(1,1)                                                    MGRP0160
      YMIN1 = Y(1,1)                                                    MGRP0170
      DO 10 J = 1,NPL                                                   MGRP0180
      DO 10 I = 1,NPTS                                                  MGRP0190
      XMAX = AMAX1(X(I),XMAX)                                           MGRP0200
      XMIN = AMIN1(X(I),XMIN)                                           MGRP0210
      YMAX1 = AMAX1(Y(J,I),YMAX1)                                       MGRP0220
      YMIN1 = AMIN1(Y(J,I),YMIN1)                                       MGRP0230
```

```
   10 CONTINUE
C
      CALL ROUND(YMAX1,YMIN1,YMAX,YMIN)
C**************************************************************************
C
C
C
      WRITE(IOUT,120) (TITLE(II),II=1,20)
  120 FORMAT('1'/32X,20A4//)
      XR = XMAX - XMIN
      YR = YMAX - YMIN
      RYS = 0.0
      IYT = 52
      DO 70 I3 = 1,11
      DO 70 I4 = 1,5
      SP = SPACE
      DIV = BAR
      IYT = IYT - 1
      IF (I4 .NE. 1) GO TO 30
      SP = MINUS
      DIV = PLUS
   30 K = 0
      DO 40 I5 = 1,11
      K = K + 1
      LINE(K) = DIV
      IF (I5 .EQ. 11) GO TO 40
      DO 41 I6 = 1,9
      K = K + 1
   41 LINE(K) = SP
   40 CONTINUE
      IYTR = 52 - IYT
      $PT = .FALSE.
      IF (I4 .NE. 1) GO TO 50
      $PT = .TRUE.
      YSC = YMAX - RYS*YR/10.
      IF(ABS(YSC) .LE. YR/200.) YSC = 0.0
      RYS = RYS + 1.0
   50 DO 60 I7 = 1,NPL
      DO 60 I7A = 1,NPTS
      IX = 100.*(X(I7A)-XMIN)/XR + 1.49999
      IY = 50.*(Y(I7,I7A)-YMIN)/YR + 1.49999
      IF (IY .NE. IYT) GO TO 60
      IF((IX .LT. 1) .OR. (IX .GT. 101)) GO TO 60
      IF(NPL.EQ.1) LINE(IX)=SYMB1
      IF(NPL.NE.1) LINE(IX)=SYMB(I7)
   60 CONTINUE
      IF($PT) WRITE(IOUT,1000) YTITLE(IYTR),YSC,(LINE(II),II=1,101)
 1000 FORMAT(3X,A1,2X,G12.4,1X,101A1)
      IF(.NOT.$PT) WRITE(IOUT,1100) YTITLE(IYTR),(LINE(II),II=1,101)
 1100 FORMAT(3X,A1,15X,101A1)
```

```
      IF(I3 .EQ. 11) GO TO 80
   70 CONTINUE
   80 RXS = 0.0
      DO 90 I8 = 1,11
      XSC(I8) = XMIN + RXS*XR/10.
      IF(ABS(XSC(I8)) .LE. XR/200.) XSC(I8) = 0.0
   90 RXS = RXS + 1.0
      WRITE(IOUT,1200) (XSC(II),II=1,11,2),(XSC(II),II=2,11,2)
 1200 FORMAT(4X,6G20.3/14X,5G20.3)
      WRITE(IOUT,130) (LABEL(II),II=1,20)
  130 FORMAT(//30X,20A4/)
      RETURN
      END
      SUBROUTINE ROUND(YMAX1,YMIN1,YMAX,YMIN)
      DIMENSION SEGM(12)
      DATA SEGM/1.,1.2,1.5,2.,2.5,3.,4.,5.,6.,7.5,10.,12./
      ISCALE = -1
      IF(YMAX1-YMIN1) 20,20,5
    5 IF((YMAX1-YMIN1) .LE. 10) GO TO 10
      ISCALE = ISCALE + 1
      YMAX1 = YMAX1/10.
      YMIN1 = YMIN1/10.
      GO TO 5
   10 IF((YMAX1-YMIN1) .GE. 1.) GO TO 20
      ISCALE = ISCALE - 1
      YMIN1 = YMIN1 * 10.
      YMAX1 = YMAX1 * 10.
      GO TO 10
   20 IYMIN = YMIN1 * 10.
      IYMAX = YMAX1 * 10.
      IF(YMIN1 .LT. 0.) IYMIN = IYMIN - 1
      IF(YMAX1 .GT. 0.) IYMAX = IYMAX + 1
      IF(IYMAX .NE. IYMIN) GO TO 30
      IYMAX = IYMAX + 1
      IYMIN = IYMIN - 1
   30 CENTER = ((IYMAX+IYMIN)*1./(IYMAX-IYMIN)*1.)*1.
      LEVEL = 6.50 - 4.51 * CENTER
      IF(LEVEL .EQ. 11) GO TO 40
      IF(LEVEL .EQ. 1) GO TO 50
      IF(ABS(CENTER) .GT. 1.) GO TO 175
      SEG = AMAX1((IYMAX/(11.-LEVEL)),IYMIN/(1.-LEVEL))
      DO 35 KI=1,12
      IF(SEGM(KI) .GE. SEG) GO TO 36
   35 CONTINUE
   36 YMAX = SEGM(KI)*(11-LEVEL)*10.**ISCALE
      YMIN = SEGM(KI)*(1-LEVEL)*10.**ISCALE
      GO TO 1000
   40 YMAX = 0.0
      DO 45 KI=1,12
      IF(10.*SEGM(KI) .GE. (1-IYMIN)) GO TO 46
```

```
   45 CONTINUE                                                       ROND0380
   46 YMIN = -SEGM(KI)*10.**(ISCALE+1)                               ROND0390
      GO TO 1000                                                     ROND0400
   50 YMIN = 0.0                                                     ROND0410
      DO 55 KI=1,12                                                  ROND0420
      IF(10.*SEGM(KI) .GE. (IYMAX-1)) GO TO 56                       ROND0430
   55 CONTINUE                                                       ROND0440
   56 YMAX = SEGM(KI)*10.**(ISCALE+1)                                ROND0450
      GO TO 1000                                                     ROND0460
  175 YMAX = 1.*IYMAX * 10.**ISCALE                                  ROND0470
      YMIN = 1.*IYMIN * 10.**ISCALE                                  ROND0480
      KI = 12                                                        ROND0490
 1000 YMAX = YMAX * 1.00001                                          ROND0500
      YMIN = YMIN * 1.00001                                          ROND0510
      RETURN                                                         ROND0520
      END                                                            ROND0530
      SUBROUTINE DWFM(NC)                                            DWFM0010
C                                                                    DWFM0020
C******** DRY WEATHER FLOW MODEL                                     DWFM0030
C                                                                    DWFM0040
      INTEGER IDATE1,IDATE2,IDATE3                                   DWFM0050
      COMMON INPT,IOUT                                               DWFM0060
      COMMON/SET2/ATOT,DWF,PCTTRT(3),DWFBOD,X,E,ALPHA1,ALPHA2,BETA1, DWFM0070
     1 BETA2,RF(3),DX,TRTPCT(3),ITSAG,IDISKW,IDISKD,IPR1,IPR2,IPR3,IPR4,DWFM0080
     2 XK1MAX,XK1MIN,GAMMA1,GAMMA2                                   DWFM0090
      COMMON/SET3/XM2(3),DDATA1( 31,3,3),RFLOW,RBOD,                 DWFM0100
     1 RTEMP,RDO,F1(3),F2(3),U(3),V(3),XC(3,3),                      DWFM0110
     2 TC(3,3),F(3),ULTLO(3,3),XK2T(3),DO(3),FLC(3),DC(3,3),DOCONC(3,3),DWFM0120
     3 XIDE(3,3),TE(3),DT(3,3),DXCNC(3,3),DPCT(3,31),CD(31),XM1(3),  DWFM0130
     4 XG(3),XJ(3),XDG(101),XD,TX,DTX,DTXCN,DOXDX(3,101),DOXDX1(101),DWFM0140
     5 XM12(3),H(3),DENOM(3),XK1T(3),DUMMY(8723)                     DWFM0150
      INTEGER TITLE1(20),YTITL1(51),LABEL1(20),STITLE(20),JKEY(3)    DWFM0160
      INTEGER DFREQ(31),TITLE(20),YTITLF(51),LABEL(20),KKEY(3)       DWFM0170
      DATA TITLE1/'DISS','OLVE','D OX','YGEN',' PRO','FILE','S : ',  DWFM0180
     1 'K=1 ',12*'    '/                                             DWFM0190
      DATA STITLE/'DISS','OLVE','D OX','YGEN',' PRO','FILE',' :  ',  DWFM0200
     1 'K=1 ','    ','PERC','ENT ','TREA','TMEN','T : ','J=1 ',      DWFM0210
     2 5*'    '/                                                     DWFM0220
      DATA YTITL1/'D','I','S','S','O','L','V','E','D',' ','O','X',   DWFM0230
     1 'Y','G','E','N',' ','C','O','N','C','E','N','T','R','A',,     DWFM0240
     2 'T','I','O',',',' ','M','G','/','L',15*' '/                   DWFM0250
      DATA LABEL1/'DIST','ANCE',' DOW','NSTR','EAM,',' MIL','ES  ',  DWFM0260
     1 13*'    '/                                                    DWFM0270
      DATA JKEY/'J=1 ','J=2 ','J=3 '/                                DWFM0280
      DATA KKEY/'K=1 ','K=2 ','K=3 '/                                DWFM0290
      DATA TITLE/'NORM','ALIZ','ED C','UMUL','ATIV','E : ','K= 1',   DWFM0300
     1 '; (C','URVE',' 1=P','RIMA','RY,2','=SEC','ONDA','RY,3',      DWFM0310
     2 '=TER','TIAR','Y)  ',2*'    '/                                DWFM0320
      DATA YTITLE/'%','D','R','Y',' ','W','E','A','T','H','E','R',   DWFM0330
     1 ' ','D','A','Y','S',' ','E','X','C','E','E','D','I','N',      DWFM0340
```

```
     2 'G',' ','G','I','V','E','N',' ','D','O',14*' '/
      DATA LABEL/'DO C','ONCE','NTRA','TION',', MG','/L  ',
     1 '  0<-','----','--->','15.0',':   ','0.5 ','STEP','S   ',
     2 6*'    '/
      DATA IBLANK,IONE/' ','1'/
C
      DO 950 I=1,31
      DO 950 J=1,3
      DO 950 K=1,3
      DDATA1(I,J,K)=0.0
  950 CONTINUE
C
C
C>>>>>>>> READ CARD TYPE 14 <<<<<<<<
C
      READ(INPT,1000)ND,ICALC3,ICALC4,ICALCD,IPRD,IDISKD
 1000 FORMAT(6I5)
      IF (IDISKD.NE.0) REWIND IDISKD
C
      WRITE(IOUT,1070)
 1070 FORMAT(32H1*******************************)
      WRITE(IOUT,1080)
 1080 FORMAT(32H ***** OXYGEN SAG ANALYSIS *****)
      WRITE(IOUT,1090)
 1090 FORMAT(32H *****  DWF WASTES ONLY    *****)
      WRITE(IOUT,1100)
 1100 FORMAT(32H *******************************)
      WRITE(IOUT,1110)
 1110 FORMAT(////33H ********************************)
      WRITE(IOUT,1120)ND
 1120 FORMAT(23H ***** DAYS SIMULATED =,I4,6H *****)
      WRITE(IOUT,1123) ICALC3
 1123 FORMAT(' *****    ICALC3 = ',I5,'     *****')
      WRITE(IOUT,1124) ICALC4
 1124 FORMAT(' *****    ICALC4 = ',I5,'     *****')
      WRITE(IOUT,1121) ICALCD
 1121 FORMAT(' *****    ICALCD = ',I5,'     *****')
      WRITE(IOUT,1122) IPRD
 1122 FORMAT(' *****    IPRD = ',2X,I5,'     *****')
      WRITE(IOUT,1125) IDISKD
 1125 FORMAT(' *****    IDISKD = ',I5,'     *****')
      WRITE(IOUT,1126) IPR1
 1126 FORMAT(' *****    IPR1 = ',2X,I5,'     *****')
      WRITE(IOUT,1127) IPR2
 1127 FORMAT(' *****    IPR2 = ',2X,I5,'     *****')
      WRITE(IOUT,1130)
 1130 FORMAT(33H ********************************)
      XND=ND
      D=X/5280.0
      Z=3600.*24.
```

```
      ANAVFL=0.0
C     MIXING AND RECEIVING STREAM MATHEMATICAL MODEL
      DO 5000 I=1,ND
C
C
C>>>>>>>> READ CARD TYPE 15 <<<<<<<<
C
      READ(INPT,1050) IDATE1,IDATE2,IDATE3,RFLOW,RBOD,RTEMP,RDO
 1050 FORMAT(3I2,4X,4F10.0)
C
      CS=14.652-0.41022*RTEMP+0.007991*(RTEMP**2.)-0.000077774*RTEMP**3.
      CO=CS-RDO
      IF (CO.LT.0.0) CO=0.0
      DO 2000 K=1,3
      FLO(K)=RFLOW*RF(K)+DWF
      H(K)=BETA1*FLO(K)**BETA2
      XK1=GAMMA1*H(K)**GAMMA2
      IF(XK1.GT.XK1MAX*24.) XK1=XK1MAX*24.0
      IF(XK1.LT.XK1MIN*24.) XK1=XK1MIN*24.0
      XK1T(K)=XK1*1.047**(RTEMP-20.0)
      DENOM(K)=(1.-EXP(-5.*XK1T(K)))/(0.02*RTEMP+0.6)
      XNUM=7.5999*(1.024**(RTEMP-20.))*(ALPHA1/BETA1**1.33)
      XK2T(K)=XNUM*(FLO(K)**(ALPHA2-1.33*BETA2))
      DO(K)=(RFLOW*RF(K)*CO)/FLO(K)
      U(K)=(ALPHA1*Z)*FLO(K)**ALPHA2
      V(K)=U(K)/Z
      F(K)=XK2T(K)/XK1T(K)
      F1(K)=F(K)-1.
      F2(K)=XK2T(K)-XK1T(K)
      TE(K)=0.0
      IF(U(K).GT.0.0) TE(K)=X/U(K)
      XM1(K)=SQRT(1.0+(4.0*XK1T(K)*E)/U(K)**2.)
      XM2(K)=SQRT(1.0+(4.0*XK2T(K)*E)/U(K)**2.)
      XM12(K)=XM1(K)-XM2(K)
      XJ(K)=0.0
      XG(K)=0.0
      IF(E.NE.0.0)  XJ(K)=(U(K)**2.)*(1.0-XM1(K))/(2.0*E)
      IF(E.NE.0.0) XG(K)=(U(K)**2.)*(1.0-XM2(K))/(2.0*E)
 2000 CONTINUE
      DO 2100 J=1,3
      DO 2100 K=1,3
      ULTLO(J,K)=(RFLOW*RF(K)*RBOD+DWF*PCTTRT(J)*DWFBOD)/FLO(K)/DENOM(K)
 2100 CONTINUE
      WRITE(IOUT,2200)
 2200 FORMAT(///28H1***************************)
      WRITE(IOUT,2300) IDATE1,IDATE2,IDATE3
 2300 FORMAT(14H ***** DATE : ,I2,'/',I2,'/',I2,6H *****)
      WRITE(IOUT,2400)
 2400 FORMAT(28H ***************************)
      WRITE(IOUT,2500) RFLOW,RBOD,RTEMP,RDO
```

```
 2500 FORMAT(///24H ***UPSTREAM RIVER FLOW=,F9.2,12H CFS ** BOD=,F6.2,
     /15H MG/L ** TEMP.=,F6.2,19H DEG.CENT. ** D.O.=,F5.2,9H MG/L ***)
C     OXYGEN SAG EQUATIONS
      DO 4500 J=1,3
      DO 4500 K=1,3
      TC(J,K)=0.0
      XC(J,K)=0.0
      IF(ULTLO(J,K).NE.0.0) RO=DO(K)/ULTLO(J,K)
      IF(F1(K).NE.0.0.AND.XM12(K).NE.0.0)  GO TO 3310
      DC(J,K)=ULTLO(J,K)*EXP(DO(K)/ULTLO(J,K)-1.)
      GO TO 3350
 3310 IF(ULTLO(J,K).NE.0.0) GO TO 3320
      DC(J,K)=DO(K)
      GO TO 3350
 3320 IF(RO.GE.0.0.AND.RO.LE.(1.0/F(K)))GO TO 3330
      DC(J,K)=DO(K)
      GO TO 3350
 3330 TC(J,K)=(ALOG(F(K)*(1.0-F1(K)*DO(K)/ULTLO(J,K))))/(XK1T(K)*F1(K))
      DC(J,K)=(XK1T(K)*ULTLO(J,K)/XK2T(K))*EXP(-XK1T(K)*TC(J,K))
      IF(E.EQ.0.)  GO TO 3340
      TC(J,K)=ALOG(((XM1(K)/XM2(K))-RO*F(K)+RO)*XG(K)/XJ(K))/(XJ(K)-XG(K
     .))
      DC(J,K)=(ULTLO(J,K)*XK1T(K))/(XK2T(K)-XK1T(K))*(EXP(XJ(K)*TC(J,K))
     1-(XM1(K)/XM2(K))*EXP(XG(K)*TC(J,K)))+DO(K)*EXP(XG(K)*TC(J,K))
 3340 XC(J,K)=U(K)*TC(J,K)/5280.0
 3350 DOCONC(J,K)=CS-DC(J,K)
      IF(DC(J,K).GT.CS) DOCONC(J,K)=0.0
      IF (DC(J,K).GT.CS) DC(J,K)=CS
      IF(F2(K).NE.0.0)  GO TO 3360
      DT(J,K)=XK1T(K)*ULTLO(J,K)*TE(K)*EXP(-XK1T(K)*TE(K))+DO(K)*EXP(-XK
     12T(K)*TE(K))
      GO TO 3370
 3360 DT(J,K)=(EXP(-XK1T(K)*TE(K))-EXP(-XK2T(K)*TE(K)))*XK1T(K)*ULTLO(J,
     1K)/F2(K)+DO(K)*EXP(-XK2T(K)*TE(K))
      IF(E.EQ.0.)  GO TO 3370
      DT(J,K)=(ULTLO(J,K)*XK1T(K))/F2(K)*(EXP(XJ(K)*TE(K))-(XM1(K)/XM2(K
     1))*EXP(XG(K)*TE(K)))+DO(K)*EXP(XG(K)*TE(K))
 3370 DXCNC(J,K)=CS-DT(J,K)
      IF(DT(J,K).GT.CS) DXCNC(J,K)=0.0
      IF (DT(J,K).GT.CS) DT(J,K)=CS
      IF (ITSAG.EQ.1.AND.J.EQ.IPR1.AND.K.EQ.IPR2)
     1 WRITE(IDISKD) IDATE1,IDATE2,IDATE3,DXCNC(J,K)
C     METHOD OF INTEGRATING DEFICIT EQUATION
      XIDE(J,K)=(ULTLO(J,K)+DO(K))/XK2T(K)
      IF (E.NE.0.0) XIDE(J,K)=ULTLO(J,K)*XK1T(K)/(XK2T(K)-XK1T(K))*
     1 (XM1(K)/(XM2(K)*XG(K))-1./XJ(K))-DO(K)/XG(K)
      ICHAR=IBLANK
      IF (J.EQ.3.AND.K.EQ.2) ICHAR=IONE
      WRITE(IOUT,4000) ICHAR,TRTPCT(J),RF(K),FLC(K)
 4000 FORMAT(//A1,10H***PCTTRT=,F4.2,21H   RIVER FLOW FRACTN=,F4.2,
```

```
     .21H   ***TOT.RIVER FLOW=,F7.1,10H   CFS ***)
      WRITE(IOUT,4100)DC(J,K),DOCONC(J,K),CS,XIDE(J,K)
 4100 FORMAT(21H ***CRITICAL DEFICIT=,F6.2,18H   MG/L ** DOCONC=,F6.2,21
     /H   MG/L ** SAT. D.O.=,F6.2,23H   MG/L ** INT.DEF.EQN=,F8.2,
     /15H   MG-DAY/L ***)
      WRITE(IOUT,4200)DT(J,K),DXCNC(J,K)
 4200 FORMAT(17H ***D.O. DEFICIT=,F6.2,18H   MG/L ***D.O.@X=,F6.2,
     /11H   MG/L ***)
      WRITE(IOUT,4300)TC(J,K),XC(J,K),TE(K),D,V(K)
 4300 FORMAT(8H *** TC=,F7.2,15H   DAYS *** XC=,F6.2,14H   MI. *** TX=,
     /F7.2,20H   DAYS *** DIST. X=,F6.2,16H   MI. *** VEL.=,F5.2,
     /10H   FPS ***)
      WRITE(IOUT,4400)XK1T(K),XK2T(K),ULTLO(J,K),H(K)
 4400 FORMAT(9H *** K1T=,E11.5,15H 1/DAY *** K2T=,E11.5,24H 1/DAY *** UL
     /TIMATE BOD=,F10.1,17H MG/L *** DEPTH =,F6.2,10H  FEET ***)
      NN1=1
      IF (ICALC3.EQ.1 .OR. ICALC4.EQ.1) NN1=1.0+DOCONC(J,K)*2.0
      IF (ICALC3.EQ.2 .OR. ICALC4.EQ.2) NN1=1.0+DXCNC(J,K)*2.0
      IF (NN1.LT.1) NN1=1
      IF (NN1.GT.31) NN1=31
      DDATA1(NN1,J,K)=DDATA1(NN1,J,K)+1.0
 4500 CONTINUE
C
C <<<<<<<<<<     D.O. PROFILE CALCULATIONS     >>>>>>>>>>
C
      IF (ICALCD.EQ.0) GO TO 7400
      TITLE1(8)=KKEY(IPRD)
      STITLE(8)=KKEY(IPRD)
      DO 7000 IDX=1,101
         XDG(IDX)=(IDX-1)*DX
         XD=XDG(IDX)*5280.0
         DO 7000 J=1,3
            TX=XD/U(IPRD)
            IF (F2(IPRD).NE.0.0.AND.XM12(IPRD).NE.0.0) GO TO 7100
            DTX=XK1T(IPRD)*ULTLO(J,IPRD)*TX*EXP(-XK1T(IPRD)*TX)+DO(IPRD)
     1          *EXP(-XK2T(IPRD)*TX)
            GO TO 7150
 7100       DTX=XK1T(IPRD)*ULTLO(J,IPRD)*(EXP(-XK1T(IPRD)*TX)-
     1     EXP(-XK2T(IPRD)*TX))/ F2(IPRD)+DO(IPRD)*EXP(-XK2T(IPRD)*TX)
            IF (E.EQ.0.0) GO TO 7150
            DTX=(ULTLO(J,IPRD)*XK1T(IPRD))/F2(IPRD)*(EXP(XJ(IPRD)*TX)-
     1           (XM1(IPRD)/XM2(IPRD))*EXP(XG(IPRD)*TX))+DO(IPRD)*
     2           EXP(XG(IPRD)*TX)
 7150       DTXCN=CS-DTX
            IF (DTX.GT.CS) DTXCN=0.0
            IF (DTX.GT.CS) DTX=CS
            DOXDX(J,IDX)=DTXCN
 7000    CONTINUE
C
C <<<<<<<<<<     END OF D.O. PROFILE CALCULATIONS     >>>>>>>>>>
```

```
C
C
C <<<<<<<<<<     PRINT OUT MATRIX CF D.O. VALUES     >>>>>>>>>>
C
      WRITE(IOUT,7050) DX
 7050 FORMAT(/////' ',84('*'),/' **   DISSOLVED OXYGEN PROFILES FOR ',
     1 'ALL DRY WEATHER FLOW TREATMENT RATES (J=1,3)   **',/' **',
     2 10X,'DISTANCE --> 100 INTERVALS, EACH INTERVAL = ',F10.2,
     3 ' MILES',10X,'**',/' **',33X,'UNITS IN MG/L',34X,'**',/
     4 ' ',84('*'))
      DO 7200 J=1,3
         WRITE(IOUT,7250) TRTPCT(J),(DOXDX(J,IDX),IDX=1,101)
 7250    FORMAT(///' PERCENT TREATMENT = ',F4.2,':',6(/10X,20F6.2))
 7200    CONTINUE
      IF (ICALCD.EQ.1) GO TO 7400
      IF (ICALCD.EQ.2) CALL MGRAPH(XDG,DOXDX,101,3,TITLE1,YTITL1,LABEL1)
      IF (ICALCD.LT.3) GO TO 7400
      ICOMB=ICALCD-2
      DO 7300 IDX=1,101
         DOXDX1(IDX)=DOXDX(ICOMB,IDX)
         STITLE(15)=JKEY(ICOMB)
 7300    CONTINUE
      CALL MGRAPH(XDG,DOXDX1,101,1,STITLE,YTITL1,LABEL1)
 7400 CONTINUE
      ANAVFL=ANAVFL+FLO(3)/ND
 5000 CONTINUE
      WRITE(IOUT,5100)
 5100 FORMAT(1H1)
      WRITE(IOUT,5200)ANAVFL
 5200 FORMAT(///////////32H *** ANNUAL AVE. TOT.RIVER FLOW=,F7.1,10H   C
     /FS ***)
C
C******** FREQUENCY ANALYSIS OF DISSOLVED OXYGEN CONCENTRATIONS
C
      DO 6000 I=1,31
 6000 CD(I)=(I-1)*0.5
      DO 6050 K=1,3
      TITLE(7)=KKEY(K)
      DO 6040 J=1,3
      DO 6010 I=1,31
 6010    DFREQ(I)=DDATA1(I,J,K)
      IF( ICALC3.EQ.0)  GO TO 6035
C
      CALL PLOT(CD,DFREQ,31,ND)
C***********************************************************************
C
      WRITE(IOUT,6030)J,K
 6030 FORMAT(//6H ***J=,I1,6H ***K=,I1)
      WRITE(IOUT,6032) ND
 6032 FORMAT(/////20H NORMALIZING FACTOR=,I4,7H D.DAYS)
```

```
 6035 NN2 = 0
      DO 6040 I=1,31
      NN2 = NN2 + DFREQ(I)
 6040 DPCT(J,I)=100.*(XND-NN2)/XND
C
      IF(ICALC4.GE.1)  CALL MGRAPH(CD,DPCT,31,3,TITLE,YTITLE,LABEL)
C*********************************************************************
C
 6050 CONTINUE
      RETURN
      END
      SUBROUTINE DOSAG(NEVNTS,ND)
      REAL DO(51),X,TDOW,TDOD,EVENT(51)
      INTEGER TITLE(20),LABEL(20),YTITLE(51),TDATEW(3),
     1        TDATED(3),NRKEY(10),BLANK
      INTEGER DATE(51,3),N,IDISKW,IDISKD,D,W,NEVNTS,ND
      INTEGER JKEY(3),KKEY(3),LKEY(3),MKEY(5)
      COMMON INPT,IOUT
      COMMON/SET2/ATOT,DWF,PCTTRT(3),DWFBOD,X,E,ALPHA1,ALPHA2,BETA1,
     1 BETA2,RF(3),DX,TRTPCT(3),ITSAG,IDISKW,IDISKD,IPR1,IPR2,IPR3,IPR4,
     2 XK1MAX,XK1MIN,GAMMA1,GAMMA2
      DATA JKEY/'J=1 ','J=2 ','J=3 '/,KKEY/'K=1 ','K=2 ','K=3 '/,
     1     LKEY/'L=1 ','L=2 ','L=3 '/,MKEY/'M=1 ','M=2 ','M=3 ',
     2      'M=4 ','M=5 '/
      DATA TITLE/'DISS','OLVE','D OX','YGEN',' PRO','FILE',
     1      ',    ',13*'    '/
      DATA YTITLE/'D','O',' ','C','O','N','C','E','N','T','R',
     1      'A','T','I','O','N',' ','A','T',' ','X',' ','=',7*' ','.',
     2      3*' ','M','I','L','E','S',' ','I','N',' ','M','G','/',
     3      'L',4*' '/
      DATA BLANK/' '/,NRKEY/'0','1','2','3','4','5','6','7','8','9'/
      DATA LABEL/'SIMU','LATE','D EV','ENTS',',NOT',' TIM','E-SC',
     1 'ALED',' ON ','GRAP','H (S','EE T','ABLE',' ABO',
     1 'VE) ',5*'    '/
       N=NEVNTS+ND
       TITLE(8)=JKEY(IPR1)
       TITLE(9)=KKEY(IPR2)
       X=X/5280.0
       T=X
       IFLAG=0
       DO 20 I=1,9
          Y=T/(10.0**(9-I)/100.0)
          INTGR=IFIX(Y)+1
          IF (INTGR.GT.1) IFLAG=1
          J=I
          IF (I.GE.8) J=J+1
          YTITLE(23+J)=NRKEY(INTGR)
          IF (IFLAG.EQ.0.AND.INTGR.EQ.1.AND.J.LT.8) YTITLE(23+J)=BLANK
          REALN=INTGR-1
          T=T-(REALN*(10.0**(9-I)/100.0))
```

```
 20     CONTINUE
      IF (IDISKW.GT.0) REWIND IDISKW
      IF (IDISKD.GT.0) REWIND IDISKD
      ICNT=0
      IF (ND.EQ.0.AND.NEVNTS.GT.0) GO TO 100
      IF (ND.GT.0.AND.NEVNTS.EQ.0) GO TO 200
      IF (ND.GT.0.AND.NEVNTS.GT.0) GO TO 300
      WRITE(IOUT,10)
 10   FORMAT(//' NEVNTS AND ND VALUES EQUAL TO 0 CONFLICT WITH '
     1 'VALUE OF ITSAG GREATER THAN 0')
      GO TO 999
C
C <<<<<<<<<<      WET WEATHER DO VALUES ONLY      >>>>>>>>>>
C
 100  TITLE(10)=LKEY(IPR3)
      TITLE(11)=MKEY(IPR4)
      DO 150 I=1,N
         ICNT=ICNT+1
         EVENT(ICNT)=I
         READ(IDISKW) (DATE(ICNT,I2),I2=1,3),DO(ICNT)
         IF (ICNT.LT.51) GO TO 125
            WRITE(IOUT,110) X
 110        FORMAT('1',/' LISTING OF WET WEATHER EVENTS AND CORRESPOND'
     1       ,'ING D.O. VALUES AT X = ',F10.2,' MILES DOWNSTREAM',
     2       ///' EVENT NO.',T17,
     3       'DATE',T30,'D.O.'/'+__________',T17,'____',T30,'____'/)
            DO 130 I1=1,51
               WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DO(I1)
 115           FORMAT(' ',F8.0,T15,I2,'/',I2,'/',I2,T29,F6.2)
 130           CONTINUE
            CALL MGRAPH(EVENT,DO,51,1,TITLE,YTITLE,LABEL)
            ICNT=0
            GO TO 150
 125     IF (I.LT.N) GO TO 150
            WRITE(IOUT,110) X
            DO 140 I1=1,ICNT
               WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DO(I1)
 140           CONTINUE
            I3=ICNT+1
            DO 145 I1=I3,51
               EVENT(I1)=N+1+I1-I3
               DO(I1)=0.0
 145           CONTINUE
            CALL MGRAPH(EVENT,DO,51,1,TITLE,YTITLE,LABEL)
 150     CONTINUE
      GO TO 999
C
C <<<<<<<<<<      DRY WEATHER DO VALUES ONLY      >>>>>>>>>>
C
 200  DO 250 I=1,N
```

```
      ICNT=ICNT+1
      EVENT(ICNT)=I
      READ (IDISKD) (DATE(ICNT,I2),I2=1,3),DO(ICNT)
      IF (ICNT.LT.51) GO TO 225
         WRITE(IOUT,210) X
  210    FORMAT('1',/' LISTING OF DRY WEATHER EVENTS AND CORRESPOND',
     1   'ING D.O. VALUES AT X = ',F10.2,' MILES DOWNSTREAM',///
     2   ' EVENT NO.',
     3   T17,'DATE',T30,'D.O.'/'+_________',T17,'____',T30,'____'/)
         DO 230 I1=1,51
            WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DO(I1)
  230       CONTINUE
         CALL MGRAPH(EVENT,DO,51,1,TITLE,YTITLE,LABEL)
         ICNT=0
         GO TO 250
  225 IF (I.LT.N) GO TO 250
         WRITE(IOUT,210) X
         DO 240 I1=1,ICNT
            WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DO(I1)
  240       CONTINUE
         I3=ICNT+1
         DO 245 I1=I3,51
            EVENT(I1)=N+1+I1-I3
            DO(I1)=0.0
  245       CONTINUE
         CALL MGRAPH(EVENT,DO,51,1,TITLE,YTITLE,LABEL)
  250 CONTINUE
    GO TO 999
C
C <<<<<<<<<<     WET AND DRY WEATHER VALUES     >>>>>>>>>>
C
  300 TITLE(10)=LKEY(IPR3)
      TITLE(11)=MKEY(IPR4)
      READ(IDISKW) (TDATEW(I1),I1=1,3),TDOW
      W=0
      READ(IDISKD) (TDATED(I2),I2=1,3),TDOD
      D=0
      NMIN1=N-1
      DO 450 I=1,NMIN1
         ICNT=ICNT+1
         EVENT(ICNT)=I
         IF (W.EQ.NEVNTS) GO TO 320
         IF (D.EQ.ND) GO TO 310
         IF (TDATEW(3).LT.TDATED(3)) GO TO 310
            IF (TDATEW(3).GT.TDATED(3)) GO TO 320
               IF (TDATEW(1).LT.TDATED(1)) GO TO 310
                  IF (TDATEW(1).GT.TDATED(1)) GO TO 320
                     IF (TDATEW(2).LT.TDATED(2)) GO TO 310
  320    DO(ICNT)=TDOD
         DO 330 I1=1,3
```

```
         DATE(ICNT,I1)=TDATED(I1)
 330     CONTINUE
      D=D+1
      IF (D.EQ.ND) GO TO 350
      READ (IDISKD) (TDATED(I2),I2=1,3),TDDD
      GO TO 350
 310  DD(ICNT)=TDDW
      DO 340 I1=1,3
         DATE(ICNT,I1)=TDATEW(I1)
 340     CONTINUE
      W=W+1
      IF (W.EQ.NEVNTS) GO TO 350
      READ(IDISKW) (TDATEW(I1),I1=1,3),TDDW
 350  IF (ICNT.LT.51) GO TO 450
         WRITE(IOUT,410) X
 410     FORMAT('1',/' LISTING OF COMPOSITE WET AND DRY WEATHER ',
     1   'EVENTS AND CORRESPONDING D.O. VALUES AT X = ',F10.2,
     2   ' MILES DOWNSTREAM',///' EVENT NO.',T17,'DATE',T30,'D.O.'/
     3   '+_________',T17,'____',T30,'____'/)
         DO 430 I1=1,51
            WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DD(I1)
 430        CONTINUE
         CALL MGRAPH(EVENT,DD,51,1,TITLE,YTITLE,LABEL)
         ICNT=0
 450   CONTINUE
      ICNT=ICNT+1
      EVENT(ICNT)=N
      IF (W.LT.NEVNTS) GO TO 455
         DD(ICNT)=TDDD
         DO 453 I2=1,3
            DATE(ICNT,I2)=TDATED(I2)
 453        CONTINUE
         GO TO 460
 455     DD(ICNT)=TDDW
         DO 458 I2=1,3
            DATE(ICNT,I2)=TDATEW(I2)
 458        CONTINUE
 460  WRITE(IOUT,410) X
      DO 440 I1=1,ICNT
         WRITE(IOUT,115) EVENT(I1),(DATE(I1,I2),I2=1,3),DD(I1)
 440     CONTINUE
      I3=ICNT+1
      DO 445 I1=I3,51
         EVENT(I1)=N+1+I1-I3
         DD(I1)=0.0
 445     CONTINUE
      CALL MGRAPH(EVENT,DD,51,1,TITLE,YTITLE,LABEL)
 999  RETURN
      END
```

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

Project Officers: Richard Field and Chi-Yuan Fan, Storm and Combined Sewer Section, Edison, N.J., (201) 321-6674, FTS 340-6674

16. ABSTRACT

A simplified continuous receiving water quality model has been developed as a planning guide to permit preliminary screening of areawide wastewater treatment strategies. The model simulates the hypothetical response of the stream or tidal river system to the separate and combined effects of waste inputs from: 1) upstream sources, 2) dry weather urban sources, and 3) wet weather urban sources. The total hours of runoff-producing rainfall throughout a year are separated into storm events by defining a minimum interevent time. For a given storm event, the runoff and pollutant loads are summed and critical dissolved oxygen concentrations are estimated as a function of several hydrodynamic and biochemical parameters. Alternative control strategies are evaluated in terms of relative impacts by determining the probability of occurrence of water quality violations. Model output includes the downstream dissolved oxygen sag curves computed per each event, and the dissolved oxygen profile computed at a user-specified location downstream for all simulated events. An application to the Des Moines River at Des Moines, Iowa, is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Combined sewers, Storm sewers, Mathematical models, Surface water runoff, Computer programs, Stream pollution, Water pollution	Urban runoff pollution, Des Moines (Iowa), Combined sewer overflows, Water pollution effects, Urban hydrology, Hydrologic models, Water pollution treatment	13B
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