DEVELOPMENT OF FREQUENCY FUNCTIONS FOR NON POINT SOURCE RISK EVALUATION

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DEVELOPMENT OF FREQUENCY
FUNCTIONS FOR URBAN NON-POINT
SOURCE RISK EVALUATION

FINAL REPORT

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# TABLE OF CONTENTS

INTRODUCTION ................................................. 1
1.1 General ................................................. 1
1.2 Problem Definition ................................. 2
1.3 Objective .............................................. 4
1.4 Method ................................................ 4

LITERATURE REVIEW ............................... 6

MODEL DEVELOPMENT .......................... 10
3.1 Objective ........................................... 10
3.2 General Logic of the Model ................. 11
3.3 Model Building and Verification .......... 13
3.4 Model Variables and Parameters ........... 15
3.5 Model Components .............................. 18
3.6 Evapotranspiration, Infiltration and Percolation 21
3.7 Pollutant Loading .............................. 23
3.8 Pollutant Emission ............................. 24
3.9 Computational Form ............................ 26
3.10 Summary of Principal Assumptions ....... 28

APPLICATION TO FIELD DATA ............... 30
4.1 Field Data Selection ......................... 30
4.2 Description of Data Sites ................... 31
4.3 Data Selection and Preparation .......... 32
4.4 Data Analysis .................................... 33

RESULTS ............................................... 35
5.1 Method of Computation .................... 35
5.2 Calibration Results .......................... 36
5.3 Verification Results ......................... 50
5.4 Summary .......................................... 61
TABLE OF CONTENTS (Cont'd.)

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS.</td>
<td>63</td>
</tr>
<tr>
<td>6.1 Conclusions</td>
<td>63</td>
</tr>
<tr>
<td>6.2 Recommendations</td>
<td>64</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>66</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>68</td>
</tr>
<tr>
<td>A. Computer Program Listing</td>
<td></td>
</tr>
<tr>
<td>B. Measured and Predicted Probability Density Functions</td>
<td></td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1. Field Data Site Characteristics</td>
<td>30</td>
</tr>
<tr>
<td>Table 2. Means and Standard Deviations</td>
<td>33</td>
</tr>
<tr>
<td>Table 3. Initial Estimates of Parameter Values (Burke Pond Site)</td>
<td>37</td>
</tr>
<tr>
<td>Table 4. Optimum Parameter Values (Burke Pond Site)</td>
<td>38</td>
</tr>
<tr>
<td>Table 5. Comparison of Actual and Predicted Moments (Burke Pond Site)</td>
<td>44</td>
</tr>
<tr>
<td>Table 6. Optimum Parameter Sensitivity Analysis</td>
<td>51</td>
</tr>
<tr>
<td>Table 7. Optimum Parameter Values (Stedwick Inlet Site)</td>
<td>52</td>
</tr>
<tr>
<td>Table 8. Comparison of Actual and Predicted Moments</td>
<td>58</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Model Elements Logic Flow Chart.</td>
</tr>
<tr>
<td>2</td>
<td>Infiltration - Soil Moisture Relationship</td>
</tr>
<tr>
<td>3</td>
<td>Maximum Onset Infiltration-Rainfall Relationship</td>
</tr>
<tr>
<td>4</td>
<td>Comparison of Actual and Predicted Runoff Series, Burke Pond Site.</td>
</tr>
<tr>
<td>5</td>
<td>Comparison of Actual and Predicted COD Time Series, Burke Pond Site.</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of Actual and Predicted TP Time Series, Burke Pond Site.</td>
</tr>
<tr>
<td>7</td>
<td>Comparison of Actual and Predicted TN Values, Burke Pond Site.</td>
</tr>
<tr>
<td>8</td>
<td>Comparison of Actual and Predicted Runoff Functions, Burke Pond Site.</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of Actual and Predicted COD Frequency Functions, Burke Pond Site.</td>
</tr>
<tr>
<td>10</td>
<td>Comparison of Actual and Predicted TP Frequency Functions, Burke Pond Site.</td>
</tr>
<tr>
<td>11</td>
<td>Comparison of Actual and Predicted TN Frequency Functions, Burke Pond Site.</td>
</tr>
<tr>
<td>12</td>
<td>Comparison of Actual and Predicted Runoff Time Series, Stedwick Inlet Site.</td>
</tr>
<tr>
<td>13</td>
<td>Comparison of Actual and Predicted COD Time Series, Stedwick Inlet Site.</td>
</tr>
<tr>
<td>14</td>
<td>Comparison of Actual and Predicted TP Time Series, Stedwick Inlet Site.</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Figure 15. Comparison of Actual and Predicted TN Values, Stedwick Inlet Site</td>
<td>57</td>
</tr>
<tr>
<td>Figure 16. Comparison of Actual and Predicted Runoff Frequency Functions, Stedwick Inlet Site</td>
<td>59</td>
</tr>
<tr>
<td>Figure 17. Comparison of Actual and Predicted COD Frequency Functions, Stedwick Inlet Site</td>
<td>60</td>
</tr>
<tr>
<td>Figure 18. Comparison of Actual and Predicted TP Frequency Functions, Stedwick Inlet Site</td>
<td>61</td>
</tr>
<tr>
<td>Figure 19. Comparison of Actual and Predicted TN Frequency Functions, Stedwick Inlet Site</td>
<td>62</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

1.1 General

The objective of this research is to develop a microprocessor based simulation tool for predicting the concentrations of non-point source pollutants in urban water systems. The developed procedure will be used to assess the risk of urban water pollution from non-point sources.

Research over the past decade has resulted in the development of complex models of water runoff, sediment erosion and chemical migration into water systems. Such models are generally not useful as practical water pollution management tools due to their complex structure and the required use of a large scale computer for their application. On the other hand, such models have been shown, upon calibration and verification, to yield measures of pollution concentrations that are statistically identical to corresponding measures obtained directly from Instrumented watersheds. The models have been used to predict time series outflows of pollutants such as pesticide, nitrogen and phosphorous to surface waters and to determine chemical residues in the soil.
Sensitivity analyses of the developed models have identified the major parameters that affect the predicted results. Sediment transport is a function of water flow in a system simulation. Also, chemical simulations are driven by the hydrologic and sediment sections of the model, as movements of chemicals are determined by water flow and sediment transport. Initial investigations indicated that the sensitivity results and findings of previous investigations, using the complex simulations, could be employed to develop a conceptually simpler analysis that depends on a smaller number of parameters and that can be implemented in a microprocessor simulation. The microprocessor based simulation may then be readily used to develop statistical measures of the time-varying concentration of contaminants. Calculations may then be made to determine pollution measures such as frequency of occurrence and durations of specified concentrations, and concentration level distributions.

1.2 Problem Definition

Non-point source pollution is an area of increasing concern to urban environments such as Washington, D.C. Surface waters in such areas are degraded by pollutants, particularly sediment and
siltation from surrounding lands. Previous investigations have employed mathematical models to simulate the process of water transport and sediment erosion through which pollutants are introduced into the environment. Such simulations have been shown to yield a high degree of accuracy when calibrated and compared to measurements made from test watersheds. Previous model investigations have been performed in complex, large scale computer simulations, resulting in time consuming and expensive simulation assessments. Urban planners require practical tools to assess the risk of non-point pollution in urban environments; such tools must be easily accessible, convenient to use and cost effective.

The approach of this investigation entails the adaptation and simplification of existing rainfall, runoff, soil moisture and sedimentation models in a microprocessor based simulation. The research results provide a management tool for evaluating the probability that a specified level of pollution will occur, given information on the extent of rainfall and the physical description of the exposed area. The developed tool can be used in the assessment of pollution exposure and in the evaluation of the risk of non-point source pollution.
The objective is to develop and test a daily time increment small watershed continuous simulation model of non-point source pollution emissions. The model is to incorporate soil moisture accounting, soil loss computations for pervious areas and pollutant accumulation and wash-off computations for impervious areas. The model parameters are to form a small and manageable set. To the extent practical, members of the parameter set will be selected using physical characteristics of the watershed. The remaining small subset will be calibration parameters. The intended use of the model is to study the convolution of rainfall distributions to pollutant distributions using the method of derived distributions. The derived distributions are to be determined using time series simulations.

1.4 Method

The variables and logic of previously developed complex models of the physical processes will be analyzed by examining sensitivity results. Those variables and model assumptions that have little to no bearing on results will be eliminated. Simplifications will be sought that are conceptually correct and which capture as much of the output response as possible. These
simplifications will be integrated into mathematical models that will fit on microcomputers and that generate output time series quickly. The simplified model will be checked against field data, calibrated and verified.
2. LITERATURE REVIEW

Stormwater from urban areas is a serious source of water pollution. Urban runoff quality has been a recurring topic of investigation over the past century. The pollution generated as the result of a rainfall event can exceed that of raw sanitary sewage. The Metropolitan Washington Council of Governments Water Resources Planning Board has found that non-point pollution is a serious surface water quality problem for the Washington area, and planning tools for local non-point pollution management programs are needed. The Environmental Protection Agency 1978 Need Survey estimated that $106 billion for stormwater pollution control will be required by the year 2000. Engineers have been concerned over the years with the problem of estimating urban stormwater runoff. For the most part of last century, engineers used ad hoc rules to assess runoff. A typical rule of thumb is that about half of rainfall would appear as runoff from urban surfaces. Later, empirical formulas became the principal mechanism for determining quantities of urban runoff. Some 100 empirical formulas have been published by Chow (1962). Probably the most prominent empirical formula is the Rational Formula (known as the Lloyd-Davies method in the United Kingdom).
The Rational Formula employs the relation \( Q = CIA \), where \( Q \) is the peak discharge, \( C \) is a runoff coefficient, \( I \) is the rainfall rate in inches per hour for a selected duration equal to the time of concentration for the drainage area and \( A \) is the geographical drawing area. The hydrograph, a graph of discharge versus time, for a storm event extended the rational method from peak flow to flow per unit precipitation.

Hydrograph motivated methods, since their early introduction, have formed the basis for much of the later developments in the estimation of runoffs. Tholin and Keifer (1959) developed the Chicago Hydrograph Method. This graphical method was later computerized by Keifer (1970). Engleson (1962) introduced the unit hydrograph concept to the analysis of sewered drainage areas in an urban catchments.

The search for improved methods of predicting urban water quality, combined with the increasing availability of digital computers led to the introduction of simulation methods. Watkins (1962) reported the development of an urban catchments model called the British Road Research Laboratory Model (RRLM). Dawdy (1965) developed a rainfall-runoff event simulation for the U.S. Geological Survey. Later, this model [Dawdy, et al. (1970] was adapted to urban catchments. Engelson (1970) and his
collaborators at MIT developed the complex MIT model. Most of these earlier models were developed for rural settings, later adapted to urban catchments and generally do not include a water quality component.

Several comprehensive simulation models have been developed which apply to an urban catchments and also include a water quality component. Crawford (1971) reported the development of the Hydro Comp Simulation Program (HSP), as an extension of the Stanford Watershed Model. An urban component has since been added. The EPA (1971) sponsored the development of the Storm Water Management Model (SWMM), a huge (14,000 cards) Program which has been refined in several versions. The University of Cincinnati (1970) developed an urban runoff model (UCURM) which has been widely used (e.g., Danner (1982)). Finally, the U.S. Army Corps of Engineers (1974) developed the Storage, Treatment, Overflow and Runoff Model (Storm).

A major need in the field of urban planning and applied hydrology is to adapt existing models to the assessment of urban water quality in a timely and cost effective manner. Work by Dr. G. K. Young and his collaborators at Catholic University over the past ten years has demonstrated that significant
progress can be made in this regard through the use of systems analyses guided by
data from model verification and calibration studies. (See e.g. Young and Danner
(1982), Michael et al. (1982), Danner, et al. (1974)). This work has resulted in the
introduction of conceptually and computationally simpler simulation tools for
studying water quality in an urban catchments.
This project represents a consolidation and extension of the efforts by Dr. G. K.
Young and his associates to develop conceptually simple and yet accurate tools
for the study and assessment of urban water quality.
3. MODEL DEVELOPMENT

3.1 Objective

The objective of the model is to provide a conceptually valid and computationally simple method to simulate storm runoff and pollution emission form an urban catchments. The model concept is developed from the well documented principles of runoff, evapotranspiration, soil moisture, and sedimentation, combined with pollutant-soil mixing and transport processes. Model simplifications are obtained by exploiting recently developed calibration and testing results relating catchments model sensitivity to specific model parameters. Analysis of these results allow the determination of a small number of key parameters that can be combined in a catchments behavior model which is computationally efficient and yet achieves the prediction accuracy of complex models.

The model is to be used as an intermediate analysis tool to generalize input/output frequency function relationships. Given an input precipitation frequency function in the form of a time series, the model will compute the output frequency functions for runoff volumes and pollutant concentrations. Analysis of the output time series will yield runoff and pollution level exceedance probabilities, in the form of cumulative frequency functions or frequency density functions.
3.2 **General Logic of the Model**

The general logic of the model is shown in Figure 1. The model structure is defined by two input processes consisting of rainfall and dust fall time series, two output processes consisting of runoff and pollution emission time series, and analysis algorithms that transform the input into output.

The rainfall and urban pollutant functions are initially accumulated onto an urban catchments surface consisting of pervious and impervious areas. For ease of discussion and without loss of generality, we assume that there are two continuous and disjoint areas representing the pervious and impervious portions of the catchments.

During periods between storms, the surface accumulation is reduced by the physical processes of evapotranspiration and pollutant decay. During a storm, similar but distinct processes are applied within the pervious and impervious areas. On the pervious area, the pollutant is mixed with the rainfall and is partially or totally removed with the discharge, depending upon the extent of rainfall, geometry of the catchments, and physical properties of the soil and vegetal cover.
Figure 1. Model Elements Logic Flow Chart
Rainfall accumulated on the pervious area is either discharged directly along with the pollutant or it infiltrates the soil surface and enters the vegetation root zone. There, pollutant mixing occurs in a thin active layer, whose thickness is determined by the chemical and soil properties. Portions of the precipitation and pollutant may then be discharged, washed off or retained, depending upon the extent of rainfall, soil moisture, vegetal cover and catchments slope. Some portion of the volume in the root zone may also be lost due to deep percolation as the root zone becomes saturated.

The total runoff and pollutant emission is obtained by summing the amounts from the pervious and impervious areas.

### 3.3 Model Building and Verification

The following model building sequence is followed:

1. Generate a conceptual model logic. The conceptual model is based on known physical relationships, whose parameters can be estimated to the maximum extent practicable, from site specific attributes.

2. Fit as many of the parameters of the conceptual model as possible using a priori logic and site specific data.
3. Utilize statistical measures for the parameters that remain, such as ordinary least squares (OLS); constrain the OLS as necessary to known dimensions and conditions (for example, force the intercept to zero if a zero intercept is called for).

4. Apply the model using given input files to generate a model output time series.

5. Compare the model output time series to the known site measurements and quantitatively evaluate “goodness of fit” using the K-S statistic (Massey (1951)).

6. Calibrate the model's coefficients to achieve a better fit. Conduct the calibration by adjusting those coefficients having the greatest uncertainty associated with them.

7. Guide the calibration with knowledge of parameter sensitivity gained throughout the model building activity or gained by formal sensitivity studies.

The model building sequence as it progresses will evaluate the sensitivity of the various parameters and assumptions that comprise the logic. Parameters and assumptions that are insensitive are candidates for sound default values or "hard coded" logic sequences that do not permit change by the analyst.
Conversely, sensitive parameters and assumptions are subject to calibration and need careful estimation. Logic and equations may also be found to be of greater or lesser importance and this information may be used in model specification.

Available watershed site data will be split prior to model building. Part of the data will be used for model building. The remaining data will be used for verification.

For the data site applicable to this task, the models) will be "set up" and run for time series simulation and event prediction as if the known measured output data did not exist.

Site-specific information will be used to estimate the parameters and default values will be selected as necessary.

The predictions will then be compared to the actual measured data in the project data sets. The standard errors of estimate will be calculated. If necessary, additional calibration will be conducted.

3.4 Model Variables and Parameters

The runoff/pollution concentration model may be envisioned as an approximately linear dynamical system with pairwise function input consisting of rainfall and pollution loading functions of time. Output consists of the two-time varying
runoff and pollution concentration functions. The system is characterized by a number of parameters that apply within the system analysis to transform the input process into output processes.

The system components are defined as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
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<tbody>
<tr>
<td>X1(t)</td>
<td>Rainfall time series (inches/day)</td>
</tr>
<tr>
<td>X2(t)</td>
<td>Pollution loading time series (lbs/acre/day)</td>
</tr>
<tr>
<td>Y1(t)</td>
<td>Runoff time series (inches/day)</td>
</tr>
<tr>
<td>Y2(t)</td>
<td>Pollution emission time series (lbs/acre/day)</td>
</tr>
</tbody>
</table>

Variables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>- Fraction of Catchment that is impervious</td>
<td>0 ≤ P ≤ 1</td>
</tr>
<tr>
<td>Imax</td>
<td>- Maximum infiltration</td>
<td>inches/day</td>
</tr>
<tr>
<td>Vmax</td>
<td>- Root zone saturation volume</td>
<td>inches</td>
</tr>
<tr>
<td>Por</td>
<td>- Porosity</td>
<td>0 ≤ P ≤ 1</td>
</tr>
<tr>
<td>d</td>
<td>- Root zone depth</td>
<td>inches</td>
</tr>
<tr>
<td>2,</td>
<td>- Active mixing layer depth</td>
<td>inches</td>
</tr>
</tbody>
</table>
| Kw        | - Runoff coefficient                            | (Inches/day)
Intermediate Function Variable Used in Calculations

\( V_pM \) - Pervious area root zone volume

\( I (t) \) - Infiltration

\( L_p(t) \) - Pervious area component of pollutant loading

\( q_d(t) \) - Impervious area component of runoff

\( q_p(t) \) - Pervious area component of runoff

\( W_i(t) \) - Impervious area components of pollutant emission

\( W_pM \) - Pervious area component of pollutant emission

\( l'(t) \) - Portion of active layer depth removed
WS(t) - Soluble part of WP(t)
WB(t) - Sorbed part of WP(t)

3.5 Model Components

Catchment Description The catchment consists of a typical urban watershed with surface and subsurface drainage components. The entire catchment, A, consisting of a surface area and subsurface volume is divided into a net impervious component, I, and a net pervious component, P. The impervious area represents paved areas such as streets and sidewalks as well as roofs. The pervious area consists of unpaved soil surface, which may contain some degree of vegetation.

Rainfall. Rainfall is assumed to be applied uniformly to the catchment for a period of time, T. For the purpose of the model, rainfall data is provided as input. We let X(t) denote the amount of rainfall at time t.

Runoff. All rainfall onto the Impervious area is assumed to be converted to runoff. Therefore, if qI(t) represents the impervious area runoff, then qI(t) = CR(t)

Where C is the fraction of A that is impervious.
In the pervious area, the runoff process may be described in terms of the rainfall, infiltration, evapotranspiration and percolation processes. During dry periods, the volume of water in the root zone is depleted by the processes of evapotranspiration and deep percolation. The water volume balance at any time may be expressed as

\[
\frac{dV}{dt} = I(t) - P(t) - e(t)
\]

and the condition of no surface runoff during dry periods may be expressed as

\[
q(t) = 0 \text{ if } R(t) = 0.
\]

During wet periods, the water balance is given by

\[
\frac{dV}{dt} = I(t) - P(t)
\]

Where \( I(t) \) is the infiltration volume, which represents the volume of water added from the surface to root zone storage. \( I(t) \) Is represented as

\[
I(t) = I_{\text{max}}(t) - \frac{I_{\text{max}}(t)}{V_{\text{max}} - V(t_0)} \times (V(t) - V(t_0))
\]

where \( I_{\text{max}}(t_0) \) Is the maximum value of infiltration experienced at \( t_0 \), the time of storm initiation, \( V(t_0) \) is the root zone volume at the onset of the storm, and \( V_{\text{max}} \) Is the saturation volume of the root zone defined by

\[
V_{\text{max}} = \text{Porosity} \times \text{Root Depth Volume} = \text{Por.} \times V
\]
The amount of pervious surface runoff is then computed as the difference between pervious surface rainfall and the increment to root zone storage.

That is,

\[ Q_p(t) = (1-C) R(t) - \frac{dV}{dt} \]

The total runoff is then given by

\[ Q(t) = q(t) + Q_p(t) \]

### 3.6 Evapotranspiration, Infiltration and Percolation

The assumed infiltration versus soil moisture relationship is shown in Figure 2. Maximum infiltration is seen to occur at the time of storm initiation and the infiltration rate decreases linearly to zero at the maximum allowable soil moisture condition, defined by the product of soil porosity and root zone depth. Figure 3 indicates the assumed relationship between maximum onset infiltration rate and rainfall. We assume that the maximum infiltration rate is constant for small storms, but increases linearly with rainfall amount after some threshold rainfall intensity is achieved. Hence, the rainfall infiltration curve is a function of the three parameters A, B, and C representing the small storm constant value, the slope of the large storm linear curve and its intercept. The three parameter set reduces to two parameters for the special case, A = C.
FIGURE 2. INfiltration-Soil Moisture Relationship

FIGURE 3. Maximum Onset Infiltration-Rainfall Relationship
Evaporation, infiltration and percolation are all processes that occur in the pervious area. Percolation represents the movement of water from the upper zone (root zone) adjoining the surface to a lower zone which connects to ground water. Percolation is assumed to be constant in the model.

Evapotranspiration is assumed to be subject to seasonal fluctuations. That is, evapotranspiration is taken as a constant value, which may change monthly. Evapotranspiration is assumed to occur only during dry periods.

Infiltration or movement of water through the soil surface into the soil, is defined as a linear function of soil moisture for a given rain level. It assumes its maximum value when the pre-storm soil moisture is zero and it decreases linearly to zero with increasing soil moisture to a fully saturated upper zone. The maximum infiltration is a site specific input, whereas a minimum value of zero is reached when the soil moisture reaches the saturation or maximum moisture volume stage. Maximum soil moisture is defined by the condition $V_{\text{max}} = P_{\text{or}} \times V$ where $P_{\text{or}}$ is the porosity of the soil and $V$ is the volume of the root depth zone.
3.7 Pollution Loading

Pollution loading consists of the traffic debris and dust accumulation onto the pervious and impervious surfaces of the catchment. The pollution is assumed to build up during the periods between storms with a fraction of the build-up being lost each day through dissipation to the street or soil surface and the atmosphere In accordance with a first order loss mechanism. That is, the daily loss is directly proportional to the total accumulation.

Let \( L_P(t) \), \( L_I(t) \) be loading functions that represent the application of pollution to the pervious and impervious surfaces respectively. Let \( W_P(t) \), \( W_I(t) \) be the accumulated pollution levels on the respective surface. Then at any time, the accumulated pollutant loading is

\[
\begin{align*}
\frac{dW_P}{dt} &= L_P(t) \\
\frac{dW_I}{dt} &= L_I(t)
\end{align*}
\]
3.8 Pollutants Emission

The pollution that accumulates on the impervious and pervious surfaces during the dry periods between storms is partially or totally removed during a storm. The amount of pollutants removed is a function of the amounts accumulated through the loading functions, the rainfall intensity and duration and the physical properties of the Impervious and pervious components of the catchment.

On the Impervious area, we assume that the pollutant emitter during a storm is proportional to the product of the accumulated pollution and the rainfall intensity. That is, at any time instance we have

\[ \frac{dW_1}{dt} = K \cdot W_1 \]

We assume further that \( K = K_W \cdot R \) such that

\[ (dW/dt) = - K_W \cdot R \cdot W \]

Where \( K_W \) is the runoff coefficient.

Further, during the dry periods, assume that some of the pollutant is dissipated by biotic on physical mechanisms.
Including chemical exchanges between the pollutant and the atmosphere. This loss is assumed to be proportional to the amount of pollution present, and it is modeled by

\[
dW_1/\text{dt} = K_2 W_1 + L_1(t)
\]

On the pervious surface, the pollutant that is accumulated during dry periods is assumed to be partitioned into a soluble part, \( W_S(t) \), which is dissolved into the rainfall and washed off during a storm, as runoff and a sorbed part, \( W_B(t) \), which becomes part of the sediment which is then removed or retained as part of sediment processes. Let \( a \) denote the fraction of the pollutant that is soluble. Then in \( 1 - a = l - W_B(t)/W_P(t) \) of the pervious surface area, the pollutant will be mixed in a thin layer of soil near the surface and then washed off with the removed sediment. Let \( k \) denote the depth of the active layer and let \( 2' \) denote the amount of \( Z \) that is removed by sediment processes at time \( t \).

Then at any time during the storm, the amount of pollutant washed away is given by

\[
(1 - a) W_P(t) l' (t)
\]

and the remaining pollutant is given by

\[
(1 - l'/l) (1 - a) W_P(t)
\]
This remaining amount is then subject to further partitioning in time until either the storm ends or the entire pollutant is removed. During non-raining periods, the pollution is assumed to dissipate according to the relationship.

\[
\frac{dW_p}{dt} = K_p W_p
\]

\[(dW/dt) = K_1 W_i\]

When \(K_p, K_1\) are pollution dissipation constants.

3.9 Computational Form

A discrete form of the mathematical model is required in order to admit a digital simulation. The discrete form is obtained by evaluating the continuous form developed above at discrete time steps and approximating the differential operators by finite difference equations. The discrete time steps selected are equally spaced and separated by the time step, \(A_t\). Unless otherwise specified, we take \(A_t\) as unity such that end time step represents a unit increase in the time variable. By applying this approach to the model developed above, we obtain algorithms that can be evaluated in a digital computer.

For any function of time, \(f(t)\), let

\[f_1 = f(i \cdot \Delta t), \quad i = 0, 1, 2...N.\]
Then in this notation, we obtain the following algorithms:

**Impervious Area Runoff**

\[ q_{l_1} = C_l R_l \]

**Pervious Area Runoff**

Dry period water balance:

\[ \text{Vi+1} = \text{Vi} - \text{Pi} - \text{Pi} \]

Wet period water balance:

\[ \text{Vi+1} = \text{Vi} - \text{Pi} + I_i \]

**Infiltration**

\[ I = I_{\text{max}} - \text{Imax} \]

\[ \text{Vmax} - V_o \]

**Runoff**

\[ q_{Pi} = (1-C) R_l - (\text{Vit}_1 - \text{V}_l) \]

**Pollution Concentration**

Impervious surface:

\[ W_{I_i} = W_{I_{i-1}} - K_1 W_{I_{i-1}} + L I_i \] (dry period)

\[ W_{I_i} = W_{I_{i-1}} - K_2 R_{i-1} W_{I_{i-1}} + L I_i \]

\[ = W_{I_{1-1}} (1 - K_2 R_{i-1}) \] (wet period)

Pervious surface:

\[ W_{Pi+1} = W_{Pi} - K_1 W_{Pi-1} + L P_i \] (dry period)

\[ W_{Si} = a W_{Pi} \]

\[ \text{WB}_i = (1-a) W_{Pi} \] (wet period)

\[ W_{Pi+1} = (1-l'/l) (1-a) W_{Pi} \]

\[ L_{1i} = C \cdot \text{PK} \cdot S \cdot R_{ii} \cdot (1-a) \]
3.10 Summary of Principal Assumptions

The primary assumptions used in the development of the runoff pollutant concentration model are the following:

(1) The pollutant loading forcing function is constant over the time period for both the pervious and impervious areas.

(2) The average rainfall for the catchment removes 90% of the accumulated impervious area pollutants in a 24-hour period.

(3) Evapotranspiration rate changes slowly due only to seasonal effect and is constant during a given month.

(4) Deep percolation is constant.

(5) The soil is fully saturated at the beginning of the study period (late winter/early spring).

(6) Soil loss increases linearly with rainfall. The rate of increase is a function of catchment slope and soil condition.

(7) An average rain (rainy day) washes off one-half of the active layer on the pervious area.

(8) Daily infiltration is directly proportional to daily rainfall and inversely proportional to soil moisture.

(9) Maximum Infiltration rate is a function of soil moisture and rainfall intensity.
4. APPLICATION TO FIELD DATA

4.1 Field Data Selection

Field data were desired to validate and evaluate the nonpoint source prediction model developed in this project. Typical urban watershed data were sought, with special interest toward data for the Washington, D.C. Metropolitan Area. Fortunately, some local data were identified. During the years 1979-1982, the Metropolitan Washington Council of Governments (MWCOG), the Northern Virginia Planning District Commission (NVPDC) and the Virginia Polytechnic Institute (VPI) collaborated in a field data collection effort of over 600 station-storms under the auspices of the Nationwide Urban Runoff Program (NURP). These urban watershed studies were selected as the field data for use in the assessment of the model.

The MWCOG study included the collection of data on precipitation, runoff and pollutant concentrations at twelve monitoring sites, six of which were pond facilities (retention or detention) requiring inflow and outflow monitoring. Two sites were selected for analysis from this set of twelve sites, Burke Pond Site located in Burke, VA and Stedwick Inlet, located in Montgomery Village near Gaithersburg, Maryland.
4.2 Description of Data Sites

The Burke Pond site consists of a medium density single family residential development. The Stedwick site was a similar watershed that consisted of townhouse/garden apartments. The principal characteristics of the two sites are shown in Table 1. The two sites have comparable slopes and impervious ground cover. The Stedwick site is 50% larger than Burke Pond although both qualify as small watersheds. Stedwick is also more developed, consisting of mostly residential properties containing significantly less curb and gutter area than the Burke site.

Table 1. Field Data Site Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Burke Pond</th>
<th>Stedwick Inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Acres Inflow)</td>
<td>18.3</td>
<td>27.4</td>
</tr>
<tr>
<td>Average Density</td>
<td>3.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Impervious Group Cover</td>
<td>32.7</td>
<td>33.8</td>
</tr>
<tr>
<td>Effective Impervious Group Cover</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Inflow %)</td>
<td>25.1</td>
<td>25.1</td>
</tr>
<tr>
<td>Representative Slope (~)</td>
<td>4.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Watershed Area With</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curb and Gutter (~)</td>
<td>100.0</td>
<td>79.7</td>
</tr>
</tbody>
</table>
The two sites differed primarily with respect to soil condition. The Burke Pond Site is characterized as hydrologic soil group C. This group of soils is characterized by slow infiltration rates when thoroughly wetted and a slow rate of water transmissions such as, high runoff potential. The Stedwick Site is characterized as hydrologic group B, whose soils have moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Therefore, the Stedwick Site should have moderately low runoff potential.

4.3 Data Selection and Preparation

The MWCOG study collected data on rainfall, runoff, and chemical concentrations. State-of-the-art measurement techniques were employed to measure baseflow, runoff, wetfall, dryfall and high volume particulates. Rainfall and pollutant loading levels were selected as the input or loading functions of interest. The chemicals COD, nitrogen and phosphorous were selected for use in assessing the simulation model.

The field data had been recorded in units of cfs for flow and mg/L for concentration. To obtain the units of inches (flow) and pound (loads) required In the simulation model, the following conversion factors were used:
Load (Ibs) = Flow (cfs) x Concentration (mg/L) x sec x .0000624

Rain or Runoff (inches) = Flow (cfs) x sec x 1728
sq. ml x (5280)^2 x 14

Missing data values in runoff were estimated by regressing inch of runoff against inches of rain and antecedent dry period (days). The 1981 calendar year was taken as the time period of interest as the data were fairly complete for that period.

4.4 Data Analysis
Analysis of the data entailed the derivation of statistical measures (1st and 2nd moments) to characterize the measured time series. The time series are assumed to represent realization of stationary processes. As such, it is expected that low order moments should suffice for their characterization. Also, the physical parameters of the test site were measured or computed in order to provide a basis for a comparison of the field data with the results of the simulation model.

Table 2 shows the means and standard deviations of the 1981 data from the Burke Pond and Stedwick sites. Rainfall is essentially constant for the two sites. The runoff values, however, vary substantially. The runoff volume for the moderate infiltration capacity Stedwick site is only 1/3 of the runoff.
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>BURKE POND SITE</th>
<th>STEDWICK INLET SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain</td>
<td>R</td>
<td>0.448</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>0.488</td>
</tr>
<tr>
<td>Rain &gt; 0.05</td>
<td>X</td>
<td>0.589</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>0.483</td>
</tr>
<tr>
<td>Runoff</td>
<td>X</td>
<td>0.267</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>0.305</td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td>43.663</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>24.477</td>
</tr>
<tr>
<td>TP</td>
<td>k</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>0.465</td>
</tr>
<tr>
<td>TN</td>
<td>R</td>
<td>3.056</td>
</tr>
<tr>
<td></td>
<td>$S_x$</td>
<td>2.539</td>
</tr>
</tbody>
</table>
volume of the Burke Pond site which has a slow infiltration rate. The pollutant washed off is comparable between the sites on an absolute basis. This is attributable to the larger Stedwick catchment size combined with the larger runoff potential of the Burke Pond site.
5. RESULTS

5.1 Method of Computation

The simulation model developed in Chapter 3 was calibrated and verified with respect to the field data for the two data sites. This entailed the initial selection of model parameters based on the site specific data and then refinement of the parameter values based on an empirical optimization process designed to produce unbiased, minimum variance estimates of the parameters.

Formally, the computational procedure is as follows:

**Calibration:**

1. Select parameters based on physical dimensions.
2. Apply model and conduct sensitivity analysis of bias.
3. Adjust bias to zero modifying sensitive parameters.
4. Apply model and conduct sensitivity analysis of standard error of estimate.
5. Iterate on 2, 3, 4, and 5 to get bias and standard errors simultaneously adjusted.

**Verification:**

1. Adjust the calibrated parameters to a second watershed.
2. Run the model and compare the results based on standard error analysis.
5.2 Calibration Results

Optimum Model Parameters

The Burke Pond site was selected to calibrate the simulation model. Table 3 shows the Initial estimate of the parameter values based on physical dimensions and engineering analysis. Table 4 shows the optimum values of the model parameters obtained by application of the calibration procedure outlined in 5.1. It is noted that the slope and evapotranspiration parameters were fixed by the geographic and environmental conditions of the site and hence these parameters were not subjected to the optimization process.

Comparison of Actual and Predicted Results

Figures 4 - 7 shows the comparison of field measurements (actual) and simulation prediction (predicted) results based on the 1981 year data for the Burke Pond site. Qualitatively, the results show excellent agreement between the predicted and actual runoff results. The accuracy of predicted pollution concentrations is less; however, the agreement is still quite good.
<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUE</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Infiltration (Imax)</td>
<td>0.033</td>
<td>Inches/day</td>
</tr>
<tr>
<td>Percolation</td>
<td>0.067</td>
<td>Inches/day</td>
</tr>
<tr>
<td>Root Zone Depth</td>
<td>18.0</td>
<td>Inches</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.4</td>
<td>Inches</td>
</tr>
<tr>
<td>Slope</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>Soil Loss Coefficient</td>
<td>58.6</td>
<td></td>
</tr>
<tr>
<td>'Active Layer Thickness</td>
<td>5.4 x 10^-6</td>
<td>Inches</td>
</tr>
<tr>
<td>Washoff Coefficient</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Heavy Rain Infiltration Intercept</td>
<td>-0.30</td>
<td>Inches</td>
</tr>
<tr>
<td>Heavy Rain Infiltration Slope</td>
<td>0.73</td>
<td>ft/ft</td>
</tr>
<tr>
<td>Partition Coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>TP</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>TN</td>
<td>0.80</td>
<td>-</td>
</tr>
<tr>
<td>Pollutant Dissipation Coefficient</td>
<td></td>
<td>1/day</td>
</tr>
<tr>
<td>COD</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Monthly Evapotranspiration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E(1) E(2) E(3)</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>E(4) E(5) E(6)</td>
<td>0.09</td>
<td>0.19</td>
</tr>
<tr>
<td>E(7) E(8) E(9)</td>
<td>0.2</td>
<td>0.18</td>
</tr>
<tr>
<td>E00) E(11) E(12)</td>
<td>0.08</td>
<td>0.05</td>
</tr>
</tbody>
</table>
TABLE 4. OPTIMUM PARAMETER VALUES
(BURKE POND SITE)

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUE</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Infiltration (I_{\text{max}})</td>
<td>0.275</td>
<td>Inches/day</td>
</tr>
<tr>
<td>Percolation*</td>
<td>0.067</td>
<td>Inches/day</td>
</tr>
<tr>
<td>(Root Zone Depth*)</td>
<td>18.0</td>
<td>Inches</td>
</tr>
<tr>
<td>Porosity*</td>
<td>0.4</td>
<td>Inches</td>
</tr>
<tr>
<td>Slope*</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>Soil Loss Coefficient*</td>
<td>58.6</td>
<td></td>
</tr>
<tr>
<td>Active Layer Thickness</td>
<td>1.08 x 10^{-5}</td>
<td>Inches</td>
</tr>
<tr>
<td>Washoff Coefficient</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Heavy Rain Infiltration Intercept</td>
<td>-0.30</td>
<td>Inches</td>
</tr>
<tr>
<td>Heavy Rain Infiltration Slope</td>
<td>0.73</td>
<td>ft/ft</td>
</tr>
<tr>
<td>Partition Coefficient COD</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Partition Coefficient TP</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Partition Coefficient TN</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Pollutant Dissipation Coefficient COD</td>
<td>0.008</td>
<td>1/day</td>
</tr>
<tr>
<td>Pollutant Dissipation Coefficient TP</td>
<td>0.057</td>
<td>1/day</td>
</tr>
<tr>
<td>Pollutant Dissipation Coefficient TN</td>
<td>0.033</td>
<td>1/day</td>
</tr>
<tr>
<td>Monthly Evapotranspiration*</td>
<td>E(1) 0.02 E(2) 0.03 E(3) 0.05</td>
<td>Inches/day</td>
</tr>
<tr>
<td></td>
<td>E(4) 0.09 E(5) 0.19 E(6) 0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E(7) 0.2 E(8) 0.18 E(9) 0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E(10) 0.08 E(11) 0.05 E(12) 0.02</td>
<td></td>
</tr>
</tbody>
</table>

*Values not optimized.
FIGURE 4. COMPARISON OF ACTUAL AND PREDICTED RUNOFF TIME SERIES, BURKE POND SITE
FIGURE 5. COMPARISON OF ACTUAL AND PREDICTED COD TIME SERIES, BURKE POND SITE
FIGURE 6. COMPARISON OF ACTUAL AND PREDICTED TP TIME SERIES, BURKE POND SITE
FIGURE 1. COMPARISON OF ACTUAL AND PREDICTED TN VALUES, BURKE POND SITE
Comparison of Actual and Predicted Moments

Table 5 shows a comparison of actual and predicted moments and standard deviations for the Burke Pond site. This data provides a quantitative analysis of the qualitative results shown in Figures 4 - 7. The mean values are in agreement, indicating that the predicted values are unbiased. The standard errors are also in close agreement, indicating the simulation model preserves the field data structure through low level moments.

Comparison of Frequency Functions

Frequency functions consisting of sample probability density functions and cumulative distribution functions were computed for the actual and predicted Burke Pond site data. Non parametric tests of significance were performed to determine whether the simulation results could be deemed statistically equivalent to the actual data. The sample density functions for rainfall, runoff, COD, TP and TN are compiled in Appendix B. No direct comparison of actual and predicted densities was made due to the lack of an identical range scale between the actual and predicted data.

Figures 8 - 11 show a comparison of the simulation and actual cumulative frequency functions for the Burke Pond site. It is seen that the distributions compare well throughout, but
### TABLE 5. COMPARISON OF ACTUAL AND PREDICTED MOMENTS (BURKE POND SITE)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ACTUAL</th>
<th>PREDICTED*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.448</td>
<td>-</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>0.488</td>
<td>-</td>
</tr>
<tr>
<td>Rain &gt; 0.05</td>
<td>0.589</td>
<td>-</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>0.483</td>
<td>-</td>
</tr>
<tr>
<td>Runoff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.267</td>
<td>0.267</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>0.305</td>
<td>0.313</td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>43.663</td>
<td>44.070</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>34.477</td>
<td>38.367</td>
</tr>
<tr>
<td>TP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.372</td>
<td>0.371</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>0.465</td>
<td>0.309</td>
</tr>
<tr>
<td>TN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>3.056</td>
<td>3.046</td>
</tr>
<tr>
<td>S&lt;sub&gt;X&lt;/sub&gt;</td>
<td>2.539</td>
<td>2.445</td>
</tr>
</tbody>
</table>

*Unbiased Minimum Variance Estimates.
FIGURE 9. COMPARISON OF ACTUAL AND PREDICTED COD FREQUENCY FUNCTIONS, BURKE POND SITE
Figure 8. Comparison of actual and predicted runoff frequency functions, Burke Pond site.
FIGURE 10. COMPARISON OF ACTUAL AND PREDICTED TP FREQUENCY FUNCTIONS, BURKE POND SITE
FIGURE 11. COMPARISON OF ACTUAL AND PREDICTED TN FREQUENCY FUNCTIONS, BURKE POND SITE
that the comparison is better for large values of the variables and worst for small values. This is especially true for the pollution concentration quantities.

It was desirable to apply statistical tests of significance to the differences between the actual and predicted results. The Kolmogorov-Smirnoff test was selected. This is a non-parametric test that provides a robust test statistic which is fairly insensitive to the form of underlying distribution of the data variables. At the 0.95 significance level, the test statistic may be computed as

$$KS = 1.3581 \frac{N^{-1/2}}{2}$$

where $KS$ is the absolute value of the maximum difference between the actual and predicted frequencies in the cumulative distributions and where $N$ is the sample size, which is assumed to be large (Massey (1950)). For the Burke site data, $N = 54$ such that the critical value of the test statistic of the 95% significance level is

$$KS = 1.3581 \times (54)^{-1/2} = 0.186$$

Based on this test statistic, it was found that none of the simulation time series was significantly different from the actual data. This demonstrates that the calibration of the simulation of the Burke Pond site was successful.
Sensitivity Analysis

The sensitivity of the model to changes on the Individual parameters was assessed by computing changes in the model standard, error for specified changes in the model parameters.

Table 6 shows the percentage change In standard error resulting from ±25% change In each parameter for each of the three chemicals COD, TP, and TN. Not unexpectedly, the results show that parameter sensitivity is related to the choice of chemical.

For COD, which has a large sorbed component, the most sensitive parameters are soil loss coefficient and active layer thickness. The highly soluble pollutants TP and TN, on the other hand, are more sensitive to the dissipation and washoff coefficients.

5.3 Verification Results

The Stedwick Inlet site was used to verify the developed simulation tool, using the procedure detailed in Section 5.1. That Is, first optimum parameter values were determined through analysis of physical site data. Then a bias analysis was performed to test the adequacy of the selected parameters. The optimum parameter values are shown in Table 7. The determined parameters were then used as Input to the simulation and the simulation output processes were computed.
TABLE 6. OPTIMUM PARAMETER SENSITIVITY ANALYSIS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>BASE VALUE</th>
<th>EFFECT OF CHANGE</th>
<th>IN PARAMETER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>STANDARD ERROR</td>
<td>-25% Change</td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partition Coeff.</td>
<td>0.1</td>
<td>+1.25%</td>
<td>-2.5%</td>
</tr>
<tr>
<td>Dissipation Coeff.</td>
<td>0.02</td>
<td>-4.81%</td>
<td>+5.6%</td>
</tr>
<tr>
<td>Washoff Coeff.</td>
<td>2.5</td>
<td>+1.0%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Soil Loss Coeff.</td>
<td>59</td>
<td>+15.1%</td>
<td>-14.2%</td>
</tr>
<tr>
<td>Active Layer T.</td>
<td>0.54 x 10^{-5}</td>
<td>-12.0%</td>
<td>+19.7%</td>
</tr>
<tr>
<td>TP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partition Coeff.</td>
<td>0.8</td>
<td>+0.5%</td>
<td>-2.1%</td>
</tr>
<tr>
<td>Dissipation Coeff.</td>
<td>0.09</td>
<td>-3.8%</td>
<td>+7.1%</td>
</tr>
<tr>
<td>Washoff Coeff.</td>
<td>2.5</td>
<td>+10.5%</td>
<td>-5.6%</td>
</tr>
<tr>
<td>Soil Coeff.</td>
<td>59</td>
<td>+0.2%</td>
<td>-0.4%</td>
</tr>
<tr>
<td>Active Layer T.</td>
<td>0.54 x 10^{-5}</td>
<td>-0.5%</td>
<td>+0.2%</td>
</tr>
<tr>
<td>TN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partition Coeff.</td>
<td>0.8</td>
<td>+8.5%</td>
<td>-8.8%</td>
</tr>
<tr>
<td>Dissipation Coeff.</td>
<td>0.058</td>
<td>-7.5%</td>
<td>+10.8%</td>
</tr>
<tr>
<td>Washoff Coeff.</td>
<td>2.5</td>
<td>+1.8%</td>
<td>-1.9%</td>
</tr>
<tr>
<td>Soil Loss Coeff.</td>
<td>5.9</td>
<td>+1.6%</td>
<td>-1.5%</td>
</tr>
<tr>
<td>Active Layer T.</td>
<td>0.54 x 10^{-5}</td>
<td>-1.1%</td>
<td>+2.1%</td>
</tr>
</tbody>
</table>
### TABLE 7. OPTIMUM PARAMETER VALUES
(STEDWICK INLET SITE)

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Infiltration (Imax)</td>
<td>0.62</td>
<td>Inches/day</td>
</tr>
<tr>
<td>Percolation*</td>
<td>0.10</td>
<td>Inches/day</td>
</tr>
<tr>
<td>Root Zone Depth*</td>
<td>18.0</td>
<td>Inches</td>
</tr>
<tr>
<td>Porosity*</td>
<td>0.45</td>
<td>Inches</td>
</tr>
<tr>
<td>Slope*</td>
<td>0.047</td>
<td></td>
</tr>
<tr>
<td>Soil Loss Coefficient*</td>
<td>58.6</td>
<td></td>
</tr>
<tr>
<td>Active Layer Thickness</td>
<td>5.4 x 10^{-5}</td>
<td>Inches</td>
</tr>
<tr>
<td>Washoff Coefficient</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Heavy Rain Infiltration</td>
<td>-0.025</td>
<td>Inches</td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Rain Infiltration Slope</td>
<td>0.75</td>
<td>in/in</td>
</tr>
<tr>
<td>Partition Coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Pollutant Dissipation Coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>0.016</td>
<td>1/day</td>
</tr>
<tr>
<td>TP</td>
<td>0.097</td>
<td>1/day</td>
</tr>
<tr>
<td>TN</td>
<td>0.061</td>
<td>1/day</td>
</tr>
<tr>
<td>Monthly Evapotranspiration*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E(1) E(2) E(3)</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>E(4) E(5) E(6)</td>
<td>0.09</td>
<td>0.19</td>
</tr>
<tr>
<td>E(7) E(8) E(9)</td>
<td>0.2</td>
<td>0.18</td>
</tr>
<tr>
<td>E(10) E(11) E(12)</td>
<td>0.08</td>
<td>0.05</td>
</tr>
</tbody>
</table>

*Values not optimized.
Comparison of Time Series

Figures 12 - 15 show a comparison of the actual and predicted time series for runoff, COD, TP, and TN at the Stedwick Inlet site. Table 8 shows a comparison of first and second order moments between the actual and predicted results. Very good agreement is shown for runoff and reasonably good agreement is shown for the pollutants COD, TP and TN. The main values are unbiased, as expected. The standard deviations differ more. This suggests that certain site specific information relevant to the simulation may not be currently captured by the model.

Comparison of Frequency Functions

Frequency functions were computed for the actual and predicted Stedwick Inlet data. Figures 16 - 19 show a comparison of the actual and predicted cumulative functions. Statistical comparisons were made. The Kolmogorov-Smirnoff (KS) test statistical discussed in Section 5.2 was again used.

The agreement between the simulation and actual data is not as impressive for the Stedwick site as for the Burke Pond site used to calibrate the model. Application of the KS test statistic indicated that runoff was insignificantly different
DAY OF YEAR

FIGURE 12. COMPARISON OF ACTUAL AND PREDICTED RUNOFF TIME SERIES, STEDWICK INLET SITE
FIGURE 13. COMPARISON OF ACTUAL AND PREDICTED COD TIME SERIES, STEDWICK INLET SITE
FIGURE 14. COMPARISON OF ACTUAL AND PREDICTED TP
TIME SERIES, STEDWICK INLET SITE
DAY OF YEAR

FIGURE 15. COMPARISON OF ACTUAL AND PREDICTED TN VALUES, STEDWICK INLET SITE
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ACTUAL</th>
<th>PREDICTED*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.443</td>
<td></td>
</tr>
<tr>
<td>$S_x$</td>
<td>0.468</td>
<td>-</td>
</tr>
<tr>
<td>Rain &gt; 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.569</td>
<td></td>
</tr>
<tr>
<td>$S_x$</td>
<td>0.461</td>
<td>-</td>
</tr>
<tr>
<td><strong>Runoff</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.098</td>
<td>0.099</td>
</tr>
<tr>
<td>$S_x$</td>
<td>0.132</td>
<td>0.167</td>
</tr>
<tr>
<td><strong>COD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$3z$</td>
<td>40.262</td>
<td>40.460</td>
</tr>
<tr>
<td>$S_x$</td>
<td>34.354</td>
<td>50.561</td>
</tr>
<tr>
<td><strong>TP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>0.302</td>
<td>0.313</td>
</tr>
<tr>
<td>$S_x$</td>
<td>0.273</td>
<td>0.388</td>
</tr>
<tr>
<td><strong>TN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>2.539</td>
<td>2.567</td>
</tr>
<tr>
<td>$S_x$</td>
<td>2.224</td>
<td>3.099</td>
</tr>
</tbody>
</table>
FIGURE 16. COMPARISON OF ACTUAL AND PREDICTED RUNOFF FREQUENCY FUNCTIONS, STEDWICK INLET SITE
FIGURE 17. COMPARISON OF ACTUAL AND PREDICTED COD FREQUENCY FUNCTIONS, STEDWICK INLET SITE
FIGURE 18. COMPARISON OF ACTUAL AND PREDICTED TP FREQUENCY FUNCTIONS, STEDWICK INLET SITE
FIGURE 19. COMPARISON OF ACTUAL AND PREDICTED TN FREQUENCY FUNCTIONS, STEDWICK INLET SITE
between the actual and predicted values at 95$ significance level. Upon further analysis, it was determined that the simulation consistently under predicted small values of the pollution emissions. This prediction error trend was found to occur whenever the model predicted no runoff from the pervious area based on the large infiltration characteristics of the Stedwick sites. Because it appears that the Stedwick site has inherent characteristics that are dissimilar to the calibration site (Burke Pond), it is not possible to correct the observed error trend within the context of the current model. When the lowest 1% of the pollution emission data was eliminated and the KS significance test again performed, it was found that COP, TP, and TN differences were all insignificant at the 95$ significance level.

5.4 Summary

Calibration and verification analysis of the developed daily accounting model indicates that the model is a highly accurate tool for predicting runoff and pollutant emission frequency functions from urban watershed. Applications of the model to two small watersheds having vastly different runoff and pollution emission characteristics indicated that consistently good prediction accuracy is achieved for sets of input conditions. Larger errors
were observed between the simulation and actual data at the site used for model verification for small values of the pollutant emissions. Such small pollutant levels are usually not of critical importance in an urban water quality assessment. Further, it is suspected that this prediction anomaly is related to the unusual runoff characteristics of the Stedwick Inlet site used in the verification and not principally due to the model structure.
6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research project has led to the following conclusions:

1. A daily accounting model of urban runoff and pollutant concentrations was developed as a tool for urban water planning and analysis.

2. The model is feasible on a microcomputer.

3. The model has the following parameters:

   Maximum Infiltration Percolation
   Root Zone Depth Porosity
   Slope
   Soil Loss Coefficient
   Active Layer Thickness
   Washoff Coefficient
   Heavy Rain Infiltration Intercept
   Rain Infiltration Slope
   Partition Coefficient
   Pollutant Dissipation Coefficient
   Evapotranspiration

Highly sorbed pollutants

   Soil loss coefficient  Active layer thickness

Highly soluble pollutants

   Dissipation coefficient
   Washoff coefficient
5. Impervious area rational design methods and pervious area soil moisture accounting methods can be integrated into one accurate and simple model system.

6. The model can be used to generate emission frequency functions for small urban watersheds for different rainfall inputs and cultural factors.

6.2 Recommendations

The following recommendations are made:

1. This research should be continued along the lines of additional validation of the modeling technique by application to additional watersheds.

2. Additional simulation modeling should be performed by providing Monte-Carlo rainfall inputs in order to analyze the mapping of inputs to outputs.

3. Research should be performed to simplify the mapping functions such that system outputs can be derived directly from inputs without recourse to simulation.

4. Sensitivity analysis indicates the following ranking of most sensitive parameters:
7. REFERENCES


APPENDIX A

COMPUTER PROGRAM LISTING
REM
REM
REM
REM
REM SUBROUTINE (MEANS, STANDARD DEVIATIONS)
7000 FOR KP = 1 TO 3
7010 AWAactual(KP) - TAWactual(KP) / KN
7015 AWoffm(KP) - TAWoff(KP) / KN
7017 SWAWoff(KP) - ((TAWoffsq(KP) / KN) - ((TAWoff(KP) / KN) - 2) I
7018 SWAWoff(KP) - SQR(SWAWoff(KP))
7020 SDAWactual(KP) - (TAWactual sq(KP) / KN) - ((TAWactual(KP) / KN) - 2))
7025 SDAWactual(KP) - SQR(SDAWactual(KP))
7030 NEXT KP
7035 PRINT "SUM MEAN ST. OEV."
7038 PRINT "COD > 0"
7039 PRINT USING "t#Y#.ii#"; TAWactual(1), AWAactualM(1), SWAWactual(1)
7040 PRINT "TP > 0"
7041 PRINT USING "•Af w. 4#f"; TAWactual(2), AWAactualM(2), SDAWactual(2)
7042 PRINT "TN > 0"
7043 PRINT USING "4d#k. i l #"; TAWactual(3), AWAactualM(3), SWAWactual(3)
7045 PRINT "EST. 000 > 0"
7046 PRINT USING "#wf #. f #i "; TAWoff(1), AWoffM(1), SDAWoff(1)
7047 PRINT "EST. TP > 0"
7048 PRINT USING "•M•#. i l l "; TAWoff(2), AWoffM(2), SDAWoff(2)
7049 PRINT "EST. IN > 0"
7050 PRINT USING "frOY. 1Y0"; TAWoff(3), AWoffM(3), SDAWoff(3)
7055 RETURN
REM EXECUTIVE PROGRAM
REM POLLUTION CONCENTRATION MODEL FOR URBAN WATER QUALITY
REM WRITTEN JUNE 1984
REM DATE LAST MODIFIED 08/16184

KEY OFF

REM ALL INTEGER VARIABLES MUST BEGIN WITH I-N
REM ALL PRESTON VARIABLES MUST BEGIN WITH A-H
REM ALL DOUBLE PRECISION VARIABLES MUST BEGIN WITH O-Z

OEFINT I-N
OEFSNG A-H
DEFDBL O-Z

DIM IMNTH(12), EVAP(12)
DIM IDAYV(365), ARAINV(365), ARUNOFFV(365),
ATSSV(365), A000V(365), ATPIV(365), ATVV(365)
DIM AV(365), APCNT(8), OI(100)
DIM ALR(3), AKD(3), AKWASH(3), ALPHA(3), AWSOL(3), ASLOSS(3), AWSORB(3), AWOFF(3)
DIM AWI(365,3), AWP(365,3), AWACTUAL(3), ALPHAT(3), ALRT(3),
AKOT(3), 3PCNT(10, 3)
DIM SE(3), BIAS(3), AWACTUALM(3), TAWACTUAL(3), AWOFFM(3), TAWOFF(3), SDAWA
CTUAL(3), SDAWOFF(3), DIFF(3), DIP(200,3)

CLS

PRINT: PRINT: PRINT 101 BEEP
PRINT " INITIATION TIME -": TIMES
IF (AS="Y") OR (AS="y") THEN GOSUB 1000
GOSUB 1600: GOSUB 6800
IF (A$="Y") OR (A$="y") THEN GOSUB 6100
IF (BS="Y") OR (BS="y") THEN GOSUB 6040
999 END

1000 REM SUBROUTINE LOAD
OPEN SEQ. OUTPUT FILE

INPUT "ENTER NUMBER OF RECORDS TO BE LOADED":N
FOR I = 1 TO N
PRINT "ENTER DAY RAIN RUNOFF TSS COD TPI TN"
BEEP
INPUT [DAY, ARAIN, ARUN, ATSS, ACOD, ATPI, ATTN]
WRITE #I, [DAY, ARAIN, ARUN, ATSS, 8000, AT-01, ATTN]
NEXT I
CLOSE
RETURN
REM UTINE (DEFINE CONSTANTS)

REM BUILD MONTH ENO VECTOR
M 1 TO 13
REM 1=1 MNTH + 31 + 28
M 1 TO 2 (I), MNTH(I) + MNTH(I-1)

REM 1 MNTH
IF I-4 THEN MNTH(I) + MNTH(I-1) + 30
IF I-6 THEN MNTH(I) + MNTH(I-1) + 30
IF I-9 THEN MNTH(I) + MNTH(I-1) + 30
IF I=11 THEN MNTH(I) + MNTH(I-1) + 30:

NEXT I 1460 REM
REM ENTER OTHER CONSTANTS 1480 REM
AVMAX=.62: APMPRV=.11: AIMAXT=.62: APMPRVT=.11
ARUNPC=.5
APT=1: APOR=45: APORT=.45
AVMAX-APOR*AL
AVO-18!

DIFF1=0! T = R A U N O F F 1 = 0 ! : N1=0: TCQI=0!
DIFF2=0! TARUNOFF2 = 0 ! : N2=0: TCQQ2=0!
TARAINISO=0! TARUNOFF2SQ=0!
TARUNOFFISQ=0! TCQQISQ=0!
TOO2SQ=0!

EVAP(1)=.02: EVAP(2)=.03: EVAP(3)=.05: EVAP(4)=.09
EVAP(5)=.02 1560 EVAP(5)=.19: EVAP(6)=.25:
EVAP(7)=.2: EVAP(8)=.18
EVAP(9)=.12: EVAP(10)=.08: EVAP(11)=.05:
EVAP(12)=.02 1580 REM ENO CONSTANT DEFINITION
RETURN
1592 REM
1594 REM
1596 REM
1598 REM
1600 REM SUBROUTINE (BUILD DATA VECTOR FROM FILE)
1610 REM READ IN INPUT DATA FROM FILE
1640 REM OPEN INPUT FILE
1650 OPEN "SURKE4.DAT" FOR INPUT AS 12
1670 INPUT i2, IDAY, ARAIN, ARUN, ATSS, ACOD, ATTN, ATPI
1680 REM WHILE (NOT EOF(2))
1681 FOR I = 2 TO 72
1682 REM CHECK VALIDITY OF DAY t
1683 IF IDAY > 365 THEN PRINT "INVALID DAY ".I0AY: ENO
1685 IF (IDAY <= 39) THEN PRINT USING (IDAY,ARAIN,ARUN,ATSS,ACOD,ATPI,ATTN)
1670 REM BUILD RUNOFF VECTOR
1680 I0AYV(IDAY) = IDAY: ARAINV(IDAY) = ARAIN:
1681 ARUNOFFV(IDAY) = ARUN:
1682 ATSSV(IDAY) = ATSS: ACODV(IDAY) = ACOD:
1683 ATPIV(IDAY) = ATPI: ATNV(IDAY) = ATTN
1684 REM WEND 1796 NEXT I
1797 CLOSE
1799 RETURN
1800 REM SUBROUTINE (COMPUTE RUNOFF)
1810 AV(0) = AVO
1820 FOR K = 1 TO 365
1830 REM FIND MONTH
1840 FOR M = 1 TO 12
1870 IF (K < 32) THEN M = 1: GOTO 1890
1874 IF (K > 334) THEN M = 12: GOTO 1890
1878 IF ((IMNTH(M-1) < K) AND (IMNTH(M) > K)) THEN GOTO 1890
1880 NEXT M
1890 IF (ARAINV(K) = 0) THEN AV(K) = AV(K-1) + (AP + EVAP(M))
1895 CHKRAINF = (0.1 - APMPRV) - ARAINV(K)
1896 CHKRAINF = ARAINV(K)
1897 IF ((ARAINV(K) <> 0) THEN AV(K) = AV(K-1) + (AP + EVAP(M))
1898 IF (AI MAXI < AI MAX) THEN AI MAXI = AI MAX
1900 IF (APMPRV < ARAINV(K)) THEN AV(K-1) = (AI NF = CHKRAINF)
1910 IF ((ARAINV(K) <> 0) THEN AV(K) = AV(K-1) + AINF
1911 IF AV(K) < 0 THEN AV(K) = 0!
1920 COI = APKPRV * ARAINV(K)
1930 COP = ((1 - APMPRV) + ARAINV(K)) - (AV(K) - AV(K-1))
1931 COP = ARAINV(K) - AINF
1932 COP = (1 - APMPRV) - COP
1934 IF (COP < 0) THEN COP = 0!
1940 COQ = (COI + COP)
1945 GOSUS 6300
1950 IF ISCR > 0 THEN GOSUS 3050 ELSE IF (ISCR = 0) THEN GOSUB 4050
1960 GOSUS 4500
1962 GOSUB 6500
1980 NEXT K
1982 GOSUB 4600
1983 GOSUB 6600
1984 GOSUB 4700
1985 GOSUB 6700
1986 PRINT STOP TIME ; TIMES
1990 RETURN
3000 REM SUBROUTINE PRINT FORMAT FOR SCREEN
3050 IF IPRINT > ISCRL THEN LOCATE 24,1: IPRINT=0: INPUT CS ELSE
3071 PRINT USING "*t#i":K,M
3074 PRINT USING " /I.1/";ARAINV(K),ARUNOFFV(K),COO,CQI,COP,
3080 PRINT USING "t.###":AWI(K,1),AWI(K,2),AWI(K,3),AWP(K,1),AWP(K,2),AWP(K,3)
3090 PRINT
3095 PRINT "WSOL SLOSS WSORS WOFF ACTUAL" 3100 FOR IP=1 TO 3
3110 PRINT USING "f.#i":AWSOL(IP),ASLOSS(IP),AWSORB(IP),AWOFF(IP),AWACTUAL(IP)
3115 RETURN
4050 REM PRINT TO LINE PRINTER IF ISCRL = 0
4052 IF L > 0 THEN GOTO 4130
4054 IF LCNT = 0 THEN GOTO 4074
4056 PRINT: PRINT: PRINT
4060 PRINT "K M"
4062 PRINT "RAIN RUNOFF QQ QI OP AV EVAP AINF COO
4064 PRINT "WICOO WITP WITN WP000 WPTP WPTN"
4066 LCNT=LCNT + 7
4074 PRINT USING "*t###":K,M
4075 IF(ARUNOFFV(K) =0) THEN COO=0!:CQI=0!:CQP=0!
4076 IF(ARUNOFFV(K) =0) THEN GOTO 4545
4078 PRINT USING "*t.###":ARAINV(K),ARUNOFFV(K),COO,CQI,COP,
4080 PRINT USING "###":AWI(K,1),AWI(K,2),AWI(K,3),AWP(K,1),AWP(K,2),AWP(K,3)
4090 PRINT
4093 AWACTUAL(IP)=ACOOV(K): AWACTUAL(IP)=ATPIV(K): AWACTUAL(IP)=ATNV(K)
4100 FOR IP=1 TO 3
4102 IF(ARUNOFFV(K) =0) THEN
4105 PRINT USING "*f.#i":AWSOL(IP),ASLOSS(IP),AWSORB(IP),AWOFF(IP),AWACTUAL(IP)
4110 NEXT IP
4120 LCNT=LCNT + 7
4124 IF (LCNT > 62) THEN LCNT=0: PRINT: PRINT: PRINT 4130 RETURN
4140 REM
4150 REM
4160 REM
4170 REM
4500 REM SUBROUTINE STATISTICS ( SUM )
4510 IF (ARAINV(K) > 0) THEN OIFF1=OIFF1+(C00- ARUNOFFV(K))'2: TARUNOFFI=TARUNOFFI +ARUNOFFV(K): N1=N1+1: T0001=TCQ1+CQQ: TCQ1SQ=TCQ1SQ+(CQQ'2)
4515 IF ARAINV(K) > 0 THEN TARAINI=TARAINI+ARAINV(K): TARAINISO=TARAINISO+(ARAINV(K))'2: TARUNOFFISO=TARUNOFFISO+(ARUNOFFV(K))'2:
4518 IF ARAINV(K) > .05 THEN DIFF2=DIFF2+(CQQ-ARUNOFFV(K))'2: TARUNOFF2=TARUNOFF2+ARUNOFFV(K): N2=N2+1: T0002SQ=TCQ2SQ+CQQ: TCQ2SQ=TCQ2SQ+(CQQ'2)
4520 IF ARAINV(K) > .05 THEN TARAIN2=TARAIN2+ARAINV(K): TARAIN2SQ=TARAIN2SQ+(ARAINV(K))'2: TARUNOFF2SQ=TARUNOFF2SQ+(ARUNOFFV(K))'2:
4530 REM BUILD HISTOGRAM VECTOR
4535 IF (L=0) AND (ARAINV(K) > .05) THEN K1=K1+1: DI(K1)=CQQ
4540 RETURN
4550 REM
4560 REM
4570 REM
4580 REM
4600 REM SUBROUTINE STATISTICS ( COMPUTE )
4620 SE1=(DIFF1/N1): SE1=SQR(SE1)
4630 SE2=(DIFF2/N2): SE2=SQR(SE2)
4640 BIAS1=(TCQ1/TARUNOFFI)
4650 BIAS2=(T0002/TARUNOFF2)
4652 GOSUB 5000
4660 RETURN
4665 REM
4670 REM
4680 REM
4690 REM
400 REM SUBROUTINE STATISTICS (PRINT)
402 BEEP
404 BEEP
405 BEEP
406 BEEP
410 PRINT "IMAX AP AL APOR"
412 PRINT USING "lI.i3I"; IMAX, AP, AL, APOR
415 PRINT
420 PRINT "SE1 SE2 BIAS1 BIAS2"
422 PRINT USING "/l.III"; SE1, SE2, BIAS1, BIAS2
425 PRINT
430 RETURN
440 REM HISTOGRAM VALUES
450 REM COMPUTE MAXIMUM MINIMUM RANGE DELTA
4610 AMAX = 0:
4615 REM COMPUTE MAXIMUM MINIMUM RANGE DELTA
4620 IF (DI(I1) > AMAX) THEN AMAX = DI(I1)
4625 IF (DI(I1) < AMIN) THEN AMIN = DI(I1)
4630 NEXT I1
4635 ARANGE = AMAX - AMIN
4640 ADELTA = ARANGE / 10
4645 ALOW = AMIN: AHIGH = ALOW + ADELTA
4650 IFREQ = 0
4655 PRINT " AMIN AMAX COUNT"
4660 PRINT USING "If.#•I"; AMIN, AMAX, K1
4665 PRINT "INTERVAL RANGE FREQ SUM"
4670 REM COMPUTE FREQUENCIES
4675 FOR 11 = 1 TO 10
4680 FOR 12 = 1 TO K1
4685 IF (DI(12) > ALOW) AND (DI(12) < AHIGH) THEN
4690 IFREQ = IFREQ + 1
4695 NEXT 12
4700 NEXT 11
4705 PRINT USING "If.#•I"; ALow, AHIGH, IFREQ, ISUM
4710 PRINT
4715 RETURN
4720 REM
4730 REM
4740 REM
4750 REM
4760 REM
4770 REM
4780 REM
4790 REM
4800 REM
4810 REM
4820 REM
4830 REM
4840 REM
4850 REM
4860 REM
4870 REM
4880 REM
4890 REM
4900 REM
4910 REM
4920 REM
4930 REM
4940 REM
4950 REM
4960 REM
4970 REM
4980 REM
4990 REM
5000 REM SUBROUTINE (COMPUTE STANDARD DEVIATION)
5005 REM COMPUTE MEAN VALUES 5010 ARAIN I M - TARAIN I / N1
5015 ARAIN2 M - TARAIN2 / N2 5020 CQQ I M - TCQQ1 / N1
5025 CQQ2 M = TCQQ2 / N2
5030 ARUNOFF I M - TARUNOFF I / N1 5035 ARUNOFF2 M - TARUNOFF2 / N2
5040 REM RAIN STATS
5045 SDRAI N1 "((TARAIN1 SQ/N1)-(TARAIN1/N1) - 2))
5050 SDRAI N1 = SQR (SDRAI N1)
5055 SDRAI N2 "((TARAIN2 SQ/N2)-(TARAIN2/N2) - 2))
5060 SDRAI N2 = SQR (SDRAI N2)
5065 REM PREDICTED RUNOFF '
5070 SDRUNOFF1 - ((TARUNOFF1 SQ/N1)-(TARUNOFF1/N1) - 2))
5071 SDRUNOFF1 = SQR (SDRUNOFF1)
5073 SDRUNOFF2 - ((TARUNOFF2 SQ/N2)-(TARUNOFF2/N2) - 2))
5075 SDRUNOFF2 = SQR (SDRUNOFF2)
5080 SDCQQ1 - ((TCQQ1 SQ/N1)-(TCQQ1/N1) - 2))
5081 SDCQQ1 = SQR (SDCQQ1)
5085 SDCQQ2 "((T0002 SQ/N2)-(T0002/N2) - 2))
5086 SDCQQ2 = SQR (SDCQQ2)

6000 REM PRINT STANDARD DEVIATION STATS.
6001 PRINT "SUM MEAN ST.
6002 PRINT "RAIN > 0
6003 BEEP
6004 BEEP
6005 PRINT USING "#1.1**"; TARAIN1, ARAIN1 M, SDRAI N1
6009 PRINT USING "#1.05"; TARAIN2, ARAIN2 M, SDRAI N2
6104 PRINT "RUNOFF > 0" USING
6105 PRINT "RUNOFF > 0.05" USING
6109 PRINT "COQ > 0" USING
6125 PRINT USING "#1.111"; T0001, CQQ1 M, SDCQQ1
6130 PRINT USING "#1.05"; T0002, CQQ2 M, SDCQQ2
6135 RETURN
6036 REM
6038 REM
6039 REM
REM SUBROUTINE (SE, BIAS)
FOR KP - 1 TO 3
SE(KP) = DIFF(KP) / KN: SE(KP) - SQR(SE(KP))
BIAS(KP) = TAWOFF(KP) / TAWACTUAL(KP)
NEXT KP
GOSUB 7000
RETURN
REM SUBROUTINE POLLUTION STATISTICS (PRINT)
PRINT "ALPHA KD KWASH PKACTIVE L."
PRINT USING "##---": ALPHA(1), AKD(1), AKWASH, CPK, CALAYER
PRINT USING "#rl-----": ALPHA(2), AKD(2)
PRINT USING "####": ALPHA(3), AKO(3)
PRINT BEEP
SE(COD) SE(TP) SE(TN) BIAS(000) BIAS(TP) BIAS(TN)
PRINT USING "##.###": SE(1), SE(2), SE(3), SIAS(1), BIAS(2), BIAS(3)
RETURN
REM SUBROUTINE (POLLUTION PREDICTION ERROR HISTOGRAM)
FOR KP = 1 TO 3
ISUM = 0
AMAX = 0: AMIN = 0: IFREQ = 0
FOR I1 = 1 TO K1
IF (DIP(I1,KP) > AMAX) THEN AMAX = DIP(I1,KP)
IF (DIP(I1,KP) < AMIN) THEN AMIN = DIP(I1,KP)
NEXT I1
ARANGE = AMAX - AMIN
DELTA = ARANGE / 101
ALOW = AMIN: AHIGH = ALOW + DELTA
IFREQ = 0
PRINT USING "####": AMIN, AMAX, K1
6865 PRINT "INTERNAL RANGE FREQ"
FOR I1 = 1 TO K1
IF ((DIP(12,KP) > ALOW) AND (DIP(I2,KP) < AHIGH)) THEN IFREQ = IFREQ + 1
NEXT I1
PRINT USING "####": AMIN, AMAX, K1, 6865, PRINT "INTERNAL RANGE FREQ"
REM COMPUTE FREQUENCIES
FOR I1 = 1 TO 10 6880 FOR 12 - 1 TO K1 6885 IF (DIP(12,KP) < ALOW) AND (DIP(I2,KP) < AHIGH) THEN IFREQ
NEXT I2
NEXT 12
I SUM = I SUM + IFREQ
TOTAL = K1: ASUM = I SUM / TOTAL
PRINT "TOTAL: K1: ASUM: I SUM/ TOTAL"
PRINT I FREQ = 0
NEXT 11
NEXT KP
RETURN
APPENDIX B
MEASURED AND PREDICTED PROBABILITY DENSITY FUNCTIONS

FIGURES B1 - 134: BURKE POND SITE
FIGURES B5 - 138: STEDWICK INLET SITE
FIGURE B-1. MEASURED AND PREDICTED RUNOFF PROBABILITY DENSITY FUNCTIONS, BURKE POND SITE
Figure B-2. Measured and predicted COD probability density functions, Burke Pond site
FIGURE B-3. MEASURED AND PREDICTED TP PROBABILITY DENSITY FUNCTIONS, BURKE POND SITE
FIGURE B-4. MEASURED AND PREDICTED TN PROBABILITY DENSITY FUNCTIONS, BURKE POND SITE
Figure B-5. Measured and predicted runoff probability density functions, Stedwick inlet site.
FIGURE B-6. MEASURED AND PREDICTED COD PROBABILITY DENSITY FUNCTIONS, STEMWICK INLET SITE
FIGURE B-7. MEASURED AND PREDICTED TP PROBABILITY DENSITY FUNCTIONS, STEDWICK INLET SITE
FIGURE B-8. MEASURED AND PREDICTED TN PROBABILITY DENSITY FUNCTIONS, STEDWICK INLET SITE