Flood Control Modeling

Fall 1972

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FLOOD CONTROL MODELING

BY

PETER E. DELLE DONNE

A Research Report Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in Industrial Engineering and Management Science

FLORIDA TECHNOLOGICAL UNIVERSITY

November 1972
ABSTRACT

This is a research report that discusses some continuous and discrete modeling techniques. The report applies these techniques to the analysis of Canal 38 (Kissimmee River) part of Central and South Florida Flood Control District. The analysis is based on recorded data for defining the physical systems parameters. Established parameters are mathematically related to define a descriptive model for Canal 38. The modeling procedure of 'trial and error' is used to assemble the model with measures of merit, the integral square error, and root mean squared error. General simulation considerations are discussed for application of the mathematical model.
PREFACE

This research report is the documentation on a study of the Central and South Florida Flood Control Districts flood control Canal 38. The investigator built an analytical tool, that is, a mathematical model, to aid the Flood Control Districts flood damage problem with Canal 38. The study provides a basis for the analysis and modeling technique used to develop a mathematical model.

Appreciation is expressed to Dr. Barney L. Capehart, professor, who introduced the author to the field of system modeling and the problems of flood damage in the Flood Control District. The author acknowledges the guidance and assistance of his Committee, Dr. Martin P. Wanielista, the Committee Chairman, Dr. George F. Schrader and Professor M. F. Zaldivar, Committee members. Thanks are also given to Messrs. Robert Hamerick, Lalit Sinha, and Hans Ile, of the Central and South Florida Flood Control Districts for their cooperation in supplying necessary data for this study. Finally, the author expresses his sincere appreciation to the typist, on-line draft critic, and draft format manipulator, his wife.
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I. INTRODUCTION

Ever since man was economically damaged or threatened by flood events, he has attempted to control or avoid them. With increasing population and land value, flood mitigation has been brought into sharper focus in recent years [17]. Federal flood mitigation activity dates from 1936, with present responsibility under the U. S. Corps of Engineers and the U. S. Department of Agriculture. Aiding the Corps of Engineers locally are state government agencies. The Central and South Florida Flood Control District is such an agency, and flood control is the subject of this report.

In this report, dynamic modeling of a flood control system will be presented, as well as, general simulation considerations.

PROBLEM HISTORY

The Central and South Florida Flood Control District (FCD) is responsible for the management and operation of a water resource system, which covers approximately 16,000 square miles in area [1]. One of
the major natural drainage areas within the FCD boundaries is the Kissimmee River - Lake Okeechobe system, which includes a range of land use from the sprawl of cities to wilderness and farm lands.

To ensure their initial emphasis, flood control, the FCD in consultation with the Army Corps of Engineers improved channels and built control structures where believed necessary. The purpose of one of these canals, Canal 38, or Kissimmee River, is to guide flood waters from Lake Kissimmee to Lake Okeechobe.

Canal 38 is located in the central Florida counties of Osceola and Okeechobee. The drainage area for Canal 38 is approximately 758 square miles. The main natural channel of the river meanders extremely over a distance of approximately 90 miles, with a total fall of about 35 feet. Canal 38 control structures consist of five gated spillways: 65A, 65B, 65C, 65D, and 65E. Maximum flows are experienced in September and October, while lowest flows occur during the spring. Lands in this lower basin are generally grassy prairies with scattered pinewoods and palmetto growths.

Only once since the construction of Canal 38 has it been tested by 'Mother Nature'. In the early
part of October, 1969, a flood event in the lower Kissimmee River Basin occurred which caused considerable damage to the structures.

ENVIRONMENTAL NEED

The flood control Canal 38 of the Flood Control District is part of a complex system designed to abate flood damage. Canal 38 was constructed to withstand the flood with frequency of 1 in 20 years. However, in October, 1969, a 'flash' flood did occur and coupled with a prolonged rainfall through September and October, 1969, produced damaging results to Canal 38 facilities. Thus, for future analysis a mathematical model and computer simulation is needed.

OBJECTIVE

The objective of this report is to analyze data recorded by the Florida Flood Control District. From the data analysis establish parameters that will effect the building of an inventory-like model for the flood control reach, Canal 38. The similarity to inventory models is that each section of the reach will be treated as the warehouse or storage 'tank', and each section gate complex as a means of deleting storage or a control valve for
material flow. The model building process will be a method of 'trial and error' with model validation based on the integral square error and root mean square.

SUMMARY OF RECOMMENDATIONS

It is recommended that simulation work be carried out with the model developed in this report. Estimates of runoff, user inputs and outputs, and seepage (base flow) be developed and incorporated into the model to provide a better definition of the model. Further modeling be considered for minimizing damage and maximizing cost effectiveness and benefits.
II. DYNAMIC MODELING

Most scientists and engineers have realized that one of the basic problems in research is to first find the right question and then the right answer [2]. There exists enumerable data for many phenomena, but the equations that model the data are usually lacking. Modeling is a convenient device that saves storing all possible information about some physical phenomenon. With a mathematical model and a small amount of data, we can generate the original information.

To construct a dynamic model we go through phases of problem recognition, problem formulation, analytical modeling, simulation, evaluation of results (comparison with observation and prediction), and finally reformulation if necessary.

In order to create the analytical model, a study of the concepts of modeling is needed. These concepts will cover continuous, discrete, and statistical modeling.

CONTINUOUS MODELING

Continuous systems are those systems described by differential equations [3]. Ordinary differential equations
are used to express relations between changes in physical quantities. A system of ordinary differential equations of the form,

\[ f_1[t, x_1(t), x_2(t), \ldots, x_N(t)] = 0 \]

involves a set of unknown functions, \( x_N(t) \), and their derivatives with respect to a single independent variable, \( t \).

The procedure for using differential equations in modeling is to apply the least intricate model to the physical system, use it in the simulation, and evaluate the results. Based on this evaluation you can determine if reformulation of your model will be necessary.

We have as mathematical modeling tools both linear and nonlinear ordinary differential equations of the form:

a. Non-Interactive Model
   1) Linear, time varying coefficient
      \[ \begin{align*}
      \dot{x}_1(t) &= g_1(t) \cdot x_1(t) , \quad x_1(0) = c_1 \\
      \dot{x}_2(t) &= g_2(t) \cdot x_2(t) , \quad x_2(0) = c_2
      \end{align*} \]
2) Nonlinear self interaction

\[
\dot{x}_1(t) = g_1(t) \cdot x_1(t) + g_2(t) \cdot x_1^2(t) \\
+ g_3(t) \cdot x_1^3(t) + \ldots
\]

\[
\dot{x}_2(t) = g_1(t) \cdot x_2(t) + g_2(t) \cdot x_2^2(t) \\
+ g_3(t) \cdot x_2^3(t) + \ldots
\]

b. Interactive Model

Linear

\[
\dot{x}_1(t) = \underline{g}(t,x_1,x_2) = g_{11}(t) \cdot x_1(t) \\
+ g_{12}(t) \cdot x_2(t)
\]

\[
\dot{x}_2(t) = \underline{g}(t,x_1,x_2) = g_{21}(t) \cdot x_1(t) \\
+ g_{22}(t) \cdot x_2(t)
\]

Nonlinear

\[
\dot{x}_1(t) = \underline{h}(t,x_1,x_2) = h_{11}(t) \cdot x_1(t) \\
+ h_{12}(t) \cdot x_2(t) \\
+ h_{13}(t) \cdot x_1(t) \cdot x_2(t) \\
+ h_{14}(t) \cdot x_1^2(t) + \ldots
\]

\[
\dot{x}_2(t) = \underline{h}(t,x_1,x_2) = h_{11}(t) \cdot x_1(t) \\
+ h_{12}(t) \cdot x_2(t) \\
+ h_{13}(t) \cdot x_1(t) \cdot x_2(t) \\
+ h_{14}(t) \cdot x_1^2(t) + \ldots
\]
An alternative approach to ordinary differential equations modeling is transfer function modeling. The transfer function approach may be applied to a system, or part of a system, that is linear, time invariant and its initial state is in equilibrium. The important difference between differential equations and transfer functions is that the latter does not take into account the initial state of the physical system [4]. This is because the transfer function itself is the Laplace transform of the deviation of a system's output (or state variable) from equilibrium. The advantage of the transfer function approach is that it substitutes algebraic equations for linear differential equations, thus facilitating their solution. "A disadvantage of transfer function modeling applied to ecological systems is that these systems are rarely in a state of equilibrium initially." [4]

Transfer function modeling is strictly input/output data matching. For a system with input $f(t)$ or $F(s)$, and output $x(t)$, or $X(s)$, the transfer function $H(s)$, has the form:

$$ H(s) = \frac{X(s)}{F(s)} = \frac{S^m + b_{m-1}S^{m-1} + \ldots + b_1S + b_0}{S^m + a_{m-1}S^{m-1} + \ldots + a_1S + a_0} $$

or in the 'block box' form

```
F(s) ---- H(s) ---- X(s)
```
Transfer function modeling is used for systems analysis. For example, to have the power to predict quantitatively the energy dynamics of an animal's response to its environment and to its own nutritional condition, we need the conceptual framework and mathematical tools of the systems analysis approach [5].

The dynamics of a system are characterized mathematically by the relationship between input and output. To understand this dynamic behavior we must thoroughly analyze its input/output relationships. We generally recognize the problem that most physical and biological systems do not work on the basis of relationship by correlation. It is less generally recognized that such systems operate on the basis of the relationships between quantities (storages) and transfers (flows) of matter and energy. We have relied upon regression models partially because there is not enough known about most biological systems to build storage-flow models, but also because we are used to thinking in terms of relationship and not in terms of process [4].

The methodology of systems analysis, then, usually begins with the construction of a block (flow) diagram, a graphic model in which the storages and flows associated with known or suspected components of the system are identified.
The procedure for transfer function or block (flow) modeling is similar to ordinary differential diagram equations—except that a collection of transfer functions is used in the iterative process.

**Integrator**

\[ F(s) \rightarrow \frac{1}{S} \rightarrow X(s) \]

**Differentiator**

\[ F(s) \rightarrow S \rightarrow X(s) \]

**Exponential Filters**

\[ F(s) \rightarrow \frac{1}{S+a} \rightarrow X(s) \quad \text{or} \quad F(s) \rightarrow \frac{1}{(S+a)^n} \rightarrow X(s) \]

**Second Order Filters**

\[ F(s) \rightarrow \frac{W_n^2}{S^2 + 2 \xi W_n S + W_n^2} \rightarrow X(s) \]

**Lead-Lag Filters**

\[ F(s) \rightarrow \frac{(S+a)^n}{(S+b)^n} \rightarrow X(s) \]
DISCRETE MODELING

For discrete modeling, difference equations are our mathematical tools [3]. Like ordinary differential equations, difference equations express relations between changes in physical quantities. A system of difference equations of the form,

\[ f_i[t, X_1(t), X_2(t), \ldots, X_1(t+1), X_2(t+1), \ldots] = 0 \]

involves a set of unknown functions, \( X_n(t) \) and their displacements with respect to a single independent variable, \( t \).

The application of difference equations is exactly the same as ordinary differential equations. Begin with the least complex model applicable to the physical system, perform simulation, and evaluate the results. Based on this evaluation, model reformulation is decided.

Modeling steps for difference equations:

a. Non-Interactive Model
   1. Linear, time varying coefficients
      \[ X_1(t+1) = g_1(t) \cdot X_1(t) \quad , \quad X_1(0) = C_1 \]
      \[ X_2(t+1) = g_2(t) \cdot X_2(t) \quad , \quad X_2(0) = C_2 \]
   2. Nonlinear, self-interactive
      \[ X_1(t+1) = g_1 \cdot X_1(t) + g_2 \cdot X_1^2(t) + \ldots \]
      \[ X_2(t+1) = g_1 \cdot X_2(t) + g_2 \cdot X_2^2(t) + \ldots \]
b. Interactive Model

Example

\[\begin{align*}
X_1(t+1) &= g(t, X_1, X_2) = g_{11} \cdot X_1(t) + g_{12} \cdot X_2(t) \\
X_2(t+1) &= g(t, X_1, X_2) = g_{12} \cdot X_1(t) + g_{22} \cdot X_2(t)
\end{align*}\]

1. Linear, time varying coefficients

\[\begin{align*}
X_1(t+1) &= g_{11}(t) \cdot X_1(t) + g_{12}(t) \cdot X_2(t) \\
X_2(t+1) &= g_{21}(t) \cdot X_1(t) + g_{22}(t) \cdot X_2(t)
\end{align*}\]

2. Nonlinear, time varying coefficients

\[\begin{align*}
X_1(t+1) &= g_{11} \cdot X_1(t) + g_{12} \cdot X_2(t) \\
&\quad + g_{13} \cdot X_1(t) \cdot X_2(t) + g_{14} \cdot X_1^2(t) \\
&\quad + g_{15} \cdot X_2^2(t) + \ldots \\
X_2(t+1) &= g_{21} \cdot X_1(t) + g_{22} \cdot X_2(t) \\
&\quad + g_{23} \cdot X_1(t) \cdot X_2(t) + g_{24} \cdot X_1^2(t) \\
&\quad + g_{25} \cdot X_2^2(t) + \ldots
\end{align*}\]

For the same considerations as discussed in the continuous modeling section, we can discuss transfer function modeling of discrete models. The transforms are Z-transforms which have the same type of characteristics as Laplace transforms discussed earlier.

The transfer function resulting from the Z-transform operation may be implemented by relating the
input/output variables of the physical system. For example with an input \( x(Z) \) and output \( y(Z) \) the discrete transfer function may be represented as,

\[
G(Z) = \frac{y(Z)}{x(Z)} = \frac{A_0 + A_1 Z^{-1} + A_2 Z^{-2} + \ldots + A_N Z^{-N}}{b_0 + b_1 Z^{-1} + b_2 Z^{-2} + \ldots + b_q Z^{-q}}
\]

Some advantages and disadvantages of transfer function modeling have been mentioned while discussing Laplace transforms, and further discussion follows in the simulation section.

A modeling technique that is not an addition to continuous and discrete modeling, but rather a supplement to them is state variables [4]. The purpose of state variables is to redefine the model into a notation more comfortable to the engineer and also to aid in the solution which will be discussed later. We have examined differential equations describing dynamical systems. Now suppose we have an \( N^{th} \) order differential equation that we would like to replace by a set of \( N \) first order equations. Consider a system described by the following \( 4^{th} \) order differential equation [16]:

\[ \dddot{y} + a \dddot{y} + b \dot{y} + c y + d y = f(t). \]
Using a change of variable technique, \( y = X_1 \), put this system into state variable form

Let

\[
\begin{align*}
\dot{x}_1 &= \dot{y} = x_2 \\
\dot{x}_2 &= \ddot{y} = x_3 \\
\dot{x}_3 &= \ldots \\
\dot{x}_4 &= \ddots = x_4
\end{align*}
\]

\[
\dot{x}_4 = -ax_4 - bx_3 - cx_2 - dx_1 + f(t)
\]

or in matrix form

\[
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2 \\
\dot{x}_3 \\
\dot{x}_4
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
-d & -c & -b & -a
\end{bmatrix}
\begin{bmatrix}
x_1 \\
x_2 \\
x_3 \\
x_4
\end{bmatrix} +
\begin{bmatrix}
0 \\
0 \\
0 \\
f(t)
\end{bmatrix}
\]

or

\[
\dot{X} = AX + BU
\]

where

- \( A^* \): is the system matrix \((N \times N)\)
- \( B^* \): is the input distribution matrix \((N \times M)\)
- \( X \): state vector \((N \times 1)\)
- \( U \): input vector \((M \times 1)\)

*These parameters may be time varying.
The state variable technique can also be used with difference equations. For example consider the difference equation

\[ y(k+4) + ay(k+3) + by(k+2) + cy(k+1) + dy(k) = f(k) \]

Using the change of variable technique again, \( x_1(k) = y(k) \), the equation can be put into state variable form as follows:

Let

\[
\begin{align*}
X_1(k+1) &= y(k+1) = X_2(k) \\
X_2(k+1) &= y(k+2) = X_3(k) \\
X_3(k+1) &= y(k+3) = X_4(k) \\
X_4(k+1) &= -aX_4(k) - bX_3(k) - cX_2(k) - dX_1(k) + f(k)
\end{align*}
\]

or in matrix form

\[
\begin{bmatrix}
X_1(k+1) \\
X_2(k+1) \\
X_3(k+1) \\
X_4(k+1)
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
-d & -c & -b & -a
\end{bmatrix}
\begin{bmatrix}
X_1(k) \\
X_2(k) \\
X_3(k) \\
X_4(k)
\end{bmatrix} +
\begin{bmatrix}
0 \\
0 \\
0 \\
1
\end{bmatrix} f(k)
\]

or

\[ X(k+1) = A X(k) + B f(k) \]

Now that we have the framework to model our system, the next step is to validate the model. A procedure, combined with experience and insight, is simply trial and error.
PHYSICAL DESCRIPTION

As previously discussed, Canal 38 exists between Lake Kissimmee and Lake Okeechobee [1]. The straight line distance between the two lakes is about 52 miles, but the Kissimmee River distance is about 90 miles with a total fall of about 35 feet (see Figure 1).

Vertical lifting gates which allow water to flow onto adjacent spillways, termed gated spillways, are the control system for Canal 38. The five gated spillway structures: 65A, 65B, 65C, 65D, and 65E are physically described in Table I [1].

<table>
<thead>
<tr>
<th>Control Gate</th>
<th>Number Of Gates</th>
<th>Width x Height (Feet)</th>
<th>Safety Maximum Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65A</td>
<td>3</td>
<td>27 x 13.7</td>
<td>11,000</td>
</tr>
<tr>
<td>65B</td>
<td>3</td>
<td>27 x 13.7</td>
<td>14,000</td>
</tr>
<tr>
<td>65C</td>
<td>4</td>
<td>27 x 13.7</td>
<td>18,000</td>
</tr>
<tr>
<td>65D</td>
<td>4</td>
<td>27 x 13.7</td>
<td>21,300</td>
</tr>
<tr>
<td>65E</td>
<td>6</td>
<td>27 x 13.7</td>
<td>24,000</td>
</tr>
</tbody>
</table>
In order to gain further information about the physical characteristics of Canal 38, actual construction blue prints were obtained, as well as, design specifications [6, 7]. Table II summarizes the data abstracted from the prints and specifications.

### Table II

**CANAL 38 PHYSICAL CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Reach Section</th>
<th>65</th>
<th>65A</th>
<th>65B</th>
<th>65C</th>
<th>65D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manning's Coefficient of Roughness (n)</td>
<td>.03</td>
<td>.03</td>
<td>.03</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>Average Bottom Elevation MSL (ft)</td>
<td>17.8</td>
<td>10.6</td>
<td>2.9</td>
<td>3.8</td>
<td>-8.9</td>
</tr>
<tr>
<td>Average Ground Elevation (ft)</td>
<td>46.6</td>
<td>41.6</td>
<td>34.7</td>
<td>28.2</td>
<td>22.9</td>
</tr>
<tr>
<td>Average Bottom Width (ft)</td>
<td>90.</td>
<td>100.</td>
<td>140.</td>
<td>268.</td>
<td>225.</td>
</tr>
<tr>
<td>Reach Length (ft)</td>
<td>57134.</td>
<td>64154.</td>
<td>43138.</td>
<td>51021.</td>
<td>39794.</td>
</tr>
</tbody>
</table>
The side slope for Canal 38 is one (1) foot vertical on two (2) feet horizontal. Figure 2 diagrams a cross-section of Canal 38.

**FIGURE 2**
CROSS-SECTION CANAL 38
The sections (65, 65A, etc.) were further divided into upper and lower portions. Upper and lower divisions were due to the data recorded for stage readings in each section.

Stage readings were recorded for the periods April, 1970, through March, 1972, for both the upper and lower divisions of the sections [8]. For the same period, each section maintained daily rainfall and gate height change logs. Complementing the preceding data logs, information was gathered for the same period on total monthly evaporation rates [9]. The logs, stage, rainfall, gate heights, and evaporation rates were then formatted for computer program use.

ASSUMPTIONS

The following assumptions were made to aid in defining the dynamic system:

1. The evaporation rates were recordings of the Lake Alfred Experimental Station located approximately 30 miles northwest of section 65. The monthly total readings were averaged for daily evaporation rates used in all sections of Canal 38.
2. It is known that Canal 38 is used by the public for irrigation, drainage, and any other use allowed by the Flood Control District. The exact amount that might effect the volume of Canal 38 is only known to be "small". Also, estimates of groundwater seepage, sub-surface flows, transpiration rates, or other hydrological parameters not previously mentioned as recorded are unknown. Therefore, a parameter $\varepsilon$ will be defined that combines the unknowns mentioned here-in.

3. The side slopes and bottom of the canal were assumed to be straight for computations of cross-sectional area and volume.

4. Coefficient of discharge for the gated spillways was assumed to be that for rectangular orifice head cement material [10].

5. Due to misplaced information, gate 4 for sections 65C and D and gates 4, 5, and 6 of section 65E were given the same height change as gate 3 for the same section.
6. It was assumed that both the rainfall and evaporation effected an area 100 feet long either side of the control structures.

7. The FCD suggested that Lake Istokpoga does not effect Canal 38 at present because the connecting spillway has yet to be completed.

A block flow diagram of the dynamic system, Canal 38, follows in Figure 3.
FIGURE 3
CANAL 38 BLOCK FLOW DIAGRAM

P: PRECIPITATION
E: EVAPORATION
F: STREAM FLOW
Q: GATE DISCHARGE
ε: UNKNOWN PARAMETERS
MATHEMATICAL EQUATIONS

1. Equation to compute wet cross-sectional area:

FIGURE 4
PARAMETER DESCRIPTION OF CANAL CROSS-SECTION

\[ BW = \text{Bottom Width (ft)} \]
\[ WL = \text{Water Level (ft)} \]
\[ SW = \text{Surface Width (ft)} \]
\[ WA = \text{Wet Area (ft}^2) \]

\[ SW = BW + 4. \ast WL \]
\[ WA = WL \ast 0.5 (BW + SW) \]
\[ = WL \ast 0.5 (BW + BW + 4. \ast WL) \]

then

\[ WA = WL \ast (BW + 2. \ast WL) \quad (1) \]
2. Hydraulic radius for trapezoidal channel [11]:
Let \( Z = (SW - BW)/WL \)
\[ X = WL/BW \]
then we can say \( R \) the hydraulic radius
\[ R = \frac{1 + Z \times X}{1 + 2 \times X \times \sqrt{1 + Z^2}} \times WL \quad (2) \]

3. Streamflow, Manning's equation [12]:
Let flow, \( F \), be the discharge in cubic feet per day.
\[ F = 1.49/n \times WA \times R^{2/3} \times \sqrt{S} \quad (3) \]
where \( n = \) Manning's coefficient of roughness
\( S = \) Energy Gradient
\[ = |\text{Head Loss}|/\text{Length} \]

4. Gate discharge through a submerged orifice [11]:
Let gate discharge, \( Q \), be the discharge in cubic feet per day.
\[ Q = CA \sqrt{2gh} \quad (4) \]
\( C = .06 \), coefficient of discharge for submerged orifices [10].
\( A = \) area of opening (\( ft^2 \))
\( h = \) difference in water surface elevation (\( ft \))
\( g = \) gravity (\( ft^2/day \))
5. Equations for calculating dynamic surface level:

Figure 5 displays a section side view of Canal 38.

**FIGURE 5**

**CANAL SECTION SIDE VIEW**

\[ \begin{align*}
WLL &= \text{Water Level Lower (ft)} \\
WLU &= \text{Water Level Upper (ft)} \\
A_1 &= \text{Area of Rectangle (ft}^2) \\
A_2 &= \text{Area of Triangle (ft}^2) \\
L &= \text{Length of Section (ft)}
\end{align*} \]

Once a calculated volume is established, a surface level need be computed. Using equation (1) for area then,

\[ A_1 = WLL \times (BW + 2 \times WLL) \]

\[ A_2 = 0.5 \times (WLU - WLL) \times (BW + 2(WLU - WLL)) \]
Let \( V = \text{volume of Figure 4} \) and \( h = \text{WL} - \text{WLL} \)

\[ V = L \times (A_1 + A_2) \]

or

\[ V = L \times \text{WLL} \times \text{BW} + 2 \times L \times \text{WLL}^2 \]
\[ + 0.5 \times L \times h \times \text{BW} + h^2 \]

then

\[ \frac{V}{2L} = \text{WLL}^2 + 0.5 \times \text{BW} \times \text{WLL} \]
\[ + 0.25 (h \times \text{BW} + h^2/L) \]

also

\[ \text{WLL}^2 + 0.5 \times \text{BW} \times \text{WLL} \]
\[ + [0.25 (h \times \text{BW} + h^2/L) - \frac{V}{2L}] = 0 \]

solving for \( \text{WLL} \)

\[ \text{WLL} = -\frac{\text{BW}}{2} \]
\[ + \sqrt{(\frac{\text{BW}}{2})^2 + (-h \times \text{BW} - h^2/L + 2\frac{V}{L})} \]

(5)

MODELING TECHNIQUE

Since information about the physical parameters and mathematical relationships have been defined, and a system block flow diagramed, we are able to establish a modeling technique.

The modeling technique, 'trial and error', consists of the following steps:

1. Pick a model.
2. Simulate or determine the best fit to the real-world system.
3. Compute a performance index.
4. Check if the index is satisfactory.
5. If satisfactory, use the model.
6. If unsatisfactory, repeat procedure until the criterion is met.

Figure 6 is a flow diagram of the modeling procedure.
Some possible statistical measures that can be used to compute the performance index [13] are as follows:

1. The linear correlation coefficient, defined by,

\[
LCC = \frac{\sum_{i=1}^{N} X_i Y_i - \left(\sum_{i=1}^{N} X_i\right)\left(\sum_{i=1}^{N} Y_i\right) \left[\sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i\right)^2\right]^{\frac{1}{2}}}{\left[\sum_{i=1}^{N} Y_i^2 - \left(\sum_{i=1}^{N} Y_i\right)^2\right]^{\frac{1}{2}}}
\]

where \(N\) is the number of observations of the observed variable \(X\) and generated variable \(Y\), also \(X\) and \(Y\) are assumed to have a linear relationship. LCC has the following properties

i) \(-1 \leq LCC \leq +1\)

ii) The closer the value of LCC to either +1 or -1, the better is the agreement between the two variables for the assumed linear relationship

iii) A value of LCC closer to zero indicates that the two variables are uncorrelated.

2. The special correlation coefficient, defined by,

\[
SCC = \frac{2 \sum_{i=1}^{N} X_i Y_i - \sum_{i=1}^{N} Y_i^2}{\sum_{i=1}^{N} X_i^2}
\]
measures the agreement between the known variable X and its estimated value Y in terms of sums of squares of their deviation.

SCC exhibits the following properties:

i) SCC ≤ + 1

ii) SCC = + 1 if \( X_i = Y_i, \; i = 1, N \)

iii) SCC = 0 if \( Y_i = 2X_i \)

By comparing the linear correlation coefficient LCC and the special correlation coefficient SCC we observe that

a. SCC is similar to LCC in that the closer is the value of SCC to + 1 the better is the agreement between observed and calculated values.

b. SCC does not have the property of invariance under change of scale and location.

c. The distribution of SCC is unknown, hence the test of significance of the value of SCC cannot be performed.

Thus, although SCC is not a correlation coefficient in the usual sense, it still can
be used as a measure of agreement between observed and calculated values of a variable.

3. A statistical measure of yet another type is the integral square error (ISE). ISE describes the agreement between the time distribution of the calculated and observed values of a variable. The smaller the value of ISE, the better the agreement between the observed and the calculated values. The ISE is defined by,

$$\text{ISE} = \left( \frac{\sum_{i=1}^{N} (X_i - Y_i)^2}{\sum_{i=1}^{N} X_i} \right)^{1/2} \times 100 \quad (8)$$

Table III gives possible ratings that might be applied to these statistical measures. These ratings are meant as a guide, not a rule for their evaluation.
TABLE III
SUGGESTED RATING TABLE FOR STATISTICAL MEASURES [13]

<table>
<thead>
<tr>
<th>Correlation Coefficient (LCC)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.99 &lt; \text{LCC} &lt; 1.0$</td>
<td>Excellent</td>
</tr>
<tr>
<td>$0.95 &lt; \text{LCC} &lt; 0.99$</td>
<td>Very Good</td>
</tr>
<tr>
<td>$0.90 &lt; \text{LCC} &lt; 0.95$</td>
<td>Good</td>
</tr>
<tr>
<td>$0.85 &lt; \text{LCC} &lt; 0.90$</td>
<td>Fair</td>
</tr>
<tr>
<td>$0.00 &lt; \text{LCC} &lt; 0.85$</td>
<td>Poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Special Correlation Coefficient (SCC)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.99 &lt; \text{SCC} &lt; 1.0$</td>
<td>Excellent</td>
</tr>
<tr>
<td>$0.95 &lt; \text{SCC} &lt; 0.99$</td>
<td>Very Good</td>
</tr>
<tr>
<td>$0.90 &lt; \text{SCC} &lt; 0.95$</td>
<td>Good</td>
</tr>
<tr>
<td>$0.85 &lt; \text{SCC} &lt; 0.90$</td>
<td>Fair</td>
</tr>
<tr>
<td>$0.00 &lt; \text{SCC} &lt; 0.85$</td>
<td>Poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integral Square Error (ISE)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0% &lt; \text{ISE} &lt; 3.0%$</td>
<td>Excellent</td>
</tr>
<tr>
<td>$3.0% &lt; \text{ISE} &lt; 6.0%$</td>
<td>Very Good</td>
</tr>
<tr>
<td>$6.0% &lt; \text{ISE} &lt; 10.0%$</td>
<td>Good</td>
</tr>
<tr>
<td>$10.0% &lt; \text{ISE} &lt; 25.0%$</td>
<td>Fair</td>
</tr>
<tr>
<td>$25.0% &lt; \text{ISE}$</td>
<td>Poor</td>
</tr>
</tbody>
</table>
The performance criteria used for a satisfactory model were the integral square error, \(0\% < \text{ISE} < 3\%\), and root mean square error, \(0. < \text{RMS} < 1.5\). If these criteria were satisfied, the model was accepted.

Simulation of the closed model described by Figure 7 was used for physical model description.

**FIGURE 7**

CLOSED MODEL

Rain = Rain Rate  
Flow = Stream Flow Rate  
Evap = Evaporation Rate  
\(Q\) = Gate Discharge  
\(\varepsilon\) = Undeterminable Parameters
In storage modeling a relationship among storage, inflow, and outflow is postulated. A simple relationship can be,

\[ S = C Q \]  \hspace{1cm} (8)

where, \( S \) is the storage, \( Q \) is the outflow at any time, and \( C \) is a constant called the storage coefficient \cite{13}.

The storage equation (8), when combined with the hydrologic continuity equation we have,

\[ I - Q = \dot{S} \]  \hspace{1cm} (9)

where, \( I \) is the inflow. Projecting this type of mathematical model to the Canal 38 closed system results in,

\[ \dot{V} = A_1 \cdot \text{Flow} + A_2 \cdot \text{Rain} - A_3 \cdot Q - A_4 \cdot \text{Evap} - \epsilon \]  \hspace{1cm} (10)

where,

\[ \dot{V} = \text{Rate of volume change with respect to time (ft}^3/\text{day}) \]

Flow = Streamflow (ft\(^3\)/day)

Rain = Actual volume of rain effecting stream (ft\(^3\)/day)

Q = Average discharge thru gate structures (ft\(^3\)/day)

Evap = Actual volume of evaporation effecting stream (ft\(^3\)/day)

\[ \epsilon = A_5 (A_1 \cdot \text{Flow} + A_2 \cdot \text{Rain} - A_3 \cdot Q - A_4 \cdot \text{Evap}), \]

percent of change of unknown hydrologic parameters, \((0 \leq A_5 < .1)\)

\( A_1, A_2, A_3, A_4, A_5 \) = Coefficients of hydrological parameters.
The linear, time-invariant differential equation (10) was used to simulate the upper and lower sections of Canal 38. Coefficients for equation (10) were initially guessed to be one (1.0) except A5, assumed zero (0.0) initially.

The EAI 8400 digital computer was programmed in FORTRAN IV (see Appendix A) allowing on-line change of coefficients A5 only, or A1 through A5, at the end of each run. A run would simulate 365 days for the closed system. Runge-Kutta fourth order with fixed step size was used on the integration technique. Choice of Runge-Kutta integration was to facilitate further programming in case the found differential equations were non-linear. Further discussion of integration techniques is found in Chapter III, Simulation Considerations. A step size of one-tenth (.1) day was the integration increment.

Values for the coefficients A1 through A5 were based on observed data for the period January 1 to December 31, 1971. The values in Table IV for A1 through A5 satisfied the integral square error and root mean square error criteria.
TABLE IV
MODEL COEFFICIENT VALUES
BASED ON 1971 OBSERVED DATA

L = Lower Section
U = Upper Section

<table>
<thead>
<tr>
<th></th>
<th>A₁</th>
<th>A₂</th>
<th>A₃</th>
<th>A₄</th>
<th>A₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 L</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>.04</td>
</tr>
<tr>
<td>65A U</td>
<td>-.8</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65A L</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65B U</td>
<td>-1.0</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65B L</td>
<td>.5</td>
<td>1.0</td>
<td>1.5</td>
<td>1.0</td>
<td>.04</td>
</tr>
<tr>
<td>65C U</td>
<td>-1.0</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65C L</td>
<td>.5</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65D U</td>
<td>-1.0</td>
<td>1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>65D L</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Due to lack of data describing section 65E lower, no equations were developed for section 65E. Therefore, section 65E upper would be considered the final output of the system and section 65 upper as the initial input of the system.
MODEL VALIDATION

To establish the validity of the model, the values from Table IV were applied to equation (10) for each section. The observed data for the periods April 1 through December 31, 1970, and January 1 through March 31, 1972, were then used as the real-world data input. The statistical results for 1971, 1970, and 1972 are given in Table V.

These statistical results represent the ISE for each section which needed to be less than 3% over the total run time, 365 days. Three percent of the maximum stage height, 50 feet, or 1.5 feet established the tolerated deviation from the observed data for the RMS error criterion. Hydrographs, such as Figure 8, which plot calculated and observed stage height versus time, were used as a visual aid for validation. The ordinate axis increment varies with each hydrograph from .2 to 1 foot so as to fit in the required paper constraints. The varying ordinate increment should be realized while analyzing each hydrograph. It was noted from the graphs that some calculated approximations did not follow all troughs and peaks of the observed data. The trough and peak discrepancy could be due to any combination of the following reasons:
1) A trough or peak could have occurred in the real-world data because of a canal user output or input of water. Although the $\varepsilon$ term is part of the mathematical equation to incorporate the unrecorded use, it would apply the withdrawal or addition over the total run time rather than just the period of change. Since it is impossible to know when or how much change would occur, the approximating equation could not change the value of $\varepsilon$ periodically during the run.

2) High frequency stage height oscillation was digitally filtered from both the observed and calculated data. The digital filtering smoothed the calculated data to the "step" type plot on the graphs. This digital filtering explains the periods where it seems the stage is constant.

3) The gate height changes were compacted by averaging gate height change per 12 hours. This compaction might also be a reason for the low frequency of stage height change in the calculated data.
4) Since the observed stage height changes were expressed in the closed simulation as 6th order least square polynomials, some of the extreme changes in the observed data may have been smoothed out because of this approximation.

The mathematical equations presented in this report could now be linked together as described by Canal 38 block flow diagram (see Figure 3). Linked equations could then be used as a total simulation of Canal 38, but before leaping into a simulation, such considerations as instabilities, numerical approximation techniques, and integration step size need to be studied. These simulation considerations will be generally discussed in Chapter III.

Upon user satisfaction of the simulation of Canal 38, an optimal control problem can be implemented by defining each gate of each section as control variables. Each control variable will have some mathematical interpretation implemented in the simulation. The resulting control simulation could be used for solving optimal flood canal operating procedures.
### TABLE V

STATISTICAL MODEL VALIDATION RESULTS

<table>
<thead>
<tr>
<th></th>
<th>ISE (%)</th>
<th>RMS Error (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.1</td>
<td>.88</td>
</tr>
<tr>
<td>1970</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>1972</td>
<td>.03</td>
<td>.14</td>
</tr>
<tr>
<td>65A U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.05</td>
<td>.45</td>
</tr>
<tr>
<td>1970</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>1972</td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>65A L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.18</td>
<td>1.4</td>
</tr>
<tr>
<td>1970</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>1972</td>
<td>.1</td>
<td>.38</td>
</tr>
<tr>
<td>65B U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.11</td>
<td>.86</td>
</tr>
<tr>
<td>1970</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>1972</td>
<td>.1</td>
<td>.39</td>
</tr>
<tr>
<td>65B L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.17</td>
<td>1.08</td>
</tr>
<tr>
<td>1970</td>
<td>.2</td>
<td>1.08</td>
</tr>
<tr>
<td>1972</td>
<td>.07</td>
<td>.22</td>
</tr>
<tr>
<td>65C U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.09</td>
<td>.56</td>
</tr>
<tr>
<td>1970</td>
<td>.02</td>
<td>.14</td>
</tr>
<tr>
<td>1972</td>
<td>.08</td>
<td>.25</td>
</tr>
<tr>
<td>65C L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.21</td>
<td>1.04</td>
</tr>
<tr>
<td>1970</td>
<td>.06</td>
<td>.26</td>
</tr>
<tr>
<td>1972</td>
<td>.24</td>
<td>.59</td>
</tr>
<tr>
<td>65D U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.16</td>
<td>.83</td>
</tr>
<tr>
<td>1970</td>
<td>.09</td>
<td>.38</td>
</tr>
<tr>
<td>1972</td>
<td>.15</td>
<td>.38</td>
</tr>
<tr>
<td>65D L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>.09</td>
<td>.34</td>
</tr>
<tr>
<td>1970</td>
<td>.12</td>
<td>.42</td>
</tr>
<tr>
<td>1972</td>
<td>.16</td>
<td>.32</td>
</tr>
</tbody>
</table>

** Too sparse observed data for model validation.
FIGURE 8
STAGE 65 LOWER 1971

--- OBSERVED

○ CALCULATED
ADVANTAGES AND DISADVANTAGES

A distinct advantage to the 'trial and error' modeling technique is that it allows the analyst to use judgment and experience to formulate an initial model of the system. The model is then analyzed for its reliability; thus, the analyst need not have the complete mathematical description of his problem before simulation is started.

The major disadvantage to 'trial and error' modeling is that the resulting model need not be a unique solution. Also, the analyst is forced into simulation considerations before the mathematical model is built, possibly compounding model inaccuracy with simulation problems.
III. SIMULATION CONSIDERATIONS

Digital simulation of a continuous model involves the use of a machine which operates in discrete time-steps to approximate systems whose state transformations occur in infinitesimal increments of time. Therefore, the topic of numerical method selection is relevant [3].

DISCRETE MODEL SIMULATION

The greatest advantage of using difference equations to model the physical system is that the equations are directly applicable to a digital machine. Therefore, if possible, difference equations should be used to model the system especially if a digital simulation is planned.

CONTINUOUS MODEL SIMULATION

Some models using linear, time-invariant differential equations can be solved by exact difference equations. The solution points of these difference equations will fall on the continuous solution of the differential equations.

The procedure for obtaining an exact difference equation is by transformation. 1) Laplace transform the differential equations. 2) Apply the Inverse Laplace transform to equations from step 1. 3) Transform the equations
from step 2 using Z-transforms which discretizes the model.

4) Through inversion, obtain an exact difference equation in the t domain. Although this is the exact replication of the differential equations, it is usually very difficult and time consuming to produce the exact difference equation.

Another method for solving the differential equations consists of obtaining approximate difference equations. A characteristic of approximate difference equations is that we are mathematically guessing at what the next solution point of the dynamic system should be. The most used approximate difference equations are the numerical integration methods. Numerical accuracy and stability should be part of the criteria used to select numerical methods.

To determine the order of accuracy of any numerical integration technique, we need only evaluate the first term after truncating the Taylor series expansion. We can use as an example, the Modified Euler Method and determine the order of accuracy of this technique.

Given a function

\[ f(x) = \dot{x} = -ax, \quad x(0) = C \]

Then performing a Taylor series expansion on \( x(t) \)

\[ x(t) = e^{-at} \cdot x(0) \]

\[ = [1 - at + \frac{1}{2} (at)^2 - \ldots + \frac{1}{n!} (at)^n] \cdot x(0) \]

for notation \( X(0) = X_0 \) and \( X(n) = X_n \)
then
\[ x_n e^{-at} = [1 - at + \frac{1}{2} (at)^2 - \ldots + \frac{1}{n!} (at)^n] x_n \]

the modified Euler method is
\[ x_{N+1} = x_N + \frac{t}{2} [f(x_N, t_N) + f(x_{N+1}, t_{N+1})] \]
\[ = x_N + \frac{t}{2} [-ax_N - aX_{N+1}] \]
where \( X_{N+1} = x_N - at x_N \)
then
\[ x_{N+1} = x_N + \frac{t}{2} [-ax_N - ax_N + a^2 t x_N] \]

comparing the two expansions:
Modified Euler \[ x_{N+1} = x_N - at x_N + \frac{1}{2}(at)^2 x_N \]
Taylor Series Exp \[ x_N \cdot e^{-at} = x_N - at x_N \]
\[ + \frac{1}{2}(at)^2 x_N - \frac{1}{6}(at)^3 x_N \]

Since the first term truncated is \(-\frac{1}{6}(at)^3 x_N\) then its accuracy is second order. This information guides us in numerical method selection for accuracy.

The most common sources of error are truncation and round-off error, but the most important, yet widely abused, criterion of error is numerical instability. Most numerical methods become unstable if the 'steps' are made long enough in relation to the time constants of the system. Right up to the point where instability occurs the method may still be computing with required accuracy, but a further slight increase in step-length into the region of
instability results in the generation of completely erroneous solutions. Assuming the physical system itself is stable, we must consider the stability of the numerical method.

Consider the Euler method of the form
\[ X_{N+1} = (I + AT)X_N \], [14]. For simplicity, consider the scaler case with the results being extendible to the vector case. The Euler method represents a first order difference equation in the scaler case, \( X_{N+1} = (1 + aT)X_N \).

In order for the solution to remain bounded, \( |1 + aT| \leq 1 \). That is, the single root of the characteristic equation must lie within the unit circle in what is called the 'eigenvalue plane'. In order to extend the results to the vector case, let the coefficient 'a' be complex, then \( a = \sigma + j\omega \).

Now we have
\[
|1 + (\sigma + j\omega)T| \leq 1 \\
|(1 + \sigma T) \pm j(\omega T)| \leq 1 \\
(1 + \sigma T)^2 + (\omega T)^2 \leq 1
\]

This is the equation of a circle in the eigenvalue plane, and in order to preserve numerical stability of the solution of the Euler method, the value of the step, or sample time \( T \), must be kept low enough so that the root lies within the unit circle. For a real value of \( a \), clearly \( T \) must be selected so that \( |aT| \leq 2 \) or \( T \leq \frac{2}{|a|} \).
For systems with large eigenvalues, this is an extremely severe restriction.

In a similar manner we can analyze the stability regions of many other standard numerical integration techniques and determine bounds on the value of the increment on sample time $T$. Therefore, a necessary condition for numerical stability has been established, but there is no guarantee that all values of $T$ from zero to the limiting value will yield an accurate solution. Lomax [15] has suggested that the error in any method, as is given by the lowest order nonvanishing truncation terms, loses its significance when these terms exceed about one-tenth. To rely on such error estimates, $T$ should be chosen so that $|aT| < 0.1$, where $a$ is the maximum eigenvalue of the system. However, it should be noted that $|aT| < 0.1$ is an overly restrictive sufficient condition since the necessary condition, $|aT| < 2$ is all that is required.

Yet another popular approach to solving difference and differential equations is the state variable method [14]. Although the state variable technique obtains its highest merit when applied to linear systems, we can still find application in nonlinear cases. As a note of caution, most practical ecological problems cannot have a satisfactory linear representation and doing so could lead to large differences in predicted solutions, stability, and observed measurements [4].
One of the major attributes of the state variable technique is its adaptability to automated numerical computation. What we are interested in is the impulse response and transient response for general forcing functions. The modeling technique assumes the system is in the form of state variables, i.e., a system of first order linear differential equations $\dot{X} = A(t)X$. Also all systems are considered as sampled data systems with parameters held constant over a sampling period. This does not cause any loss of generality for fixed continuous or discrete systems, or time varying discrete systems. However, for time varying continuous systems in general this will result in approximate solutions. Satisfactory results can be obtained for systems where a small enough sampling period can be chosen such that the variable terms do not change significantly over a sample period.

Since most systems including ecological systems have a forcing function $u(t)$, the form of a differential equation becomes,

$$\dot{X} = A(t)X + Bu(t)$$

where $u(t)$ is a column vector containing the input functions. The solution of 'transient response', i.e., (a system responding to an input as the system approaches
steady state), will be of the form

\[ X(t) = \phi(t, t_0)X(t_0) + \int_{t_0}^{t} \phi(t - \lambda)Bu(\lambda)d\lambda \]  

where the state transition matrix \( \phi(t, t_0) = e^{A(t-t_0)} \) for \( A \) constant (not time varying). Of course, evaluating the convolution integral on the right side of equation (11) can be very time consuming. But in the case of sampled systems of period length \( T \) and if \( u(t) \) is constant over \( T \) and \( A \) held constant over each sample period then

\[ X(T) = e^{AT}X(0) + \int_{0}^{T} e^{A\lambda}d\lambda Bu(0) \]

or in general

\[ X([k+1]T) = e^{AT}X(kT) + \left[ \int_{0}^{T} e^{A\lambda}d\lambda \right] Bu(kT) \]

Although numerical integration still seems necessary, we can use the Taylor series expansion for \( \int_{0}^{T} e^{A\lambda}d\lambda \) and integrate this series term by term. Thus the form for integrating is

\[ \int_{0}^{T} e^{A\lambda}d\lambda = I + At + \frac{At^2}{2} + \frac{(At)^2t}{3!} + \ldots + \frac{(At)^Nt}{(N+1)!} + \ldots \]

In the case where \( u(t) \) varies over the sampling period we must either resort to numerical integration, or look for a way to reformulate the problem.
The main advantage of the state variable technique is the tremendous reduction in computer time required to simulate large sets of linear, time invariant differential or difference equations.

Simulation languages essentially attempt to provide access to digital computers for purposes of studying time-behavior of dynamic systems without programming in a complex general purpose language such as Fortran. They are special purpose languages based on the common features of all simulation problems, and as such they are relatively simple and easy to use. The latest entries into the field, incorporate virtually every feature of analog computers - except instantaneous turnaround. There is little question that simulation languages, because of their great power, versatility, and simplicity, will become of leading significance to ecological modeling in the years ahead.

Some of the common simulation languages are: CSMP, CSSL, DSL, DYNAMO, GPSS, MIDAS, MIMIC, and PACTOLUS [4]. Although digital simulation languages are sophisticated, they are very computer time consuming. Therefore, hybrid simulation is often found the more economical, where applicable, than simulation languages.
IV. SUMMARY AND CONCLUSIONS

Construction of a dynamic model can be summarized by problem recognition, problem formulation, analytical modeling, simulation, evaluation of results, and reformulation if necessary. The analytical modeling procedure is either continuous or discrete in concept. Continuous modeling need be discretized for digital simulation either exactly or approximated by difference equations. If discrete modeling can be employed at the analytical model stage, it should be used if simulation with a digital computer is foreseen. If the simulation tool is an analog or hybrid system, the continuous model need not be discretized.

Employing the procedure for construction of a dynamic model summarized above, a continuous model for the flood control Canal 38 was built. Evaluation tools for the model were the integral square error and root mean square error. If the model simulated did not meet the criteria, it was reformulated and tried again. Thus, the method of 'trial and error' model building is useful to any modeling task since it is independent of the task. The validated analytical model concluded to a set of linear, time invariant differential equations whose
solution was solved by the Runge Kutta technique during the model validation stage. Previous and following years data from the base year were simulated and satisfied criteria for a valid model.

Simulation of Canal 38 should consider both hybrid and digital simulation techniques. Measures for choice of simulation tools should be economics, precision, and machine availability. If digital simulation is chosen, careful consideration of an integration technique need be analyzed.

RECOMMENDATIONS

To obtain a useful simulation for Canal 38, the model presented in this study need be linked together with a control system. The control system should optimize storage in the canal for both normal and hazardous conditions. Therefore, the control system will minimize flood damage and maximize water storage and flow conditions.
APPENDIX A
COMMON /DYNAM/ PARAM(40), WISTR(8)
COMMON/FUNC/ A1, A2, EVAPR, RAINT, Q, FLOW, A3, A4, A5
COMMON /ERR/ OBS(365), CALC(365), NPTS, ASE, SSQS,
* SOBS
COMMON /COM/ RAINT(5, 365), EVAP(365), MO(12), KLOSS
*R(5), ROTEL(5), GRNDEL(5), ROTWTH(5), GATE(5), FLAG
*TH(5), AREA(5), COFFIN(7), TL1(365), TL2(365), G1(3)
*GCHG1(0, 0, 1K), GCHG2(0, 0L, K), APRX(7), APRX1(7), YTN
*OBS1(365)
DIMENSION EVAP1(12)
DIMENSION A(80)
INTEGER TL1, TL2
EXTENDED NAME(8)
EQUIVALENCE (ERFLG, PARAM(19))
LOGICAL ERFLG
DATA MO/31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31/
REACH KSECT KRAIN LOW
C**
C $65 1 1
C $65L 1 2
C $65AU 2 2 1
C $65AL 2 3
C $65BU 3 3 1
C $65BL 3 4
C $65CU 4 4 1
C $65CL 4 5
C $65DU 5 5 1
C $65DI 5 6
C $65EU 6 6
C**
100 CONTINUE
READ(5, 910) ISTRT, LOW, KSECT, KRAIN, KOPT
C**INPUT AND CONVERT RAINFALL DATA
C
C CHECK IF NEW RAINFALL AND EVAP. IS NEEDED
C
IF(KOPT .EQ. 1) GO TO 240
ICT = 0
INEX = 0
L = 1
200 CONTINUE
ICT = ICT + 1
CALL REOF(IEOF)
READ(5,900) A
IF(IEOF.EQ.1) GO TO 243
271 CALL REOF(IEOF)
READ(5,901) IDATE,RAINR
IF(IEOF.EQ.1) GO TO 202
INEX = INEX + IDATE
C*RAIN UNITS TO FT/DAY
C
RAIN(IDATE) = RAINR* (1./12.)
GO TO 201
C*EOF ON DATA CDR
C
222 CONTINUE
NREM = MO(ICT) - IDATE
INDEX = INDEX + NREM
GO TO 200
C*EOF ON ID CDR
C
223 CONTINUE
L = L + 1
ICT = 0
IF(L.EQ.7) GO TO 220
GO TO 220
C*INPUT AND CORRECT EVAP. RATES
C
220 CONTINUE
ICT = 0
READ(5,900) A
221 ICT = ICT + 1
CALL REOF(IEOF)
READ(5,902) EVAPR, IDATE
IF (IEOF.EQ.1) GO TO 240
C
C*CONVERT TO FT/DAY EVAP. RATE
C
EVAP1(IDATE) = EVAPR*(1./12.)*(1./MO(ICT))
GO TO 221
C
240 CONTINUE
NOAYS = 0
INDX = 0
NMO = ICT - 1
DO 241 I = 1, NMO
NOAYS = NOAYS + MO(I)
L = MO(I)
DO 242 J = 1, L
INDX = INDX + 1
EVAP(INDX) = EVAP1(I)
242 CONTINUE
241 CONTINUE
C
C*INPUT COEF OF ROUGHNESS
C
C
CORF = .03
250 CONTINUE
C
C*BOTTOM ELEV.
C
260 CONTINUE
BOTEL(1) = 17.8
BOTEL(2) = 10.6
BOTEL(3) = 2.9
BOTEL(4) = 3.8
BOTEL(5) = -8.9
270 CONTINUE
C
C*GROUND ELEVATION
C
GRNDEL(1) = 46.6
GRNDEL(2) = 41.6
GRNDEL(3) = 34.7
120  GNDW1(4) = 23.2
121  GNDW1(5) = 22.9
122  280  CONTINUE
123  C
124  C=BOTTOM WIDTH
125  C
126  HTTPS(1) = 90.
127  HTTPS(2) = 140.
128  HTTPS(3) = 140.
129  HTTPS(4) = 268.
130  HTTPS(5) = 225.
131  290  CONTINUE
132  C
133  C=NUMBER OF GATES
134  C
135  GATE(1) = 3.
136  GATE(2) = 3.
137  GATE(3) = 4.
138  GATE(4) = 4.
139  GATE(5) = 6.
140  300  CONTINUE
141  C
142  C=REACH LENGTH
143  C
144  RLNGTH(1) = 57134.
145  RLNGTH(2) = 64154.
146  RLNGTH(3) = 43138.
147  RLNGTH(4) = 51021.
148  RLNGTH(5) = 39794.
149  310  CONTINUE
150  C
151  C= INPUT GATE OPERATION LOG
152  C
153  C= IDATE = DAY
154  C= TL1 = LENGTH OF TIME(HRS.) GATES WERE OPEN G1
155  C= TL2 = LENGTH OF TIME(HRS.) GATES WERE OPEN G2
156  C= GL = HEIGHT GATES OPENED(FEET)
157  C= G2 = HEIGHT GATES OPENED(FEET)
158  C
159  DO 314 I=ISTRT,NDAYS
READ(5,908) IDATE,TL1(I),TL2(I),G1,G2
DO 315 J=1,3
GCHG1(J,!) = G1(J)
GCHG2(J,!) = G2(J)
315 CONTINUE
314 CONTINUE

C***INPUT LEAST SQUARE'S COEFF. FOR INPUT FUNCTION
READ(5,903) COEFFIN

C*** INPUT LEAST SQUARE'S COEFF. FOR OBSERVED FUNC.
READ(5,909) APRY, NAME

C***INPUT LEAST SQUARE'S COEFF. FOR OUTPUT FUNC.
READ(5,903) APRY1
312 CONTINUE

C***INPUT INITIAL GUESS COEFFICIENTS FOR DIFFR. FQN.

C***DERIVATIVE=A1*FLOW + A2*RAIN - A2*Q - A4*EVAP - FF
C***WHERE EPS IS AN ERROR TERM,
EPS = A5*(A1*FLOW + A2*RAIN -A3*Q -A4*EVAP)
316 CONTINUE
READ(5,904) A1,A2,A3,A4,A5

C*** ZERO CALCULATED AND OBSERVED BUFFERS
DO 317 I=1,365
OBS(I) = 0.0
CALC(I) = 0.0
317 CONTINUE
200  S0BS = 0.
201      SSOS = 0.
202      ITIME = ISTRT - 1
203      ERFLAG = .TRUE.
204      C*PREPARE PRGR. INPUT
205      350  CONTINUE
206      ITIME = ITIME + 1
207      T1 = ITIME
208      T2 = T1*T1
209      T3 = T2*T1
210      T4 = T3*T1
211      T5 = T4*T1
212      T6 = T5*T1
213      C
214      C** COMPUTE STAGE HTGTS. COMPACT. IN 6 TH. ORDR. POLYN
215      C
216      YIN = COEFIN(1) + COEFIN(2)*T1 + COEFIN(3)*T2
217      + COEFIN(4)*T3 + COEFIN(5)*T4 + COEFIN(6)*T5 +
218      * COEFIN(7)*T6
219      C
220      OBS(ITIME) = APRX(1) + APRX(2)*T1 + APRX(3)*T2
221      * + APRX(4)*T3 + APRX(5)*T4 + APRX(6)*T5 + APRX(7)*T6
222      C
223      OBS1(ITIME) = APRX1(1) + APRX1(2)*T1 + APRX1(3)*T2
224      * + APRX1(4)*T3 + APRX1(5)*T4 + APRX1(6)*T5 + APRX1(7)*T6
225      C
226      C** SETUP INTEG ROUTINE .. AND BEGIN TO INTEG
227      C
228      C
229      C
230      C** USE 'SETUP' FOR LOWER SECTION
231      C** USE 'SETUPL' IF UPPER SECTION
232      C
233      IF(LOW .EQ. 1) GO TO 351
234      CALL SETUP(ISTRT,LOW,NAME,KSECT,KRAIN)
235      GO TO 352
236      351  CONTINUE
237      CALL SETUPL(ISTRT,LOW,NAME,KSECT,KRAIN)
238      352  CONTINUE
C  IF((ITIME+1) .EQ. (NDAYS+1)) GO TO 360
GOTO 350
C* FINISHED INTEG
360 CONTINUE
NPTS = (NDAYS - ISTRT) + 1
WRITE(6,906) A1,A2,A3,A4,A5
C
C** COMPUTE ISE AND RMS
C
CALL ISE(NAME,ISTRT,NDAYS)
C
365 CONTINUE
C
C** ALLOW A5 OR A1-1 A5 TO BE CHANGED
C
READ(4,907) IUP, A5
IF(IUP .EQ. 1) GO TO 316
IF(IUP .EQ. 2) GO TO 100
GO TO 313
C**FORMATS
900 FORMAT(80A1)
901 FORMAT(18X,I2,F10.4)
902 FORMAT(10X,F10.4,I2)
903 FORMAT(7E10.4)
904 FORMAT(5E10.4)
905 FORMAT(2X,E14.6,7H*F01 + ,E14.6,4H#R1 ,3H - , 
*E14.6,4H #01,3H - , E14.6,5H #E1 ,2H- ,E14.6)
906 FORMAT(13.5X,12.5X,12.5X,3F5.2,4X,3F5.2)
907 FORMAT(11,E10.4)
908 FORMAT(13.5X,12.5X,12.5X,3F5.2,4X,3F5.2)
909 FORMAT(7E10.4,2X,8A1)
910 FORMAT(5I10)
911 FORMAT(2A4)
END
400 CMCN

SUBROUTINE SETUP(ISRT, LOW, NAME, KSECT, KRAIN)
COMMON /DYNAM/ PARAM(40), HISTR(8)
COMMON/ FUNC/ A1, A2, EVAPR, RAINR, Q, FLOW, A3, A4, A5
COMMON/ COM/ RAIN(0, 365), EVAP(365), MO(12), HLOSF
* TH(5), AREA(5), COEF(7), T1(365), TL2(365), G1(3)
*, GCHG1(0, OLK), GCHG2(0, OLK), APRX(7), APRX1(7), YN
*, OBS1(365)
COMMON /ERR/ OBS(365), CALC(365), NPTS, ISE, SSQS,

* SOBS
EXTERNAL DERIV, RK4
DIMENSION YN(2), MAXER(1), MINER(1), FN(1)
EQUIVALENCE(YN(1), HISTR(1)), (T0, PARAM(4)),
** (H, PARAM(6)), (C0MDEL, PARAM(8)), (MINDEL, PARAM
* 12)), (ERFLG, PARAM(19)), (FN(1), HISTR(3))
REAL MAXER, MINER, MINER
INTEGER CALF
INTEGER T1, T2
LOGICAL EXPCON, ERFLG
REAL MNHT
EXTRA NAME(8)
DATA MO/31, 28, 31, 30, 31, 30, 31, 30, 31, 30, 31/
DATA MAXER, MINER/1.0, 1.0/, MINDEL/01/
DATA EXPCON/.TRUE./
DATA ERFLG/.TRUE./
C
IF (.NOT. ERFLG) GO TO 100
WRITE(6, 900) NAME
FORMAT(1H1, 5X, A1, 1X, A1, 1X, 2A1, 1X, A1, 1X, A1, 1X.
30
* 2A1)
T0 = ISTRT
J = ISTRT
L = J - 1
NDD = 1
K = KSECT
M = KRAIN
READ(5, 1) YN(1)
FORMAT(10.4)
WRITE(6, 2) YN(1)
2 FORMAT(2X,9HINIT VAL.F10.4,1X,4HFEET)
   COMDEL = .1
   CALF = 1
   ITEMP = 0
   /
   / STC /ITEMP
   C*STEP SIZE = COMDEL / CALF
   CALC(J) = YN(1)
   DIFR = YIN - CALC(J)
   HALF = .5
   IF(DIFR.LT.0.) GO TO 50
   GO TO 60
   50 CONTINUE
   HALF = -HALF
   DIFR = - DIFR
   60 CONTINUE
   YN(1) = RLENTH(K) * (CALC(J)) * (BOTWTH(K) + 2 *
   **CALC(J) + HALF * DIFR*(BOTWTH(K) + 2.*DIFR))
   10 CONTINUE
   CALL INIT(PARAM, HSRT, DPTV, RK4, RK4, NOD, T0,
   *COMDEL, CALF, 1, MIND, 0, 0, 0, EXPCON, MAXER, MINER)
   100 CONTINUE
   IF(ITEMP.EQ.0) WRITE(6,5) J, CALC(J), OBS(J)
   L = L + 1
   C*WET AREA
   WA1 = YIN * (BOTWTH(K) + 2.*YIN)
   C*HYDRAULIC RADIUS
   X = YIN / BOTWTH(K)
   R = (1.0 + 2.0*X) / (1.0 + 2.0*X * SORT(1.0+4.
   *)) * YIN
   C
   70 C******************************
   C
   72 DO 20 ICT = 1, 10
   73 C*LOWER SURFACE AREA
   74 WA3 = 100. * (BOTWTH(K) + 4.*CALC(J))
   75 C*EVAP RATE FT**3/DAY
   76 EVAPR = EVAP(L) * WA3
   77 C*RAIN RATE FT**3/DAY
   78 RAINR = RAIN(M,L) * WA3
   79 C*DISCHARGE RATE FOR GATE OPENINGS
HLOSS = ABS(CALC(J) - OBS1(J))
SORT1 = SORT(2.*32286400.*HLOSS)
C=STEP 1 CALC Q FOR GATES OPENED TL1 HRS,
Q1 = .6 * (27.*GCHG1(1,L)) * SORT1
Q2 = .6 * (27.*GCHG1(2,L)) * SORT1
Q3 = .6 * (27.*GCHG1(3,L)) * SORT1
IF(GATE(K) .GT. 3.) Q3 = (GATE(K) - 3.) * Q3+Q3
SUMQ = TL1(L) * (Q1+Q2+Q3)
IF(TL2(L) .EQ.0) GO TO 105
C=STEP 2 CALC Q FOR GATES OPENED TL2 HRS
Q1 = .6 * (27.*GCHG2(1,L)) * SORT1
Q2 = .6 * (27.*GCHG2(2,L)) * SORT1
Q3 = .6 * (27.*GCHG2(3,L)) * SORT1
IF(GATE(K) .GT. 3.) Q3 = (GATE(K) - 3.) * Q3+Q3
SUMQ = TL2(L) * (Q1+Q2+Q3) + SUMQ
C=DISCHARGE FT**3/DAY
105 Q = SUMQ / 24.
C=ENERGY GRADIENT
HLOSS = ABS(CALC(J) - YIN)
S = HLOSS / RLENGTH(K)
C=FLOW RATE FT**3/DAY
FLOW = 1.486/.03 * WAI * R**.67 * SQRT(S)
C=INTEGRATE FOR 1 STEP SIZE
CALL INTEGR(PARAM)
IF(.NOT.INTEGR) GO TO 110
WRITE(4,200)
200 FORMAT(2X,9HINTEG ERR)
PAUSE
110 CONTINUE
C=NEW VOLUME
C=NEW HEIGHT FOR NEW MEAN VOLUME
IF(YIN .LT. CALC(J)) HLOSS = - HLOSS
IF(ICT .EQ.1) J = J + 1
B = BOTWTH(K) / 2.
BSQ = B * B
AC = - HLOSS*BOTWTH(K) - HLOSS*HLOSS/RLENGTH*K**2.
AC = - HLOSS*BOTWTH(K) - HLOSS*HLOSS/RLENGTH*K**2.
Y = YN(1)/RLENGTH(K)
HT = (-B + SORT(BSQ+AC)) / 2.
C=NEW HEIGHT
CALC(1) = HT

CONTINUE

3 FORMAT(2X,5HDATE,13,5HFLOW,E11.4,2X,6HCU,FT.)

6 FORMAT(2X,7HDISCHG,E11.4,2X,5HEVAP,E11.4,2X,
*5HRAIN,
*E11.4,2X,6HCU,FT.)

5 FORMAT(2X,4HDAY,14,1X,8HCALC HT,E11.4,2X,8HBSV
*E11.4,2X,4HFEET)

RETURN

END
SUBROUTINE SETUPL(ISTR, LOW, NAME, KSECT, KRAIN)
COMMON /DYNAM/ PARAM(40), HISTR(8)
COMMON /FUNC/ A1, A2, EVAPR, RAINR, Q, FLOW, A3, A4, A5
COMMON /COM/ RAIN(5, 365), EVAP(365), MO(12), HLOSS
* R(5), BOTEL(5), GRNDEL(5), ROTWTH(5), CATF(5), PENG
* TH(5), AREA(5), COEFIN(7), TL1(365), TL2(365), C1(3)
* OBS1(365)
COMMON /ERR/ OBS(365), CALC(365), NPTS, ISE, SSQS,
* SOBS
EXTERNAL DERIV, RK4
DIMENSION YN(2), MAXER(1), MINER(1), FN(1)
EQUIVALENCE(YN(1), HISTR(1)), (T0, PARAM(4))
*(H, PARAM(6)), (COMDEL, PARAM(8)), (MINDEL, PARAM(
* 12)), (ERFLG, PARAM(19)), (FN(1), HISTR(3))
REAL MAXER, MINDEL, MINER
INTEGER CALF
INTEGER TL1, T2
LOGICAL EXPCON, ERFLG
REAL MNHT
EXTENDED NAME(8)
DATA MO/31, 28, 31, 30, 31, 30, 31, 30, 31, 30, 31/
DATA MAXER, MINER/1.0, 1.0, 1.0, MINDEL/01/
DATA EXPCON/.TRUE./
DATA ERFLG/.TRUE./
C
IF(.NOT.ERFLG) GO TO 100
WRITE(6,909) NAME
909 FORMAT(1H1, 5X, A1, 1X, A1, 1X, A1, 1X, A1, 1X, A1, 1X, A1, 1X, A1, 1X, A1
* 2A1)
T0 = ISTR
J = ISTR
L = J - 1
NDO = 1
K = KSECT
M = KRAIN
READ(5,1) YN(1)
1 FORMAT(E12.4)
WRITE(6,2) YN(1)
40 2 FORMAT(2X,9HINIT VAL ,F10.4,1X,4HFEEt)
  COMDEL = .1
  CALF = 1
  ITEMP = 0
  /  STC  /ITEMP
  C**STEP SIZE = COMDEL / CALF
  CALC(J) = YN(1)
  DIFR = CALC(J) - OBS1(J)
  HALF = .5
  IF(DIFR .LT. 0.) GO TO 50
  GO TO 60
  50 CONTINUE
  HALF = - HALF
  DIFR = - DIFR
  60 CONTINUE
  YN(1) = LENGTH(K) * (CALC(J)) * (BOTWTH(K) + 2.
  **CALC(J)) + HALF * DIFR*(BOTWTH(K) + 2.*DIFR))
  10 CONTINUE
  *1,MINDEL, 0,0,0,EXPCON,MAXER,MINER)
  100 CONTINUE
  IF(ITEMP .EQ. 0) WRITE(6,5) J, CALC(J), OBS(J)
  L = L + 1
  62 C**WET AREA
  63 WA1 = CALC(J) * (BOTWTH(K) + 2.*CALC(J))
  64 C**HYDRAULIC RADIUS
  65 X = CALC(J) / BOTWTH(K)
  66 R = (1.0 + 2.0*X) / (1.0 + 2.0*X * SORT(1.0+4.
  ));) * CALC(J)
  67 C
  68 C
  69 C
  70 C
  71 DO 20 ICT = 1, 10
  72 C*LOWER SURFACE AREA
  73 WA3 = 100. * (BOTWTH(K) + 4.*CALC(J))
  74 C*EVAP RATE FT**3 / DAY
  75 EVAPR = EVAP(L) * WA3
  76 C*RAIN RATE FT**3/ DAY
  77 RAINR = RAIN(M,L) * WA3
  78 C*DISCHARGE RATE FOR GATE OPENINGS
  79 HLOSS = ABS(YIN - CALC(J))
80  C*STEP 1  CALC Q FOR GATES OPENED TL1 HRS.
81  Q1 = .6 * (27.*SCHG1(1,L)) * 8ORT1
82  Q2 = .6 * (27.*SCHG1(2,L)) * 8ORT1
83  Q3 = .6 * (27.*SCHG1(3,L)) * 8ORT1
84  IF(GATE(K) .GT. 3.) Q3 = (GATE(K) - 3.) * Q3+Q3
85  SUMQ = TL1(L) * (Q1+Q2+Q3)
86  IF(TL2(L) .EQ. 0) GO TO 105
87  C*STEP 2  CALC Q FOR GATES OPENED TL2 HRS.
88  Q1 = .6 * (27.*SCHG2(1,L)) * 8ORT1
89  Q2 = .6 * (27.*SCHG2(2,L)) * 8ORT1
90  Q3 = .6 * (27.*SCHG2(3,L)) * 8ORT1
91  IF(GATE(K) .GT. 3.) Q3 = (GATE(K) - 3.) * Q3+Q3
92  SUMQ = TL2(L) * (Q1+Q2+Q3) + SUMQ
93  C*DISCHARGE FT**3/DAY
94  105  Q = SUMQ / 24.
95  C*ENERGY GRADIENT
96  HLOSS = ABS(CALC(J) - OBS1(J))
97  S = HLOSS / RLENGTH(K)
98  C*FLOW RATE FT**3/DAY
99  FLOW = 1.486/.03 * WA1 * R**.67 * SQRT(S)
100  C*INTEGRATE FOR 1 STEP SIZE
101  CALL INTEG(PARAM)
102  IF(.NOT.ERRFLG) GO TO 110
103  WRITE(4,200)
104  200  FORMAT(2X,9HINTEG ERR)
105  PAUSE
106  110  CONTINUE
107  C*HAVE NEW VOLUME
108  C*NEED HEIGHT FOR NEW MEAN VOLUME
109  IF(CALC(J) .LT. OBS1(J)) HLOSS = - HLOSS
110  IF(ICT .EQ. 1) J = J + 1
111  B = ROTWTH(K) / 2.
112  BSQ = B * B
113  AC = - HLOSS*ROTWTH(K) - HLOSS*HLOSS/RLENGTH(K)
114  * + 2.
115  **YN1/RLNGTH(K)
116  HT = (-B + SQRT(BSQ+AC)) / 2.
117  C*NEW HEIGHT
118  CALC(J) = HT
20 CONTINUE
21 3 FORMAT(2X,5HDATE ,13,5HFLOW ,E11.4,2X,6HCU,FT.
22  ""
23 6 FORMAT(2X,7HDSCHG ,E11.4,2X,5HEVAP ,E11.4,2X,
24  *5HRAIN.
25  *E11.4,2X, 6HCU,FT.)
26 5 FORMAT(2X,4HDAY ,14,1X,8HAIC HT ,E11.4,2X,
27  *8HRSV HT,
28  *E11.4,2X,4FEET)
29  RETURN
30  END
CIMCON

SUBROUTINE DERIV

COMMON /DYNAM/ PARAM(40), HISTR(8)
COMMON/FUNC/ A1,A2, EVAPR, RAINR, Q, FLOW, A3, A4, A5
DIMENSION YN(2), FN(1)
EQUIVALENCE(YN(1), HISTR(1)), (FN(1), HISTR(3))
PA5 = A5 * (A1*FLOW + A2*RAINR - A3*Q -
* A4*EVAPR)
FN(1) = A1*FLOW + A2*RAINR - A3*Q - A4*EVAPR - PA5
RETURN
END
SUBROUTINE ISE(NAME, ISTRT, NDAYS)
COMMON /ERR/ OBS(365), CALC(365), NPTS, ASE, SSQS,
* SSORS
EXCEPTION NAME(8)
EXCEPTION IDNAME(1)
STC 5S
CA = 0
CP = 1
JZ 6S
WRITE(1,1) NAME

1 FORMAT(2X, 8A1)
6 CONTINUE
C* SSQS = 0,0
C* SSORS = 0,0
C* CALC. SUM OF SORS
DO 20 I = ISTRT, NDAYS
SSORS = OBS(I) + SSORS
SSQS = (OBS(I) - CALC(I)) **2 + SSQS
20 CONTINUE
C* DIGITAL FILTER TO 1 DECIMAL PLACE
C
TEMP = CALC(I) * 10.
ITEMP = TEMP
CALC(I) = ITEMP / 10.
20 CONTINUE
C* PLOT CALCULATED DATA.....
C* OUTPUT FOR PLOTTING
C
/ STC 25S
/ CA = 0
/ CP = 1
/ JZ 30S
CALL WRITE
30 CONTINUE
ASE = SQRT(SSQS) / SSORS * 100.
S QE = SQRT(SSQS/NPTS)
C
WRITE(6,100) ASE
40      WRITE(6,200) SQE
41      WRITE(6,300) IFIL
42      100  FORMAT(5X,25H1SE FOR PRECEEDING COFF. ,F6.2)
43      200  FORMAT(5X,12HMEAN SQ ERR ,F14.6)
44      300  FORMAT(2X,7HFILE = ,I5)
45  RETURN
46  END
FIGURE 9
STAGE 65A UPPER 1971

- OBSERVED
○ CALCULATED
FIGURE 11
STAGE 65B UPPER 1971

- OBSERVED
○ CALCULATED
FIGURE 12
STAGE 65B LOWER 1971

- OBSERVED

- CALCULATED
FIGURE 13
STAGE 65C UPPER 1971

- OBSERVED
- CALCULATED

STAGE 65C UPPER 1971 (FEET)

DAY

0-365
FIGURE 15
STAGE 65D UPPER 1971
FIGURE 16
STAGE 65D LOWER 1971

- OBSERVED
○ CALCULATED
FIGURE 18
STAGE 65 LOWER 1972

- OBSERVED
○ CALCULATED
FIGURE 19
STAGE 65A UPPER 1972

- OBSERVED

○ CALCULATED
FIGURE 20
STAGE 65A LOWER 1972

- OBSERVED
○ CALCULATED
FIGURE 21
STAGE 65B LOWER 1970

--- OBSERVED
○ CALCULATED
FIGURE 22
STAGE 65B UPPER 1972

- OBSERVED

○ CALCULATED
FIGURE 23
STAGE 65B LOWER 1972

- OBSERVED
○ CALCULATED
FIGURE 24
STAGE 65C UPPER 1970

- OBSERVED
○ CALCULATED
FIGURE 25
STAGE 65C LOWER 1970

- OBSERVED
○ CALCULATED
FIGURE 26
STAGE 65C UPPER 1972

- OBSERVED
○ CALCULATED
FIGURE 27
STAGE 65C LOWER 1972

- OBSERVED
○ CALCULATED
FIGURE 30
STAGE 65D LOWER 1970

OBSERVED

CALCULATED
FIGURE 29
STAGE 65D UPPER 1972

- OBSERVED
○ CALCULATED
BIBLIOGRAPHY


8. Data tables and charts received in June, 1972, from Central and Southern Florida Flood Control District, West Palm Beach, Florida.


