1968

# Economic Analysis of Flood Detention Storage by Digital Computer

Digital Object Identifier: https://doi.org/10.13023/kwrri.rr.09

James Ray Villines
*University of Kentucky*

L. Douglas James
*University of Kentucky*

Research Report No. 9

# ECONOMIC ANALYSIS OF FLOOD DETENTION STORAGE BY DIGITAL COMPUTER

James Ray Villines



University of Kentucky Water Resources Institute
Lexington, Kentucky

Project Number A-001-KY
Dr. L. Douglas James, Principal Investigator

1968

## INTRODUCTION

"Economic Analysis of Flood Detention Storage by Digital Computer" is based on research performed as part of a project entitled "Economic Analysis of Alternative Flood Control Measures" (OWRR Project No. A-001-KY) sponsored by the University of Kentucky Water Resources Institute and supported in part by funds provided by the United States Department of Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379. Special thanks must also be extended to the Louisville District office of the U. S. Army Corps of Engineers for help in data gathering and the University of Kentucky Computing Center for use of their facilities.

The research goal is a practical means for economic evaluation of alternative combinations of structural and nonstructural measures for flood control for use in flood control project formulation. The result has been a pair of computer programs designed to ease the computational burden of comparing measure combinations by reproducing the mathematical steps in the design process. The Programs are described in a series of four reports.

1. Rachford, Thomas M., "Economic Analysis of Alternative Flood Control Measures by Digital Computer," Research Report No. 1

2. Villines, James R., "Economic Analysis of Flood Detention Storage by Digital Computer," Research Report No. 9

3. Dempsey, Clyde R., "The Effects of Geographical and Climatic Setting on the Economic Advantages of Alternative Flood Control Measures," Research Report No. 10

4. Cline, James Norris, "Planning Flood Control Measures by Digital Computer," Research Report No. 11

The last three of these reports may be read as a unit for a thorough understanding of the research results.

The computer program as described is continuously being revised and updated as new experience is gained by applying it in different circumstances. Any comments or suggestions the reader may have will be sincerely appreciated and should be addressed to L. Douglas James, Project Director.

ABSTRACT

The objective of this study was to develop a digital computer procedure for preliminary analysis of the economic justification of reservoir detention storage for flood control and to present a sample study illustrating its application. A computer program called the University of Kentucky Flood Control Planning Program III was developed and tested on the flood plain of the South Fork of the Licking River in northeastern Kentucky.

Given a specified reservoir site and a downstream flood plain divided into planning units, Program III selects the economically efficient combination of reservoir detention storage and the associated combination of channel improvement, flood proofing, land-use management, and residual flooding for each downstream planning unit. The Program does not attempt final measure design but isolates those combinations of measures for which detailed data collection and analysis is warranted.

This study presents a description of the basic Program logic and the results of its application along the South Fork, Licking River, as well as a FORTRAN IV listing of the computer program and a listing of the input data used in the South Fork, Licking River analysis.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF ILLUSTRATIONS

Chapter I

# ECONOMIC EVALUATION OF FLOOD DETENTION STORAGE

## USE OF DETENTION STORAGE

Since the United States first embarked upon a national program of flood control with passage of the Flood Control Act of 1936, the primary emphasis in flood control planning has been on structural measures. The specific measure most likely to receive widespread public recognition is construction of detention storage reservoirs. Dams and reservoirs are larger, more imposing, and more likely to become a center of public attraction than other structural flood control measures such as channel improvements, floodwalls, and levees. These latter measures can be highly effective for alleviating localized flooding, and are most commonly employed to protect urbanized areas and areas subject to flooding from small tributary streams.

The flood protection afforded by detention storage depends on the amount of storage provided and the fraction of the total area tributary to the point of flood hazard which is also tributary to the reservoir. Maximum protection is in the flood plain immediately downstream from a large reservoir. However, a significant reduction in flood levels may extend many miles downstream. Detention storage may be employed either in major reservoirs along the main channel or in a system of smaller reservoirs in the headwaters of the given basin. It may be provided either in a single purpose structure or included in a project which also serves several purposes other than flood control.

PROBLEMS IN ECONOMIC EVALUATION

The economic evaluation of alternative amounts of flood storage is much more complex than that for channel improvements. A reservoir does not eliminate; it only reduces downstream flooding. Each amount of flood storage produces a downstream flood-frequency relationship which can be determined by flood routing. This effect gradually declines as one proceeds downstream. For each spot along the stream, there will be an optimum combination of local measures to deal with the flood-frequency relationship associated with each amount of storage. As a consequence, while local measures may be evaluated in one pass through the problem area, detention storage can only be evaluated after one pass through the problem area for each amount of storage to be considered. Each pass provides one point of the curve of total cost (including residual flood damage) as a function of flood storage. The minimum point on the curve represents the optimum project. The curve is generally U-shaped. The minimum point is thus passed when total cost begins to rise with increasing levels of storage.

Achieving the goal of economic efficiency requires designing a detention storage reservoir covering a range of sizes. One preliminary reservoir design for each point on the cost-storage curve must be made in order to find that amount of detention storage which will yield the highest total benefits net of total project cost. Each preliminary design involves determination of the cost of constructing a reservoir to provide the necessary flood storage (including costs of dam, land acquisition, relocations and damages, etc.), the development and routing of a series of complete flood hydrographs (local measures can usually be designed from flood peaks alone) of varying probability of occurrence, and the determination of areas flooded and flood damages (direct, secondary, intangible) associated with each of the series of floods.

If the study includes the evaluation of nonstructural as well as local structural measures to supplement the flood detention reservoir, project evaluation becomes a very time-consuming exercise in repetitive arithmetic computations because of the large number of combinations of measures at varying potential levels of protection which must be considered. Nonstructural measures are attracting more and more attention and are now required to be considered by Federal agencies in compliance to Executive Order Number 11296. This requirement complicates the picture tremendously, especially since no set procedures for evaluating nonstructural measures have thus far become established. Additionally, there are often several possible upstream sites where reservoirs might be built to protect a given reach of flood plain. Economic efficiency would require a complete analysis of each site.

Within currently existing money and manpower constraints, public agencies simply cannot provide the many man-years of computational time required to manually complete a thorough analysis of all flood control alternatives. These constraints have reinforced the current practice of evaluating single alternatives selected by engineering judgment. Incomplete evaluation of alternatives is bound to produce a consequent loss in economic efficiency.

## USE OF THE DIGITAL COMPUTER IN FLOOD CONTROL PLANNING

The arrival of the digital computer promises to relieve much of the computational burden by providing extremely rapid execution of repetitive computations. The extra speed can permit planners to consider more design alternatives and thus produce designs which more nearly approach the goal of economic efficiency. Planning agencies have already begun utilizing the speed of the computer to replace desk-calculator and slide-rule methods for performing such routine (but laborious) computations as streamflow routings and streamflow frequency analysis. However, the full potential of computer analysis is far from being completely realized. The brightest hope the computer provides as a planning tool is the capability for performing types of computations which are not practical or even possible by other means. The evaluation of alternative combinations of structural and nonstructural measures for flood control fits into this category.

Obviously, the computer can never replace the judgment of experienced planners and engineers and can never accomplish alone the final design for even the simplest projects, for there are simply too many variables involved in the decision-making and design processes. However, the computer is capable of looking at many more combinations of alternatives and thus helping the planner to establish which combinations of measures deserve more detailed field investigation without wasting valuable man-time upon examination of inefficient measure combinations.

Work has already been done by Rachford (17) to develop a computer program for preliminary analysis of various combinations of structural and nonstructural measures and the selection of the least-cost combination of channel improvements, flood proofing, and land use management. This program (University of Kentucky Flood Control Planning Program I) does not provide for the analysis of reservoir detention storage as a project alternative. Program I utilizes the time-dependent optimization process developed by James (10). Program I has been refined by Cline (3) to become Program II, and has been tested by Dempsey (4) for a study site in Kentucky.

The purpose of the current project is to incorporate the reservoir detention storage alternative into the Program framework as developed by Rachford and modified by Cline. The result of this project is the development of a digital computer program known as the University of Kentucky Flood Control Planning Program III, which selects the least-cost combination of reservoir detention storage, channel improvement, flood proofing, land use management, and residual flooding for a given study reach of flood plain.

## DESCRIPTION OF STORAGE STRUCTURE

There are four basic types of dams which may be used to provide flood storage (14, pp. 173-214). These are concrete gravity, arch, buttress, and earth-fill, classified according to structural type and basic construction material. The first three of the above types are ordinarily constructed of concrete, while earth-fill dams may consist of either earth or rock, or both. These basic types may be combined into any number of more complex structures. Each variety of dam is best suited to a particular combination of foundation conditions and geographic location.

Because it was not considered feasible to incorporate several dam types into Program III at this stage of its development, it was decided to incorporate only that single type which finds the most widespread application--earth-fill. Due to the minimal investment in construction material, labor, construction equipment, and general simplicity of construction as compared with other dam types, the earth-fill dam is gaining wide acceptance for project purposes ranging from the smallest farm ponds to the mammoth Oroville Project in California. Continued improvements in earth moving machinery have caused the cost to drop with respect to that for other kinds of construction. Additionally, earth-fill dams ordinarily present the simplest geometrical configurations and thus lend themselves more readily than other types to preliminary analysis by approximative methods such as that used in Program III. Of course, the Program may be used for an approximate analysis of other dam types by making appropriate modifications to the input data. The reliability of the analysis can be expected to decrease with deviation from the assumed geometric and hydraulic configurations.

All other design features incorporated into Program III are also intended to allow the widest possible range of application. A definitive sketch of the dam and appurtenances used in program development is shown on Figure 1. The upstream face of the dam is assumed to be protected with riprap or some other protective material. The principal spillway features a horizontal reinforced-concrete conduit extending through the base of the dam, with a vertical intake tower (20, pp. 311-326) topped by an anti-vortex device and trashrack to keep debris from clogging the inlet. The outfall of the principal spillway consists of a standard impact-type energy dissipator (20, pp. 305-307).

The Program provides for a maximum of three alternate emergency spillway sites, since the choice of the emergency spillway location may depend on the dam crest elevation. The emergency spillway is taken as an open-cut chute spillway set in rock, with a concrete overflow weir structure approached through a cut in the hillside daylighted into the reservoir. The emergency spillway stilling basin is of the standard hydraulic jump type (20, pp. 292-301).

A cutoff trench beneath the dam running the length of the dam serves to prevent seepage between the base of the dam and

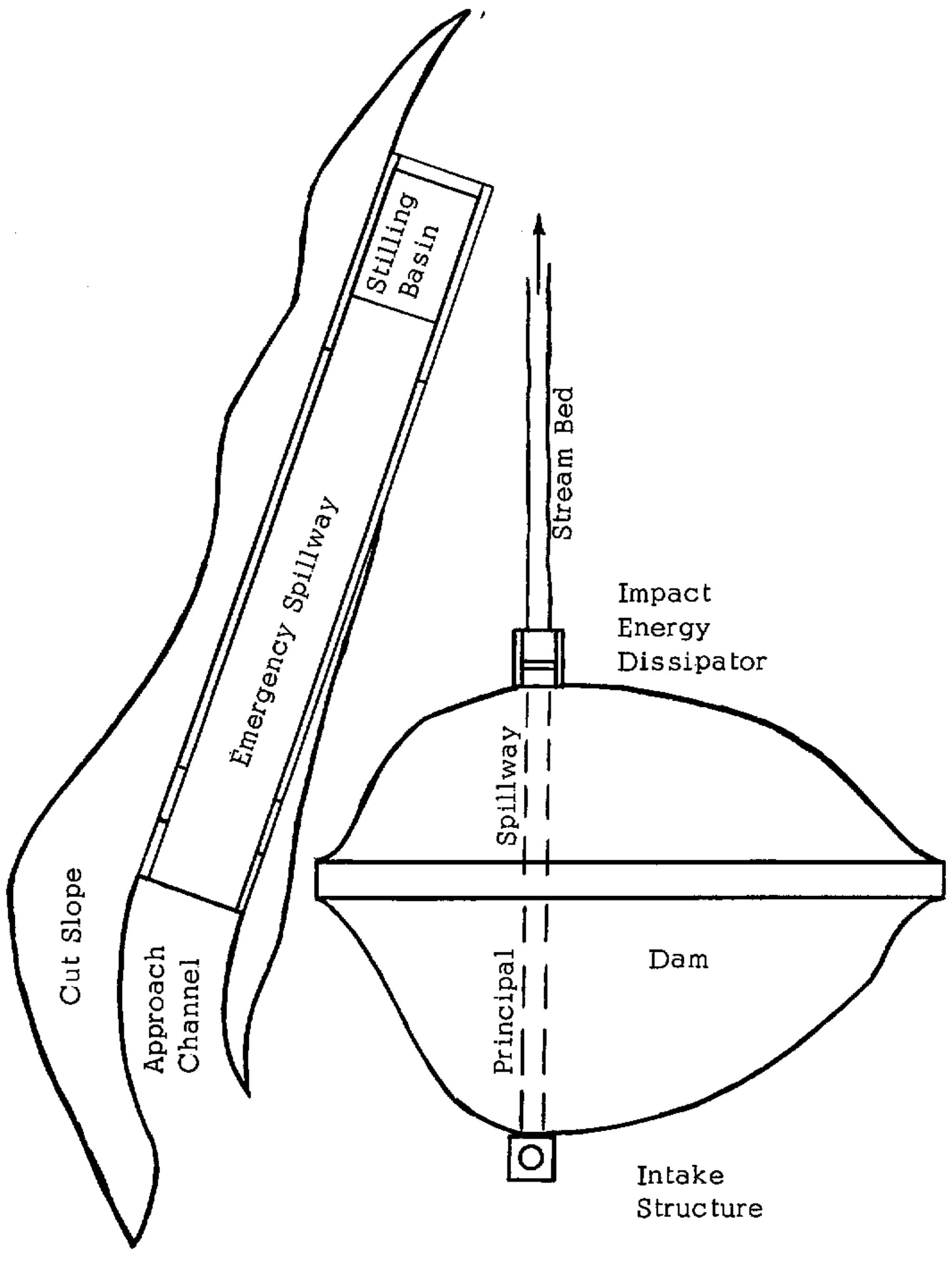



Figure 1. Sketch of Typical Dam

the bedrock of the valley floor. This trench is of variable bottom width and side slopes.

A user of Program III would naturally wish the design of the storage structure to conform as closely as possible to the design criteria which he would normally apply in his conventional analysis of detention storage for the particular area under study. This can often be accomplished through careful manipulation of certain of the input data, such as the slopes of the faces of the dam, the top width of the dam, the thickness of spillway concrete floors, retaining-wall concrete volumes, and the unit costs of various construction materials. When the type of features in the programmed design differ too radically from those desired by the user, the best recourse is to reprogram that portion of the Program which performs the portion of the design in question. Because the Program is composed of relatively independent subroutines with specific design functions, the programming may be altered with a minimum of disruption to the overall analysis.

## Chapter II

## PROGRAM DESCRIPTION

The University of Kentucky Flood Control Planning Program III contains a central control program and 29 subroutines. The central control program initializes conditions at the beginning of the analysis as well as at the beginning of each subsequent planning stage. It also controls the basic looping from stage to stage in the dynamic analysis. Each subroutine performs a specific phase of the total measure design and economic evaluation.

The program is coded in FORTRAN IV for the University of Kentucky's IBM System 360/50. The entire program requires some 132,500 bytes of storage over and above the processing system storage.

This chapter begins with a perspective view of the optimization procedure and follows with a more detailed description of the central program and each of the individual subroutines. The emphasis in this description is placed upon presentation of the design procedures used by the subroutines, the major program variables evaluated in the analysis, and the logic of the decision-making process employed in optimization. A statement-by-statement description of the program is not necessary since a listing with numerous comment statements is presented in Appendix A. A listing of sample input data to the program is presented in Appendix B. A complete dictionary of the variables utilized by the program is provided by Cline (3, pp. 254-289).

## THE OPTIMIZATION PROCEDURE

The optimization procedure seeks the least cost combination of flood control measures (residual flood damage is included as a cost) by systematically comparing totals of measure cost and residual damages for combinations of alternatives defined by kind (reservoir storage, channel improvement, land use management, and flood proofing) and by design level of protection. Each kind of measure is pursued until an optimum level of installation is selected or the measure is conclusively shown to be inappropriate for the situation at hand.

## OPTIMIZATION WITHIN EACH PLANNING STAGE

At the beginning of each planning stage (the Program optimizes the flood control measures as a function of changing flood-plain conditions with time), the central program passes control to Subroutine BUILD, which monitors the entire optimization process within that stage.

If a reservoir has been constructed prior to the beginning of a given planning stage, the optimization procedure reduces to the selection of the optimum combination of channel improvement, flood proofing, land-use adjustment, and residual flood damage for each planning unit (subwatershed) downstream of the reservoir. Thus, the analysis does not consider enlarging existing reservoirs. The downstream analysis is controlled by Subroutine CHANYZ. If no reservoir has been constructed, the analysis seeks to justify a flood control reservoir based on the flood-plain conditions existing during that stage. A reservoir is considered justified if average annual benefit realized during the stage exceeds average annual cost over the reservoir design life. If it cannot be, the optimum policy is judged to be to delay construction at least one more stage.

If a reservoir can be justified during the given stage, the program then computes the discounted average flood-plain conditions over the specified structural life (TIMST, usually equal to 50 or 100 years) and bases the reservoir design size on these discounted conditions. This approach is used because it is normally impractical to periodically enlarge a reservoir with intensification of downstream flood-plain development. If conservation storage is to be provided, the storage requirement is added to the flood control storage requirement.

TRIAL RESERVOIR ANALYSIS

Subroutine BUILD first summons CHANYZ to determine the cost of the optimum downstream measures and the associated residual flooding if no flood storage is provided and then systematically tries increasing amounts of flood storage to see if total flood cost is reduced. Each increase in flood storage increases reservoir cost but reduces downstream cost. When Subroutine BUILD decides to try a reservoir designed to control a flood of specified frequency, control is passed to Subroutine DAMBLD, which supervises design of the reservoir and computation of the reservoir cost. DAMBLD first summons Subroutine DAMSIZ. DAMSIZ computes the storage provision necessary for sedimentation in the reservoir and the storage required to contain the specified design flood, then finds the height of dam (with specified freeboard) necessary to provide combined flood storage, sediment storage and conservation storage (XTRSTR), if any. DAMSIZ also computes the crest elevations of the principal and emergency spillways, selects the emergency spillway width of minimum cost via Subroutine SPLSIZ, and computes the emergency and principal spillway design flows.

DAMBLD then summons Subroutine DAMVOL to compute the embankment volume in the body of the dam, the volume of the cutoff trench beneath the dam, and the volume of the riprap to be placed on the upstream face of the dam.

DAMBLD next summons Subroutine STLBAS, which designs the stilling basin for the emergency spillway and computes the associated excavation and concrete volumes.

DAMBLD then summons Subroutine EMSPVL to design and compute the construction quantities associated with the emergency spillway. The volumes of earth and rock excavation for the approach channel and spillway chute channel are computed as are the concrete volumes in the overflow weir crest structure and channel side-walls and bottom.

Subroutine PRNSP is then summoned by DAMBLD to design the principal spillway and outlet works. PRNSP designs the spillway pipe and impact dissipator, computes the concrete volumes, and designs the trashrack.

When all construction quantities have been computed, DAMBLD summons Subroutine DMCOST to compute the total cost of the dam and reservoir from the construction quantities and the input unit costs. This total cost is then amortized over the design life of the structure using the input project discount rate.

## DOWNSTREAM OPTIMIZATION TO SUPPLEMENT TRIAL RESERVOIR

With annual cost computed for the trial reservoir design, the next step is the optimization of the measures complementary to this reservoir in each of the downstream planning units. Program control returns from DAMBLD to BUILD, which summons RESRTE to determine the mean annual, 200-year, and reservoir design flood outflow hydrographs. It then summons Subroutine CHANYZ, which initiates the downstream optimization.

The optimization begins with the unit immediately downstream from the reservoir and proceeds systematically downstream through each of the units to the end of the reach of flood plain under study. In each unit, the least cost combination of channel improvement, flood proofing, land-use adjustment, and residual flooding is selected.

## OPTIMIZATION WITHIN EACH PLANNING UNIT

After CHANYZ sets the variables determining current planning unit conditions, Subroutine CHRTE routes the mean annual, 200-year, and reservoir design floods through the unit. Subroutine RSHYDR develops the local inflow hydrograph for the tributary area added within the river reach for each of these three flood frequencies and summons Subroutine HYDCOM to combine the local inflow hydrographs with the corresponding routed hydrographs. CHANYZ finds the peaks of each of these three combined floods and then summons Subroutine CHFLDS, which uses these three peaks to establish the relationship between flood peak and frequency.

CHANYZ then summons Subroutine FPCOST to monitor the selection of the optimum policy within the unit. FPCOST computes the frequency at which flooding begins in the unit and then takes that information into Subroutine CHOPTM, which conducts the optimization.

CHOPTM evaluates the cost of unrestricted flooding (flood damage with no measures implemented) in the planning unit, finds the least cost (sum of measure cost plus residual flood damage) levels of flood proofing, land-use adjustment, and channel improvement when used separately, then finds the least cost combination of all the measures when considered together. CHOPTM uses Subroutine CD1 to compute the average annual flood damages and uncertainty costs (3, pp. 8-10) for occasions when land-use adjustment is not considered. Subroutine CD2 is used when land-use adjustment is considered. The least cost alternative is adopted as the economically optimum plan for the unit. Execution then returns to CHANYZ and the optimization of the next downstream planning unit.

## EVALUATION OF TRIAL RESERVOIR

When the optimum combination of measures for all the downstream planning units has been determined, the total cost of downstream measures plus residual flood damage is obtained as the sum of the costs for the individual units. The total cost for the trial reservoir design is then computed by BUILD as the sum of reservoir cost and downstream cost less the flood control benefit to the flood plain downstream from the reach under study. The downstream flood control benefit is computed from the amount of flood control storage in the reservoir based on information supplied in the input data (DMBN, DMBNF).

BUILD continues through the array (DF) of reservoir trial design frequencies trying progressively larger amounts of flood storage until the optimum reservoir design is found, or until it becomes evident that reservoir storage is economically infeasible in the given stage. If the least cost combination of measures includes a reservoir, the reservoir is assumed to be constructed in the current stage and the associated optimum downstream measures are assumed to be implemented. If no reservoir could be justified, the least cost combination of downstream measures is adopted as the optimum policy. In either case, execution then returns to the central program to begin the analysis of the next stage.

If no reservoir has been constructed in the previous stages, the program repeats its examination of the reservoir alternative. If a reservoir has been constructed, the analysis of subsequent stages reduces to the optimization of the downstream planning units.

## CENTRAL CONTROL PROGRAM

### PURPOSE

The central control program serves to introduce the program variables, supervise the loading of input data, initialize and keep track of changes by stage in variables expressing watershed conditions, and initiate each planning stage analysis.

### PROCEDURE

Because of the large number of variables required for the analysis, correspondence among the major subroutines is accomplished through four labeled COMMON blocks. Most of the smaller subroutines employ argument lists. The central control program introduces the labeled COMMON blocks:

FLPL1 - the arrayed variables associated with the flood plain;

FLPL2 - the single-valued variables associated with the flood plain;

RS1 - the arrayed variables associated with the reservoir; and

RS2 - the single-valued variables associated with the reservoir.

The central program then summons Subroutine RDDATA, which loads all input data and combines certain groups of data into single values for later use. Certain program variables are initialized to indicate that no reservoir has yet been constructed within the analysis. The logical variables which determine the types of measures to be considered within the analysis are then initialized in accordance with instructions received in the input data.

Next, the central program initializes the conditions in each of the subwatersheds. The value of LOC is set equal to -1 to indicate that land-use adjustment has not yet been implemented in any subwatershed flood plain. Subwatershed variables set to zero include: ADDCS(NW), the accumulated annual cost of structural measures implemented; IHOLD(NW), the number of the stage in which right-of-way for possible future channel improvements was first purchased for holding; W0(NW), the initial channel right-of-way width; T0(NW), the top width of the existing channel; NDT(NW), the number of drop structures constructed during the program; FDA(NW), the vertical fall in each drop structure; and CAP(9-11,NW), the number and capacity of highway and railroad bridges built during the analysis.

A series of trial runs showed that average annual flood damages could be estimated quickly and accurately by utilizing 16 selected flood frequencies. The 16 frequencies are stored in array DQCK.

The next action is the computation of the reduced variates for the flood frequencies in arrays DQCK(16) and DF(NDF), the array of potential design frequencies to be considered in the analysis. These reduced variates are termed Y(16) and YY(NDF) respectively. Based on the Gumbel extreme value probability distribution (9), the reduced variates are determined from the relationship.

$$(1 - f) = e^{-e^{-y}} \tag{1}$$

where f is the given flood frequency (probability of occurrence in any given year), y is the reduced variate, and e is the base of Naperian logarithms.

The central program next compares for each subwatershed the input values of length of channel improved (SIC(NW)) and total length of channel (LC(NW)) to learn which subwatershed channels were completely improved prior to the outset of the analysis. For those subwatersheds whose channels have been completely improved, Subroutine CHFIX is summoned to establish the improved channel dimensions. These channel dimensions are determined in accordance with the criteria employed by the Program when improving channels in order that the cost of any future channel enlargements may be evaluated in a consistent manner.

If the land-use adjustment alternative or the procedure of purchasing and holding right-of-way for future channel improvements is to be considered in the analysis, Subroutine CALCLU is summoned to determine for each subwatershed in each stage the per-acre cost of implementing land-use adjustment (3, pp. 16-18). This cost is also one component of the total cost of holding right-of-way as computed in CHANYZ.

The Program next initializes two more sets of variables containing subwatershed channel properties. These variables are suffixed by either "8" or "9". An unsuffixed variable indicates a subwatershed channel property as considered by the Program to exist at the beginning of any given stage. A variable suffixed by "8" indicates a subwatershed channel property associated with the least cost combination of reservoir storage and downstream flood plain cost found thus far. A variable suffixed by "9" indicates a subwatershed channel property associated with the reservoir storage currently under consideration. The properties of an optimum channel for a given reservoir storage are saved through these arrays until the Program can ascertain which amount of reservoir storage is optimum. The unsubscripted, the "8," and the "9" variables corresponding to each subwatershed channel property must initially be set at the value of that property as it physically exists prior to the outset of the analysis since no optimization has as yet taken place.

The Program then enters the loop which sends the calculations through each stage of the analysis. In all stages except the first, the loop first transfers the channel properties found optimum for each subwatershed as associated with the finally selected optimum reservoir storage in the previous stage from the "8" to the unsubscripted variable for each property.

The second action within the loop is printing the number of the stage which the analysis is entering. The final action is summoning Subroutine BUILD, which supervises the entire optimization process for the given stage. When BUILD has determined the optimum policy for the study area in the given stage, control is returned to the central program loop, and the analysis of the next stage is initiated. When the loop has gone through each stage in the total analysis period, the Program terminates.

## SUBROUTINE BRIDGE

### PURPOSE

When evaluating a channel improvement in a given subwatershed, attention must be given to the capacity of existing highway and railroad bridges. BRIDGE determines the number of bridges which must be enlarged or replaced in order to accommodate a specified channel design discharge.

The analysis assumes highway and railroad bridges constructed prior to the analysis must be replaced with larger structures if they are incapable of passing the design channel discharge. Thus the values read into CAP should represent the largest flow the existing bridge opening can be made to accommodate. The Program assumes new structures built in earlier stages can be modified at a cost to accommodate a larger flow when the analysis requires channel enlargement in a later stage.

PROCEDURE

Array CAP(NW,1-6) contains the discharge capacities for up to six initially existing highway bridges in the subwatershed. CAP(NW,7-8) contains capacities for up to two initially existing railroad bridges. Where the subwatershed has fewer than the maximum allowed number of bridges, the extra positions are filled with the number -1.0. CAP(NW,9) contains the total number of highway bridges built or enlarged during the period of analysis, and CAP(NW,10) contains the number of railroad bridges built or enlarged. CAP(NW,11) contains the design discharge for all bridges replaced or enlarged.

BRIDGE first determines the number of adequate (HA) and inadequate (HN) highway bridges by comparing the bridge capacities in CAP(NW,1-6) with the design discharge Q. Any inadequate highway bridge must be replaced. Next, the number of railroad bridges (RN) needing replacement is found by comparing the capacities in CAP(NW,7-8) with Q.

If the required channel discharge Q exceeds CAP(NW,11), all highway and railroad bridges built during prior stages must be enlarged. Otherwise, all bridges built previously are assumed adequate.

In order to account for new roads which do not exist in the input data but may be built across the channel before the Program gets to future stages, BRIDGE estimates the number of highway bridges likely to be required by various levels of urban development.

It is assumed that no new bridges will be necessary until the level of urbanization exceeds 0.25, a total of two bridges per mile of channel will be necessary for levels between 0.25 and 0.50, and three bridges per mile between 0.50 and 1.00. If this estimated number (BR) exceeds the number of highway bridges read into CAP, BRIDGE assumes that these extra bridges will be built before a later stage begins. If the subwatershed channel has thus far not been improved, these bridges would have been constructed across an inadequate channel and are assumed to require replacement. If the bridges were constructed across improved channels, they are assumed to need to be enlarged at this time but not replaced.

The values which are finally returned to STR, the calling subroutine, are HN, the number of highway bridges which are not now adequate and must be replaced; HE, the number of highway bridges built during the analysis which are not now adequate and must be enlarged; RN, the number of railroad bridges which must now be replaced; and RE, the number of railroad bridges built during the analysis which must now be enlarged.

## SUBROUTINE BUILD

### PURPOSE

For a given stage, a specified reservoir site, and a given reach of downstream flood plain divided into MW-1 subwatersheds with known local conditions, Subroutine BUILD determines the optimum size of flood retention reservoir. The size of the economically optimum reservoir is specified as the frequency of the maximum flood event the reservoir could contain without the emergency spillway overflowing.

PROCEDURE

In stage 1, when the central program summons Subroutine BUILD for the first time, there are four possible situations which the subroutine may be required to evaluate:

a. If logical variables NODAM is TRUE as a result of input variable L11 having been read 0, retention storage is not considered in the analysis.

b. If logical variable NODAM is FALSE and input variable XTRSTR has a value of 0.0, the flood retention storage will be evaluated on the basis of no conservation storage being provided. The full cost of the reservoir must be justified by flood control alone.

c. If NODAM is FALSE and XTRSTR exceeds 0.0, the Program will consider conservation storage in the amount of XTRSTR acre-feet as being included in any reservoir constructed for flood control. Only the incremental cost of adding flood storage must be justified by flood control benefits. If logical variable BLDNOW is TRUE as a result of input variable IB having been read as 1, conservation storage is to be provided in stage 1 even if no flood control storage can be economically justified.

d. If BLDNOW is FALSE as a result of input variable IB having been read as 0, conservation storage is to be provided only if the incremental cost of flood storage is also economically justified. If flood control is not justified, conservation storage will not be provided either.

If no flood control reservoir is to be considered (case "a") as a result of NODAM being TRUE, the analysis reduces to the optimization of measures in the downstream subwatersheds. BUILD first summons RSHYDR to develop the mean annual and 200-year local inflow hydrographs for the area tributary to the dam site (Subwatershed

1). These hydrographs provide the flood peak versus frequency relationship taken to Subroutine CHANYZ, which determines the economically optimum flood control policy in each downstream subwatershed. CHANYZ returns to BUILD with COSTFP, the sum of the annual cost of all measures implemented in the downstream subwatersheds plus average annual flood and uncertainty damages. This done, BUILD returns program control to the central program for beginning analysis of the next stage.

If retention storage is to be evaluated (NODAM = FALSE) but no conservation storage is to be provided (XTRSTR = 0.0), BUILD first analyzes the downstream subwatersheds via RSHYDR and CHANYZ with no reservoir in place to estimate COSTFP. If retention storage is to prove economical, it must reduce the sum of the total cost of measures implemented (cost of retention storage included) and residual flooding below what it was for the initial case with no retention storage.

When conservation storage is to be provided (XTRSTR exceeds 0.0), BUILD first summons subroutine DAMBLD to design a reservoir which would provide no flood storage. BUILD then selects the optimum measures for the downstream flood plain via RSHYDR, RESRTE, and CHANYZ in order to incorporate the effect of reservoir surcharge storage on the downstream flood frequency relationship. This is done whether conservation storage must necessarily be provided in the first stage (BLDNOW = TRUE) or whether conservation storage is not be be provided unless flood retention storage is justified (BLDNOW = FALSE). The incremental cost of enlarging the reservoir to contain flood storage must then be justified by further reduction in COSTFP.

If conservation storage must be provided in the first stage but flood retention storage does not prove economical on a discounted average annual basis over the subsequent TIMST years, BUILD adopts the design found by DAMBLD for the conservation storage reservoir. If the specified conservation storage is included in a reservoir justified for flood control, the cost of the initial conservation storage reservoir design is subtracted from the total multipurpose reservoir cost to determine the incremental cost of including flood retention storage.

## SELECTING THE OPTIMUM FLOOD CONTROL RESERVOIR

If flood retention storage can be economically justified to protect a flood plain, the optimum flood retention storage has the least total cost of reservoir, downstream structural and nonstructural measures implemented, and flooding residual to all measures. The Program provides the option of deleting all downstream measures from the analysis, but retention storage is ordinarily most effective when part of a comprehensive flood control program extending into the flood plain downstream from the reservoir. The decision to include conservation storage in a reservoir must be made outside the Program, and the amount to include is read in the input data. Any reservoir cost computed will include the cost of providing the specified conservation storage, but the cost of the conservation storage does not influence the Program's determination of the optimum flood retention storage since it is a fixed rather than an incremental cost.

The amount of flood control storage is a function of the magnitude of the flood event which a reservoir is designed to contain. Containing a given flood event does not mean the entire volume of floodwater must be impounded behind the dam. In this analysis, a reservoir is considered to contain a given flood event if the entire outflow occurs through the principal spillway (the reservoir surface rises just up to but does not overflow the emergency spillway crest). The magnitude of a flood event is customarily described by its maximum instantaneous rate of flow. The recurrence interval of an event is commonly specified as the long-term average number of years which elapse between occurrences of the maximum instantaneous rate of flow (peak) characterizing the event. The frequency of occurrence may also be expressed as the probability that an event of given magnitude will occur in any given year, the reciprocal of the number of years in the recurrence interval.

Input array DF contains NDF probabilities of occurrence which have been selected for use in the search for the optimum flood event to be contained by flood retention storage. The Program does not consider providing retention storage to contain a flood event less severe than that specified by the probability DF(MRDF).

THE OPTIMIZATION PROCEDURE

Beginning with flood probability DF(MRDF), BUILD summons Subroutine RSHYDR to determine the local inflow hydrographs for the drainage area tributary to the selected reservoir site. The hydrographs computed are those for the mean annual (2.33-year or f = 0.433), 200-year (f = 0.005) and DF(MRDF) (if different from both the previous two) flood events. Subroutine DAMBLD is then summoned to design and determine the cost of a reservoir which will contain the DF(MRDF) flood event, reserve storage capacity for sediment accumulation throughout the design life of the reservoir, and provide the read amount (XTRSTR) of conservation storage. BUILD next summons Subroutine CHANYZ, which determines the optimum flood control policy for each downstream subwatershed to supplement the flood protection afforded by the reservoir. CHANYZ returns the total cost (COSTFP) of all such measures including the expected cost of residual flooding and uncertainty costs where desired.

BUILD then determines the flood control benefits which the reservoir produces downstream of the reach of flood plain under study. These benefits (BNFDST) are determined from input array DMBN, which contains the benefits which would accrue downstream of the study reach as a result of the construction of ten selected amounts of flood control storage at the selected reservoir site. These benefits are then multiplied by a stage multiplier contained in input array DMBNF since the value of a given volume of flood control storage tends to increase with time due to increasingly intensive use of the downstream flood plain. These benefits partially offset the cost of the reservoir project and may therefore be subtracted from reservoir and downstream measure costs to yield the net economic cost of the total program being examined. Thus the cost of the current trial program is determined as COSTSM = COSTFP + COSTDM - BNFDST. A table summarizing these costs is printed (3, p. 181).

BUILD has previously estimated a basic cost (COSTFM) against which COSTSM must be compared to determine whether the provision of flood retention storage to contain the DF(MRDF) flood event can be economically justified. COSTFM represents the costs of a conservation storage reservoir and the corresponding downstream program if conservation storage is to be considered and represents the costs of a downstream program alone if no conservation storage was specified. If the cost of the current trial program (COSTSM) is more than twice the basic cost COSTFM, BUILD assumes there is absolutely no hope of economic justification for retention storage in the current stage, abandons the idea of retention storage for the present stage, and returns program control to the central program. However, if conservation storage was to be provided under option BLDNOW, BUILD adopts the design of the conservation storage reservoir.

If COSTSM is less than twice COSTFM and the program is analyzing the most frequent specified design flood DF(MRDF), BUILD will try the next rarer design frequency DF(MRDF+1) even if the current trial cost COSTSM exceeds the basic cost COSTFM. This is done because a flood control reservoir not justified to contain very small flood events may possibly become economically feasible when designed to contain somewhat larger flood events. However, when COSTSM is found to exceed the previous trial cost (COSTFT) on any trial after the first, BUILD ceases to examine rarer frequencies and adopts the least cost program found up until that trial. There is no sense in trying even larger design floods if the total cost is increasing because the marginal cost curve is U-shaped and the minimum cost point has been passed.

For each trial design frequency, the same steps are repeated; RSHYDR is summoned to develop inflow hydrographs, RESRTE routes these through the reservoir, CHANYZ determines the optimum supplemental policy in the downstream subwatersheds, beyond-reach flood control benefits are estimated, and the total trial program cost is computed and compared to the previous trial cost. If the current trial cost is lower than that of the previous trial, a yet rarer reservoir design frequency is selected and the process repeated. The process continues until some design frequency is found at which the trial program cost exceeds that of the previous trial.

If no flood storage can be justified (COSTSM always exceeds COSTFM), COSTFM without the flood storage represents the optimum project. If flood storage can be justified (COSTSM is less than COSTFM one or more times), the optimum flood storage reservoir is the one with the smallest value of COSTSM (found the last time COSTSM is less than COSTFT).

During this analysis, BUILD first attempts to justify a reservoir for flood control based on the hydrologic and economic conditions in the study area during the current stage. If a flood control reservoir can be justified for in-stage conditions, the program concludes now is the optimum time to build but returns to determine its optimum size based on the hydrologic and economic conditions expected to exist in the study area throughout the design life (TIMST years) of the reservoir. These long-term conditions are determined on a discounted average annual basis by summoning Subroutine UCFIX. If BLDNOW is TRUE, the optimum time to build is automatically taken by the Program to be now, and the analysis proceeds immediately to determining the optimum flood storage.

Discounted average annual conditions over the reservoir life are used in sizing the optimum flood storage because of the difficulty in enlarging an existing reservoir; however, the flood control policy complementing this reservoir in the downstream flood plain is based on stage conditions. Therefore, BUILD returns to CHANYZ after the flood storage has been sized to determine the optimum downstream policy for the current stage.

When a reservoir is constructed in any given stage of the analysis, BUILD deletes in all later stages portions of the analysis which deal with reservoir construction. BUILD's job then reduces to the analysis of the downstream subwatersheds, updating the flood control policy where needed. A logical extension of the Program is the incorporation of a procedure to investigate whether enlarging an existing dam and reservoir is economically feasible.

## SUBROUTINE CALCLU

### PURPOSE

Subroutine CALCLU computes the per-acre cost of implementing the land-use-adjustment alternative in each subwatershed in each stage of the analysis. CALCLU then checks the cost calculated for each stage to make sure it monotonically increases with urbanization.

### PROCEDURE

The array CLOC is to be filled with the per-acre location adjustment cost for each subwatershed in each stage (3, pp. 16-18). The discounted average level of urbanization in the subwatershed over the given stage (UN) is first computed. This level may vary between zero and full urban development, UN = 0.0 to UN = 1.0.

The level of agricultural income for the subwatershed flood plain soil is then determined. The effect of urban development on crop income on adjacent land is determined by interpolating in array FRU with the value of UN to get FUQ. The average per-acre crop income for the subwatershed flood plain is then computed as the product of FUQ and full-productivity per-acre average crop income FIF. The flood plain per-acre crop income in dollars per acre per year is called IA.

When land use is adjusted to reduce flood damage, the most severe hazard area in the flood plain is restricted from further urban development, but the restricted area may be put to agricultural use. The cost of restricting urban development from an acre of flood plain land (CLUT) may be evaluated as the present worth of the foregone urban income from that acre less the crop income and open-space amenity value of the acre (10, pp. 44-51). The cost of restricting an acre of flood-plain land in the subwatershed CLOC(NW, NSTAGE) then consists of the sum of CLUT and CLEN, the administrative cost of regulating flood plain land use.

Once the entire array CLOC(MW,NSTEMX) is filled, CALCLU proceeds stage by stage through the array for each subwatershed insuring that the location cost is at least as great as the cost in the preceding stage. Where the cost for a given subwatershed in a given stage is found to exceed the cost for the successive stage due to difficulty in providing input data to make consistently precise estimates, the cost in the given stage is reduced to that for the successive stage. This process insures that location costs will increase with urbanization. The value of open land for urban development increases with its scarcity. CALCLU ends its work by printing a table showing the location cost for each subwatershed-stage (3, pp. 157-158) and then returns control to the central program.

## SUBROUTINE CD1

### PURPOSE

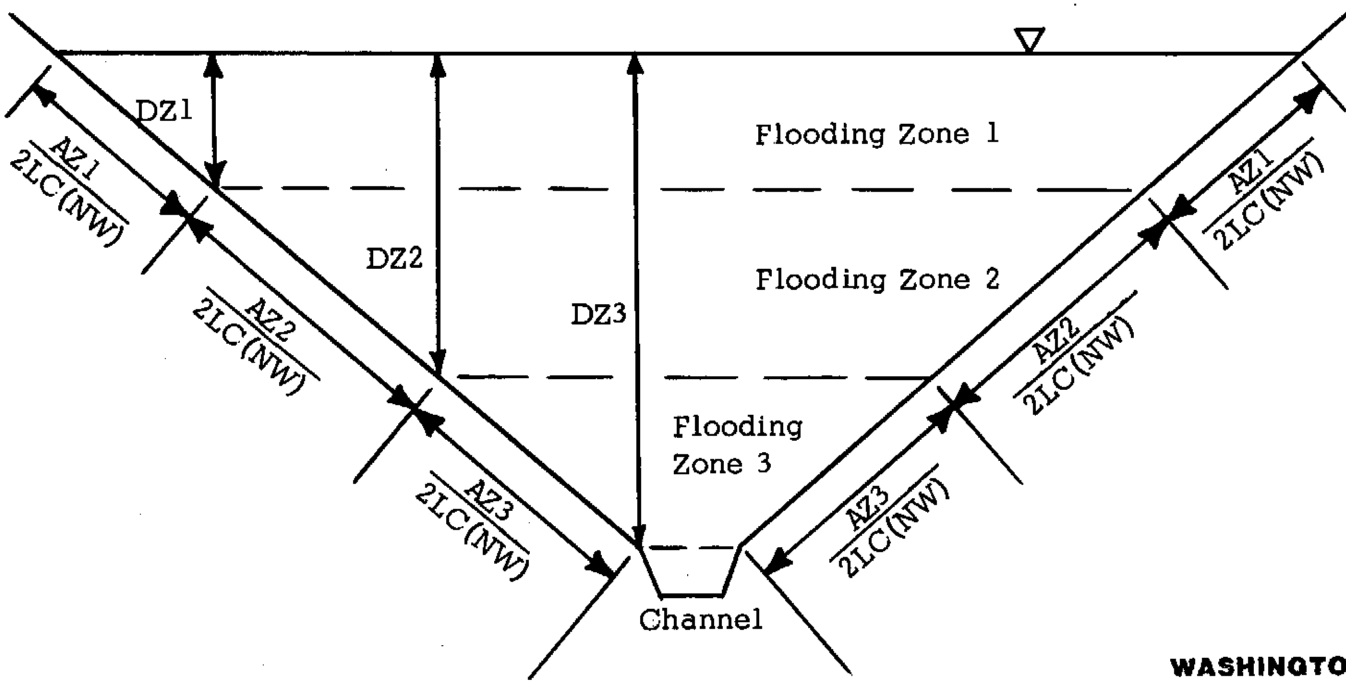
Subroutine CD1 is called to estimate the average annual and uncertainty damages due to flooding within a given subwatershed at times when land-use adjustment is not being considered.

### PROCEDURE

The average annual flood damage within a given planning unit is the sum of the annual crop damage and the annual damage to farm and urban structures. Crop damage is assumed to consist of a fixed damage associated with the fact of flooding plus a variable damage increasing with flood depth (3, pp. 86-92). The variable damage is assumed to not increase any further once the flood depth reaches about five (0.25/COEFDM) feet. Structural damage (direct plus indirect damage to buildings, contents, and yards) is assumed to vary linearly with flood depth until the depth at which one quarter of the property value is destroyed, vary linearly at half the original rate until the depth at which three quarters of the property value is destroyed, and to not be increased by still greater flood depths.

The fixed (FA) and variable (GA) flood damage to a composite crop acre is computed in Subroutine CHANYZ and brought into CD1. The fixed crop damage is estimated as the product of FA and the non-urban acreage flooded. The variable crop damage is added to this amount. For areas flooded to depths shallower than five (0.25/COEFDM) feet, it is estimated as the product of GA, the non-urban acreage flooded, and the average maximum flood depth over the area. For areas flooded to depths exceeding five feet, 5*GA is uniformly added to the fixed damage.

Flood damage to farm structures and urban property is calculated by dividing the area flooded into three zones by depth (Figure 2). Provided the depth of flooding is not deep enough to destroy more than one quarter of the market value of the property, the damage is estimated as the product of COEFDM, the value of the property flooded, and the average maximum flood depth over the shallow depth zone (3, p. 6). For depths great enough to destroy one quarter but not deep enough to destroy three quarters of the market value of the property, the damage is estimated as one quarter of the value of the property flooded plus the product of one half COEFDM, the value of the property flooded, and the






DZ1 = 0.25/COEFDM = Depth at which maximum structure damage would exceed 0.25(VLURST).

DZ2 = 0.25 + 1.0/COEFDM = Depth at which maximum structure damage would exceed 0.75(VLURST).

DZ3 = DMAX = $Q^{0.375}$K1(NW)K2(NW)

Figure 2. Flood Damage Depth Zones

average maximum flood depth in excess of 0.25/COEFDM over the intermediate depth zone. For still greater flood depths, the damage is estimated as three quarters of the value of the property flooded.

The program assumes that flood proofing will hold flood damage to farm structures and urban property to approximately one-ninth the damage to unprotected structures unless the flood proofing is overtopped in which case all effect of the flood proofing is lost (17, pp. 62-63).

For each of the 16 floods used to estimate annual flood damages, CD1 computes the excess (QXC) of the flood peak over the channel capacity. If there is no excess, flood damage is taken as zero for that flood. If there is excess, the depth and area of flooding in each of the three zones is estimated (Figure 2 ). The flood damage in each zone is then estimated based on the assumption that flood proofing will be effective in eliminating eight-ninths of the structural damages. If there is no flood proofing or if the flood at hand exceeds the flood proofing design discharge, CD1 returns a second time to each of the three zones to estimate the additional damage.

The expected average annual flood damage is estimated from the damage values for the 16 floods based on the equation

$$CD = \sum_{i=1}^{16} p_i x_i, \tag{2}$$

and the standard deviation is calculated from

$$SIGMA = \left\{ \sum_{i=1}^{16} p_i (x_i - CD)^2 \right\}^{0.5} \tag{3}$$

where $p_i$ is the flood frequency range represented by the flood causing damage $x_i$. CD1 returns the expected damage CD to the calling Subroutine CHOPTM along with the uncertainty damage estimated from

$$CU = VA*SIGMA*CRFSM/(2.0*R)^{0.5} \tag{4}$$

where VA is the desired probability that the Thomas Uncertainty Fund (5, pp. 150-152) will not be exhausted, CRFSM is the capital recovery factor for TIMST years, and R is the project interest rate.

## SUBROUTINE CD2

### PURPOSE

Subroutine CD2 is called to estimate the average annual and uncertainty damages due to flooding within a given subwatershed at times when land-use adjustment is being considered.

### PROCEDURE

The computational procedure of CD2 follows that of CD1 except for the additional complexity which must be added to account for the exclusion of new urban development from a portion of the flood plain. The purpose of using two damage evaluation subroutines was to save computational time by avoiding when it is not needed the more complex evaluation procedure required when land-use adjustment enters the picture.

Of the total area flooded (AZL), new urban development is restricted from the area of greatest hazard (AZS) but not from a higher area (AZD) subject to less severe and less frequent flooding. AZS is the area inundated by the location adjustment design flood. In estimating the damages caused by a particular flood, CD2 must determine whether AZS is confined to AZ3, extends into AZ2, or includes both AZ3 and AZ2 plus a portion of AZ1.

Instead of the double loop through the damage evaluation for each flood (with and without flood proofing) of CD1, CD2 must go through the loop six times for each of the 16 floods. The first trip estimates damage with effective flood proofing to structures in place at the beginning of the planning stage. The second adds damages caused if flood proofing of these structures either does not exist or is overtopped. The third adds damages which would occur to the new urban development with effective flood proofing if such new development occurred throughout the flood plain during the stage. The fourth subtracts damages which do not occur because urban development is excluded from the area of highest hazard. The fifth and sixth are analagous to the third and fourth but differ in that they account for additional damage when flood proofing does not exist or is overtopped.

## SUBROUTINE CHANYZ

### PURPOSE

Given the mean annual, 200-year, and reservoir design frequency outflow hydrographs from the reservoir or the mean annual and 200-year hydrographs past the potential dam site if there is no reservoir under immediate consideration, CHANYZ proceeds consecutively through the downstream subwatersheds, determining the nature and cost of the optimum flood control policy in each.

### PROCEDURE

CHANYZ keeps a running total of the costs of implementing the optimum flood control policy found for the subwatersheds. The total implemented cost (COSTFP) is initially set to zero. Then, beginning with the subwatershed just downstream from the dam site, CHANYZ determines the optimum combination of flood control measures for the subwatershed, estimates the associated cost, and adds it to the running total.

The first step in the analysis of each subwatershed is initialization of certain subwatershed conditions. Array OUTPUT(13), which contains the summary of measures and costs found optimum for the previously considered subwatershed, must be initialized at zero values. Variables IHN, IHE, IRN, and IRE, which contain the numbers of highway and railroad bridges in the previously considered subwatershed which had to be replaced or enlarged, must also be zeroed. Variable IMPROV is initialized as 1 to indicate that the channel in the subwatershed is not yet altered within the current stage. During the analysis, IMPROV will be changed to 2 if the channel is improved for the first time or to 3 if it is already improved at the beginning but enlarged during the stage. Variable RC is set -1.0 until per-acre right-of-way cost has been computed for the given subwatershed in the current stage.

The discounted average urbanization level (UN) in the subwatershed is next computed. If the analysis is sizing a reservoir previously found justified in the current stage, Subroutine UCFIX is called to determine the level of discounted average urbanization over TIMST years. Otherwise, the discounted average annual value over TIME years is computed directly. The level of urbanization (UZ) existing in the subwatershed at the beginning of the current stage is then fixed. UZ equals the read value of USUBW (NW,NSTAGE) if no land-use restrictions have been employed in previous stages. If restrictions have been instigated in a prior stage, UZ equals the level of urbanization existing at the time the restrictions became effective.

Next are calculated three factors combining subwatershed parameters for computing the cost of flood proofing. These factors (PA for flood proofing urban development which would exist without land-use restriction, PB for urbanization which would exist if the restriction was implemented, and PC for the difference between the two or new urbanization) are multiplied in CHOPTM by the three-fourths power of the excess discharge to determine the total subwatershed cost of flood proofing against that discharge. The combination of the three factors used depends on flood-plain land-use restriction policy. A similar factor, LA, for land-use restriction cost is calculated a little later.

CHANYZ next determines the relative fraction of the non-urban land which can be expected to be planted to crops as influenced by the discounted average level of urbanization (3, p. 92). This relative productivity is then used in determining the per-acre crop income IA, initial crop damage when flooded FA, and extra crop damage per foot of flood depth GA corresponding to the existing level of urbanization UN in the subwatershed.

Next, CHANYZ determines whether or not right-of-way should be purchased and held for possible future channel improvements (13). The decision criterion is whether or not such holding will save money. Money will be saved if the present worth of the projected future expenditure exceeds the present purchase cost. Both present and projected values include land and improvements. If the criterion indicates holding right-of-way through the current stage is economical, the stage number ITEMP and the economic annual holding cost per acre CHU are determined. If right-of-way had already been purchased coming into the present stage, the old value of ITEMP is kept. CHU is an economic cost based on public value rather than an annual financial cost. If the criterion rejects holding, both these values are set zero.

Subprogram CHRTE is next called to route the incoming mean annual, 200-year, and reservoir design frequency flood hydrographs through the subwatershed for both improved and unimproved channel conditions. RSHYDR is called to develop the corresponding local inflow hydrographs and to combine them with the routed hydrographs. Each of the resulting combined hydrographs is searched to find the peak rate of flow. With these two or three pairs of flood peaks specified by frequency, CHFLDS is summoned to determine the full flood-peak-frequency relationship for the subwatershed. One relationship pertains if channel improvement has been installed or is currently under analysis. The other pertains if unimproved or natural channels prevail.

FPCOST is then called to determine the optimum flood control policy for the subwatershed. The total cost (OUTPUT(13)) of the optimum policy for the subwatershed is returned to CHANYZ and added into COSTFP, the accumulated cost of the optimum policy developed in the upstream subwatersheds.

CHANYZ next selects the proper set of hydrographs to be carried downstream to the next subwatershed. The choice is determined by whether the subwatershed channels were improved as a part of the optimum flood-control-measure combination or left in their original condition. Subwatershed channel improvement will tend to accentuate downstream flood peaks. CHANYZ then proceeds to the next downstream subwatershed to repeat the process just described. When all the subwatersheds have been thus optimized, program control is returned to BUILD.

## SUBROUTINE CHFIX

### PURPOSE

CHFIX is employed at the beginning of the analysis to fix the dimensions of those channels which were improved prior to the planning period. Knowledge of initial channel dimensions is necessary for the computation of the costs of further channel enlargement. In fixing the initial channel dimensions, CHFIX employs the same design criteria used for new channel improvements even though these might differ from the criteria actually used in the initial channel construction. Such criteria standardization is required to obtain consistent channel enlargement costs.

PROCEDURE

Whether the initial channels are unlined, trapezoidal lined or rectangular lined, the computational approach is the same. Only the values of Manning's "n" and the channel side slopes differ.

The channel cross section is governed by the criteria that the bottom width to depth ratio can only vary between BDMIN and BDMAX and that the design depth cannot exceed HMAX unless holding to this maximum depth would cause the BDMAX limit to be violated (3, pp. 104-105). The channel cross section is developed by first calculating the depth of flow required to provide the capacity Q0 if BDMIN is used (17, pp. 65-67). This cross section is used unless the depth exceeds HMAX in which case greater bottom width to depth ratios in increments of 0.5 are tried until either HMAX is reduced to an acceptable level or BDMAX is reached.

The section depth and bottom width as thus calculated provide the basis for calculating the width of the flow surface (T0), the area of the channel cross section (A0), and the channel right-of-way width (W0). The flow area is assumed to equal the excavation area by specifying a cross section having a water surface at about ground level. The right-of-way width is estimated by assuming freeboard levees equalling 0.2 the design depth in height plus an allowance for levee top width and clearance outside the outside levee top.

CHFIX returns control to the central control program.

## SUBROUTINE CHFLDS

### PURPOSE

CHFLDS uses the theory of extreme values to interpolate or extrapolate from the mean annual, 200-year, and reservoir-design-frequency flood peaks, the magnitudes of the 16 flood peaks (QX) necessary for estimating flood damages in the subwatershed and the NDF flood peaks (QQ) used as a basis for evaluating alternative levels of design.

### PROCEDURE

The Program enters CHFLDS with known routed flood peaks for floods of two or three frequencies. Within the subroutine, it must interpolate or extrapolate, depending on whether the frequency at hand is within the bounded range, flood peaks for up to 26 other specified frequencies. A mathematical relationship between flood peak and frequency is needed for this purpose. That used is based on Gumbel's equations developed from the distribution of extreme values (9). While the Hydrology Committee of the Water Resources Council recommended use of a log-Pearson Type III distribution (23) for relating flood peak and frequency, this distribution was not used because the required expressions are more difficult to program and add to computer time. However, the routed flood peaks are determined by input data (3, pp. 69-75) which may be developed by following any desired frequency distribution in hydrologic data analysis. The Gumbel approach is thus not used to set the mean annual and 200-year flood peaks but only to interpolate between them.

The theory of extreme values states that if $X_1$, $X_2$, ... $X_n$ are the extreme values observed in n samples of equal size N, and if X is an unlimited, exponentially distributed variable, then as n and N approach infinity the cumulative probability P that any of the n extremes will be less than X approaches the expression

$$P = e^{-e^{-y}}, \tag{5}$$

where e is the base of Naperian logarithms and y, the reduced variate, is given by

$$y = a(X - X_f). \tag{6}$$

$X_f$ is the mode of the distribution of X, and a is called the dispersion parameter.

As applied hydrologically, if the largest flood peak is observed in each of an infinite number of years and the mode and dispersion parameter of the distribution of resulting values are computed, the probability that a flood event of given magnitude (X) will not be exceeded in any given year may be computed from the two above expressions (15, pp. 250-258).

According to Eq. 6, the magnitude of a given flood event Q is a linear function of the corresponding value of the reduced variate y, since

$$Q = Q_f + y/a. \tag{7}$$

Thus the relationship of Q and y can be represented by a straight-line arithmetic plot of Q vs. y. (Figure 3). Any two known points $(y_1, Q_1)$ and $(y_2, Q_2)$ may be used to establish this linear relationship. The dispersion parameter equals

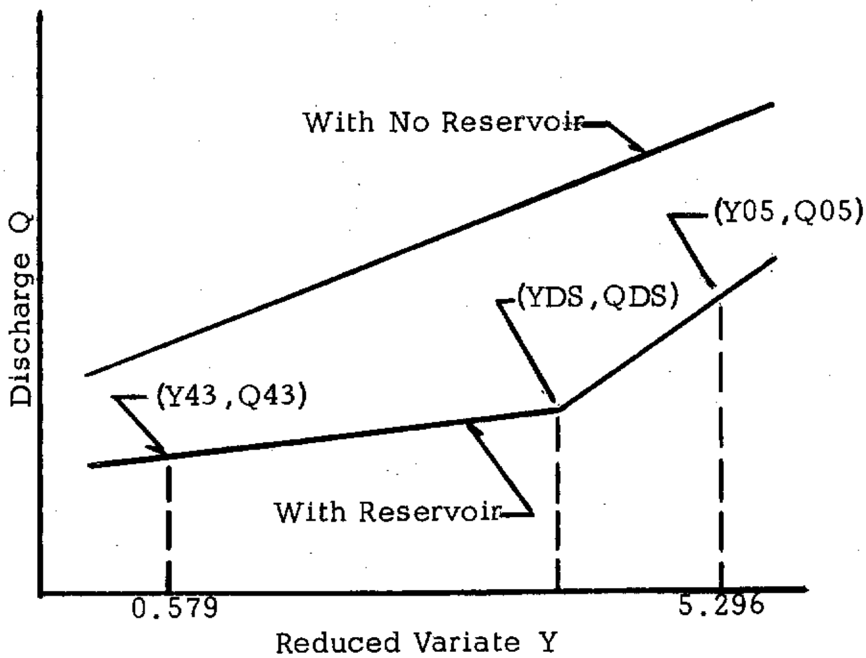



Figure 3. Effect of Reservoir on Discharge - Frequency Relationship

$$a = (y_2 - y_1) / (Q_2 - Q_1), \tag{8}$$

and the mode of the distribution is

$$Q_f = (Q_1 y_2 - Q_2 y_1) / (y_2 - y_1). \tag{9}$$

Upstream changes have significant effects upon the downstream flood frequency distribution. Increasing levels of urban land use and improvement of channels concentrate surface runoff and increase downstream flood peaks (4). However, detention reservoirs reduce the magnitude of the flood peak at every level of probability for each subwatershed downstream. Graphically, this vertically lowers the entire Q vs. y line.

Further, the presence of an upstream reservoir introduces a break into the Q vs. y line, effectively changing it into two straight lines (Figure 3 ) which intersect at the point corresponding to the frequency of the reservoir design flood. The break occurs at this frequency because lesser floods are completely contained and are discharged through the principal spillway whereas larger floods are only partially contained as the outflow is partially discharged over the emergency spillway. The effect of the reservoir is therefore most pronounced for events smaller than the reservoir design flood.

In order to employ the magnitudes of the mean annual, 200-year, and reservoir design frequency flood peaks routed downstream to a given subwatershed in determining the magnitude of the flood peak for any other level of probability, it becomes necessary to consider whether the given probability is less or greater than the reservoir design probability. If less, the appropriate portion of the flood-frequency relationship is determined by the coordinates of the mean annual and reservoir design floods. If greater, the relationship is determined by the coordinates of the reservoir design and 200-year floods. Each of the two lines is essentially a separate distribution with different values of mode and dispersion parameter.

If the reservoir design frequency under consideration is equal to the frequency of the mean annual or the 200-year flood, the broken line reduces to a single-line relationship. CHFLDS first checks the index KDF to determine the reservoir design flood frequency. If the broken distribution is indicated, two sets of values for the mode and dispersion parameter must be obtained. Two more sets to distinguish between unimproved and improved subwatershed channel conditions must be obtained if the channel-improvement alternative is to be considered and the subwatershed channels are unimproved at the present time.

With the reduced variate of the mean annual flood (0.579) and that of the 200-year flood (5.296), the necessary values of mode and dispersion parameter are calculated. The values corresponding to unimproved or improved channel conditions are obtained by inserting the proper set of flood peaks and corresponding reduced variates into Eqs. 8 and 9. When both characteristics of both portions of the distribution have thus been computed, CHFLDS determines the magnitudes of the flood events for arrays QX(2,16) and QQ(2,10).

Each column of QX is the rate of flood flow in excess of subwatershed channel capacity (QCAP) corresponding to one of the 16 selected levels of probability. The two rows provide for both improved and unimproved subwatershed channel conditions. Each value in QX is then computed as

$$QX(1 \text{ or } 2, I) = Y(I) / A + X - QCAP, \tag{10}$$

where A and X are the dispersion parameter and mode which describe the appropriate portion of the distribution for the given subwatershed channel conditions, and I is the index to one of the sixteen elements of QX and Y.

Each column of QQ is the flood peak in the given subwatershed which corresponds to one of the NDF specified levels of probability used in analyzing potential measures in the subwatershed. As with QX, two rows are provided to allow for both unimproved and improved subwatershed channel conditions. Corresponding to each of the specified NDF levels of probability is a value of the reduced variate contained in array YY(NDF). Using the proper set of mode and dispersion parameter, the array QQ is filled by the expression

$$QQ(1 \text{ or } 2, I) = YY(I) / A + X \tag{11}$$

After filling these two arrays (QX and QQ) for the given subwatershed, CHFLDS prints the NDF calculated design flood frequencies for both improved and unimproved channels as applicable if this is requested in the input control data. Finally, both sets of flood peaks are returned to CHANYZ, where they are employed in finding the optimum planning policy for the given subwatershed.

## SUBROUTINE CHOPTM

### PURPOSE

CHOPTM determines the optimum combination of channel improvement, flood proofing, and land-use adjustment to be employed in abating the damages due to flooding in a given subwatershed in a given planning stage.

### PROCEDURE

The optimum combination or "mix" of measures produces the minimum combined cost of implemented measures and residual flooding. CHOPTM determines the cost of flooding in the subwatershed with no measures implemented and follows with a systematic analysis (Figure 4 ) of the many possible combinations of measures. A tried combination of measures is temporarily adopted if it involves a lower total cost than any combination previously examined. The end result is the selection of that "mix" of measures which involves the least cost of measures plus residual flooding.

CHOPTM begins by initializing a series of variables. Most involve setting to zero values found the last time through CHOPTM so they will not affect the current analysis. The initial values of discharge against which the subwatershed is to be protected by flood proofing (QP), land-use adjustment (QL), and channel improvement (QS) are set equal to the channel capacity Q0(NW) since the

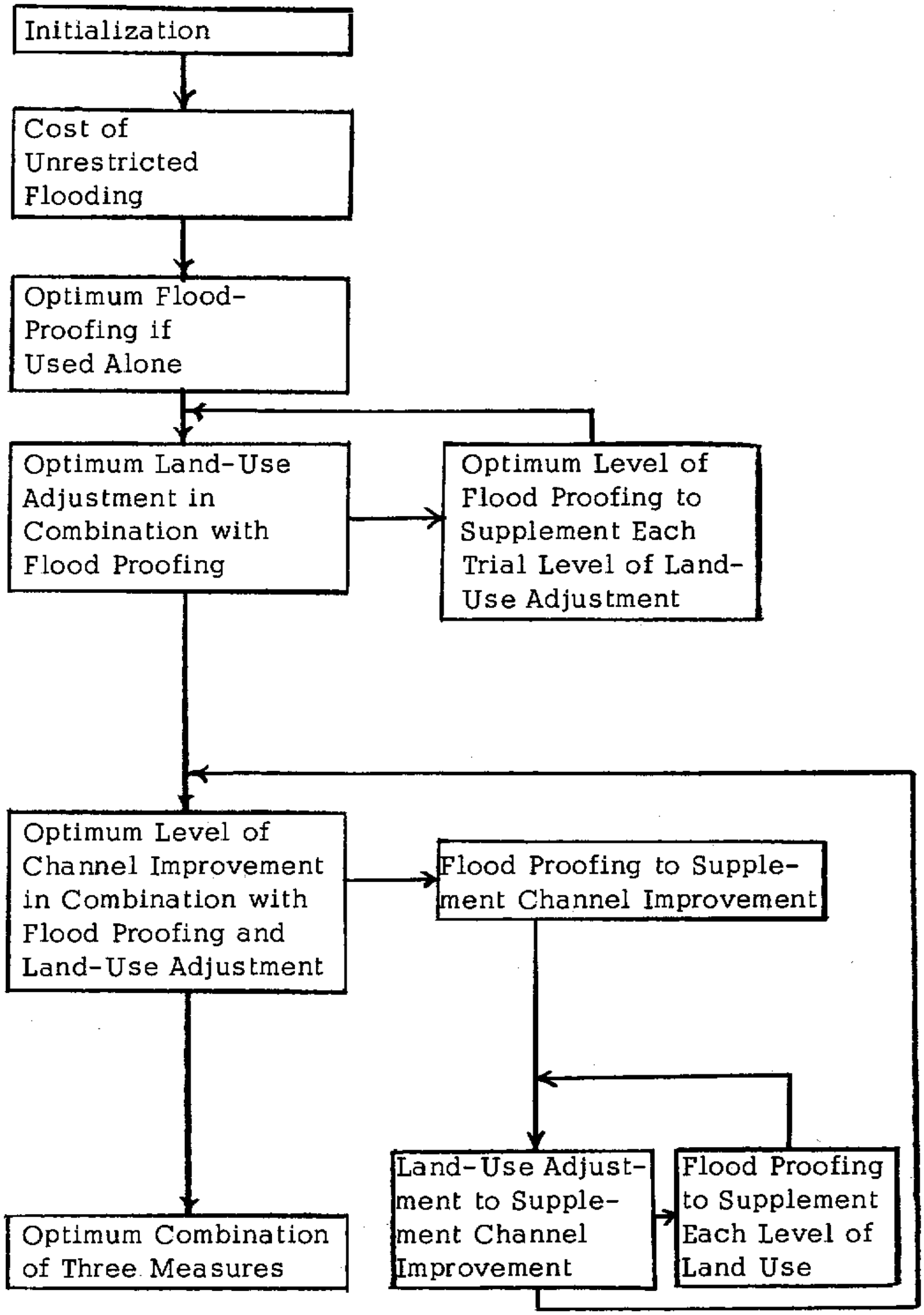



Figure 4. Schematic Outline of CHOPTM

first computation to be made is the cost of unrestricted flooding in the subwatershed.

Flood damage with no measures employed in the subwatershed is determined by summoning Subroutine CD1. CD1 returns the average annual cost of flooding (CD) in the subwatershed and the uncertainty cost (CU). These two values are summed to give CF, the total annual cost of flooding in the subwatershed. This amount also equals CT, the total cost of all measures, if no measures are employed.

The next step in the optimization is the determination of the optimum level of unilateral flood proofing. Beginning with the first or most frequent storm in the array of potential design frequencies (DF), CHOPTM computes the cost of flood proofing subwatershed structures. The cost computation takes the form

$$CP = PA*(QP-QS)^{0.75}, \tag{12}$$

where CP is the cost of flood proofing subwatershed structures against a flood of magnitude QP, QS is the existing channel capacity, and PA is the flood proofing cost factor developed in CHANYZ for this particular subwatershed.

Subroutine CD1 is then summoned to determine the annual cost of flooding in the subwatershed residual to flood proofing against a flood of magnitude QP and returns CD and CU. These costs are added to CP to give the total annual cost of the trial flood proofing policy (CTT). If this total cost is less than the total cost (CT) of any other policy thus far tried, this policy is temporarily adopted as optimum.

CHOPTM proceeds through array DF until it concludes flood proofing is too costly to be practical in the subwatershed, proofing against a larger flood will only increase the total cost, or each design frequency has been tried. A great deal of computer time is saved by making use of the fact that the total cost curve with respect to any measure tends to be U shaped. Once the total cost is increased by providing a greater level of protection, there is no need to go further. Obviously, it is also unnecessary to continue evaluation of any measure where the cost of the measure alone exceeds the current value of CT. The level of flood proofing which gave the least total cost of proofing and flooding is adopted as the best unilateral flood proofing policy for the subwatershed. Its characteristics are stored in OUTPUT and then printed if requested by the input data (3, pp. 158-160). This level of flood proofing may be abandoned later in CHOPTM if other measures are found to reduce the total cost (CT) even more.

Next comes determination of the optimum level of unilateral land-use adjustment for the subwatershed. The procedure followed is analogous to that used in optimizing flood proofing. As before, the various design frequencies in array DF are examined, beginning with DF(1). At each frequency, the cost of implementing land-use adjustment to protect against a corresponding flood event QL is determined by a relation like Eq. 12. Land-use cost factor LA replaces flood proofing cost factor PA, QL replaces QP, and land-use cost CL replaces CP.

When the cost CL of adjusting land use to keep new urban development out of the area flooded by flood event QL has been determined for the given frequency, Subroutine CD2 is summoned to determine the annual cost of residual flooding. CD2 returns the flooding damages (CD) and uncertainty cost (CU), which are added to adjustment cost CL to obtain the total cost CTT for the trial frequency. The policy is adopted if CTT is less than CT.

Before going on to consider land-use adjustment against a larger flood, CHOPTM determines the optimum level of flood proofing to be used in conjunction with the trial level of land-use adjustment. CHOPTM then moves on to the next trial level of land-use adjustment, computes the cost of adjusting to that level, computes the residual flooding and uncertainty costs, and then seeks the optimum level of flood proofing to supplement that level of land-use adjustment. This procedure continues until the optimum combination of land-use adjustment and flood proofing has been found or all combinations have been proved more costly than flood proofing alone or than no measures at all.

In considering channel improvement, CHOPTM searches DF until a frequency which corresponds to a flood greater than the existing subwatershed channel capacity is found. Subroutine STR is then summoned to determine the least costly type of channel improvement to contain the specified design discharge. Subroutine CD1 is called to determine the average annual flood damages residual to the channel improvements. If the sum of the cost of channel improvements, residual flooding, and uncertainty is less than the cost of the best combination of flood proofing and land-use adjustment, the trial channel improvements are temporarily adopted as optimum policy. Dimensions and other details of the channel improvements are saved in temporary storage locations in order that they will be known if the improvement is finally selected.

CHOPTM next evaluates flood proofing to supplement the trial channel improvement. The procedure followed is exactly the same as that for flood proofing used alone, except that CD1 must now consider the effect of channel design discharge (QS) in computing the residual flooding costs.

After finding the optimum level of flood proofing to supplement the trial level of channel improvements, CHOPTM evaluates land-use adjustment (without and with flood proofing considered as a third measure) to supplement channel improvement. The search duplicates the procedure for examining land-use adjustment and flood proofing used in conjunction except for changing the channel capacity to the trial discharge for channel improvements.

At this point, CHOPTM loops to the next frequency in array DF to repeat the analysis for a greater degree of channel improvement. When the Program concludes there is no possibility of finding a less costly combination of measures if it goes further or all possible frequencies have been examined, CHOPTM has found the optimum level of channel improvements as supplemented by flood proofing and land-use adjustment or rejected channel improvement as not economical for the given subwatershed. It must be remembered that as each combination of the three types of measures was examined, that combination was temporarily adopted if it had less cost than any combination previously examined. Each combination of measures evaluated (3, pp. 158-159) and the nature of those measures accepted as a temporary optimum (3, pp. 158-160) may be printed if requested through L5 and L6 respectively in the input data.

Although this discussion has assumed CHOPTM to be instructed to find the optimum combination of the three alternatives, the subroutine is, of course, capable of determining the optimum combination of any two of the three alternatives or the optimum level of any one alternative when used alone. This is accomplished by bypassing the portions of the analysis which involve the alternative(s) to be omitted. Read values for logical variables PP, LL, and SS indicate whether CHOPTM should consider respectively flood proofing, land-use adjustment, and channel improvement in the analysis.

One possibility which may develop in considering reducing flood damage by enlarging a previously improved but unlined channel is that lining the existing section may be more economical than enlarging it. The last portion of CHOPTM determines the cost and residual flood damage associated with such lining to evaluate this possibility.

With the optimum combination of measures and associated cost determined, CHOPTM returns control to FPCOST.

## SUBROUTINE CHRTE

### PURPOSE

Subroutine CHRTE uses the Muskingum storage method (15, pp. 228-229) to route a given flood hydrograph (HYGRAF(50)) through a reach of channel having given routing properties.

### PROCEDURE

The Muskingum storage routing parameters CM0, CM1, and CM2 are computed from read values of CHX, CHK, and HYDINT. The inflow hydrograph array HYGRAF is stored in duplicate internal array HYIN. A looped computation then calculates the routed outflow hydrograph and stores it in HYGRAF. The computational relation is

HYGRAF(J) = CM0*HYIN(J) + CM1*HYIN(J-1) + CM2*HYGRAF(J-1). (13)

CHRTE then returns the routed outflow hydrograph HYGRAF to the calling Subroutine CHANYZ.

## SUBROUTINE DAMBLD

PURPOSE

Subroutine DAMBLD monitors construction of a dam and reservoir to contain a specified design flood or provide storage for other purposes. The brief monitoring subroutine saves placing this programming into BUILD at several places and should provide greater flexibility in later program development to further refine the procedures of dam and reservoir design.

PROCEDURE

DAMBLD sequentially summons the subroutines which size the dam and reservoir required to provide the desired degree of flood control, design and compute construction quantities for the dam and appurtenances, and estimate the required construction cost. The design was originally programmed to handle an earth dam with a closed conduit principal spillway to pass the design flood and an open channel emergency spillway on either one of the abutments or through a side saddle to pass the dam safety flood (Figure 1).

Initially, DAMSIZ is called to perform the flood routing required to determine the elevations of the principal spillway inlet, the emergency spillway weir crest, the emergency flood crest, and the top of the dam. The upper and lower limits of riprap protection on the dam face are next designated. Presently, the upper and lower limits are taken as the elevations of the emergency flood crest and two feet below the top of the sediment storage respectively.

The design of the dam is completed by the calling of Subroutines DAMVOL, STLBAS, EMSPVL, and PRNSP. DAMVOL computes the volumes of embankment, cutoff trench, and riprap. STLBAS designs the emergency spillway stilling basin and computes the associated excavation and concrete quantities. EMSPVL designs the emergency spillway chute and computes the volumes of concrete and rock and earth excavation. PRNSP then designs and computes quantities for the principal spillway.

Finally, the total cost of constructing the dam and reservoir is found by taking the various construction quantities and their unit costs into DMCOST. If SPLSIZ was used to determine the optimum emergency spillway width in the current calling of DAMSIZ, the design and cost estimate is completed in the SPLSIZ optimization procedure and need not be repeated in DAMBLD. Subroutine DAMBLD finally returns control to BUILD, the calling program.

## SUBROUTINE DAMSIZ

### PURPOSE

Subroutine DAMSIZ determines the size of dam required to adequately provide for sediment deposition over the design life of the structure, store the amount of water needed for non-flood control purposes as read into input variable XTRSTR, contain sufficient flood storage to confine the design flood to outflow through the principal spillway, and allow enough surcharge flood storage to prevent the dam from being overtopped by the most severe flood likely to occur at the site.

### PROCEDURE

Sizing the dam essentially consists of finding the optimum amount of sediment, conservation, flood, and surcharge storages; setting the principal spillway crest at the top of the conservation storage and the emergency spillway crest at the top of the flood storage; and determining the required flow capacities for both spillways. Optimum sediment storage depends on sediment inflow as determined from characteristics of the tributary drainage area (3, p. 145). Optimum conservation storage depends on the economic evaluation of project purposes other than flood control, must be determined outside the Program, and when found is read as XTRSTR. Optimum flood storage depends on the reduction of downstream flood damage. The amount of flood storage required to contain a given flood specified by frequency is determined by the maximum accumulation of water in the reservoir during the passage of the flood. Net accumulation is governed by outflow from the reservoir through a spillway just large enough to empty the flood storage over a time interval prescribed by the input data. Optimum surcharge storage depends on an economic tradeoff between emergency spillway weir crest length (a more costly spillway) and dam height (a more costly dam and reservoir) as analyzed in Subroutine SPLSIZ.

The size of the principal spillway is roughly estimated from the average flow during the drawdown period for the design frequency flood. The design capacity is more accurately estimated as the peak outflow from the design flood when routed through a principal spillway of this size. This design flow occurs with a reservoir water surface elevation at the crest of the spillway.

The storage (SEDSTR) provided to accommodate the sediment accumulated over the design life (TIMST) of the reservoir is computed as the product of the area tributary to the dam site, the design life of the reservoir, and the read annual sediment inflow rate (SEDIN).

The required flood storage is first roughly estimated from cumulative runoff data (3, pp. 127-130). In order for the flood storage to empty before another rise comes downstream, the average outflow from the reservoir must equal the average inflow during the prescribed drawdown period (IMPTY). This average flow is given by the element of CUMVOL corresponding to the length of the drawdown period and corrected for the frequency of the design flood. The elements are corrected for frequency according to the ratio of the design frequency flood volume to the mean annual flood volume and placed in CUMVOD. The peak outflow (DRQ) for principal spillway design is first estimated as a multiple of this average flow (3,p.145). The necessary flood storage (FLDSTR) can be estimated by determining the maximum excess of accumulated inflow over accumulated outflow represented by any point in CUMVOL.

The elevation of the top of the conservation storage (SEDSTR+XTRSTR) is located and assigned to the principal spillway inlet (ELPRFL). The elevation of the top of the total controlled storage (SEDSTR+XTRSTR+FLDSTR) is found and assigned to the emergency spillway weir crest (ELSPFL) (Figure 5).

The initial routing conditions for a refined evaluation of FLDSTR are next determined. These consist of the "base" flow rates for the mean annual, 200-year, and reservoir design floods and the corresponding reservoir surface elevations. The "base" flow rate for a given flood is the reservoir discharge rate expected on a probability basis at the time the flood begins. If the reservoir initially contains only conservation storage, the base flow is computed as the average flow over the last two days of the IMPTY-day drawdown period. The reservoir water surface elevation is determined as the head required for this flow to pass over the emergency spillway crest. If the reservoir initially contains no conservation storage, the base flow is computed as the average rate of flow during the period between the end of the flood hydrograph and the end of the drawdown period. The reservoir water surface elevations which correspond to the base flows are then

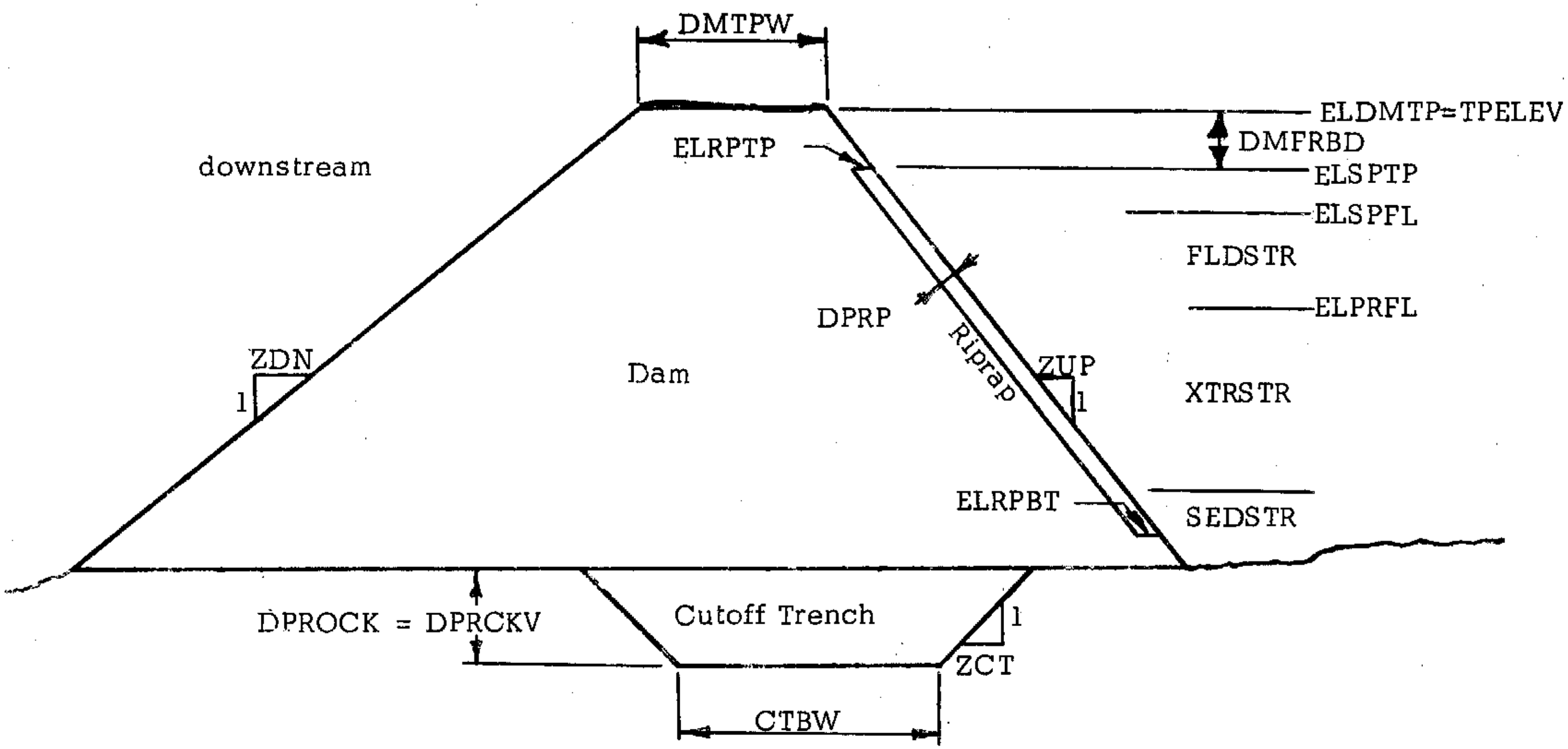



Figure 5. Dam Cross Section
(Not to scale)

computed from the head required to discharge the base flow through the principal spillway. The head with weir control over a principal spillway crest approximately sized from the design discharge (DRQ) is calculated. The head with pipe control through the principal spillway is also calculated. The higher of the two is used. Base flows and water surface elevations by frequency are printed if requested through HYDTLS (3, pp. 169-170).

If FLDSTR is to be provided in the trial design, the initial rough estimate of its required magnitude is now revised by routing the design frequency flood through the reservoir starting with the calculated initial conditions while allowing outflow only through a principal spillway capable of discharging flow DRQ under a head defined by the water surface elevation at the top of the initial estimate of FLDSTR. The emergency spillway crest elevation is set at the crest of this routed flood. The design capacity of the principal spillway is adjusted according to the peak routed outflow. The revised estimate of FLDSTR is based on the volume of reservoir storage below this elevation.

If the optimum emergency spillway width (WDEMSP) has not previously been determined for the present stage, it is now done by calling Subroutine SPLSIZ. Since the elevation of the dam top (TPELEV) and the emergency spillway design flow (QEMSP) are determined in SPLSIZ, the balance of DAMSIZ need not be executed if SPLSIZ is called at this point.

If the optimum emergency spillway width is known, SPLSIZ is not called and a very rare flood is routed through the reservoir beginning with the 200-year base flow. The routed flood peak determines the surcharge storage and, by adding the necessary freeboard, the elevation of the dam top. If the dam-top elevation exceeds the range for which the currently optimized emergency spillway width is applicable (3, pp. 134-135, 139-140), this fact is printed and DAMSIZ summons SPLSIZ to optimize the emergency spillway width for the applicable site.

DAMSIZ ends by printing the determined quantities and elevations if requested (3, pp. 178-179) and returning to DAMBLD.

## SUBROUTINE DAMVOL

### PURPOSE

Subroutine DAMVOL computes the embankment volume (VOLDAM), cutoff trench volume (VOLCT), and riprap volume (VOLRP) for the dam.

### PROCEDURE

The volume computations are a problem in solid geometry. Given the top elevation of the dam (ELDMTP), DAMVOL interpolates in arrays ELEVA and DAMLTH to determine the length of the dam along its top (DAMLNG). The volume of the dam (VOLDAM) is computed by dividing the dam into a number of sections each including the portion of the dam whose bottom elevation is included between two consecutive elevations in ELEVA, computing the volume of each section by the prismoidal formula (Eq. 17), and summing the section volumes. The method essentially assumes the contours at the point along the stream where the dam is located to be straight and perpendicular to the dam axis. The cutoff trench volume (VOLCT) is computed from DAMLNG, CTBW, ZCT and DPROCK by assuming the cutoff trench extends the entire length of the dam at a mean vertical depth equal to DPROCK (Figure 5).

The riprap volume (VOLRP) computation consists of determining the area of the upstream face of the dam between elevations ELRPTP and ELRPBT and multiplying that area by the riprap thickness DPRP.

The volumes thus computed are printed if requested (3,pp. 173-174) and returned to Subroutine DAMBLD.

## SUBROUTINE DMCOST

### PURPOSE

Given the various Program-computed construction quantities and their read unit costs (3,pp.149-153), DMCOST determines the cost of constructing a dam and reservoir.

### PROCEDURE

With the construction quantities and unit costs given, computation of the total costs is a simple process of multiplication plus adding allowances for such costs as engineering and contingencies. The costs computed include:

CEMB: The total cost of dam embankment, computed from the volumes of the dam, cutoff trench, and riprap and their respective unit costs.

CSPL: The total cost of the emergency spillway upstream from the spillway basin, computed from volumes and unit costs of spillway earth excavation, spillway rock excavation, and spillway concrete.

CSB: The total cost of the emergency spillway stilling basin, computed from volumes and unit cost of stilling basin excavation and concrete.

CPRSP: The total cost of the principal spillway including the entry structure and impact dissipator, computed from unit costs and concrete volumes of the principal spillway and impact dissipator and trashrack area.

CCLR: The cost of clearing vegetative growth from the reservoir site, where the area cleared lies between the elevation of the emergency spillway crest and the elevation five feet below the top elevation of the sediment pool.

CONCST: The total initial cost of reservoir construction, computed as the sum of the above costs of dam embankment, emergency spillway, stilling basin, principal spillway, and site clearing.

CENCN: An additional allowance for engineering and design, construction supervision, and contingencies, computed as read fractions of initial construction cost.

CTOT1: The total construction cost of the dam and reservoir equalling the sum of CONCST and CENCN.

CROW: The cost of right-of-way required by the reservoir site, computed as the cost of land and structures lying at a lower elevation than a purchase line read distance BYVERT (3, p. 141) above the dam top.

CAQR: The administrative, legal, and all other costs not for purchase of land and structures incurred as a result of the right-of-way acquisition proceedings (3, pp. 111-112).

CRELO: The cost of relocating highways, railways, and various other utilities located within the reservoir site as interpolated according to the elevation of the dam top from CRELOC (3, pp. 138-139).

CTOT2: The total cost of lands and relocations, computed as the sum of CROW, CAQR, and CRELO.

CTOT: The total initial cost of the reservoir, including construction, lands and acquisition, and relocations, computed as the sum of CTOT1 and CTOT2.

ANCOST: The annual cost of the reservoir, computed as the average annual equivalent of initial cost CTOT.

ANMAIN: The annual operation and maintenance cost of the dam and reservoir, computed as a read fraction (MDAM) of the initial construction cost CTOT1.

COSTDM: The total average annual cost of the dam and reservoir, computed as the sum of ANCOST and ANMAIN.

Subroutine DMCOST prints each of the above costs as it is calculated plus the acres of right-of-way purchased provided logical variable DMDTLS is TRUE (3, p. 178). Even though the detailed list of reservoir costs above may be omitted, DMCOST always prints the total annual cost COSTDM and the per cent probability of the flood the reservoir is designed to contain. DMCOST then returns control of program execution to DAMBLD or SPLSIZ.

## SUBROUTINE EMSPVL

PURPOSE

Subroutine EMSPVL designs and determines the construction quantities required by the emergency spillway upstream from the stilling basin. The chute is designed on a straight alignment with the water surface elevation at approximately the top of the bedrock, The chute cross section is rectangular but may be concrete lined or not, as specified by the input data. The approach channel essentially amounts to daylighting the hillside cut back into the reservoir at an elevation five feet lower than the spillway crest. The quantities calculated are the volume of concrete (SPCONC) contained in the spillway channel bottom and sidewalls and weir crest section and the volumes of earth excavation (EREX) and rock excavation (SPRKEX) associated with the spillway and approach channel.

PROCEDURE

The basic wall structure use in the emergency spillway chute is as shown on Figure 6. At a 10-foot long crest section, the side walls have the same top elevation as the dam. Within the main chute the wall height is determined by the depth of flow plus freeboard. Between these two sections, the wall height uniformly decreases until the chute bottom is ten feet below the crest elevation. At the downstream end, the required wall height is determined by the tailwater elevation plus freeboard in the stilling basin.

The computations begin by determining the depth of flow at the upstream end of the main chute by applying the energy relationship indicated on Figure 7. The energy equation becomes

$$FALL = D + 1.1\, V^2/2g \tag{14}$$

and can be combined with the relationship

$$V = QEMSP/(D*WDEMSP) \tag{15}$$

to solve for D, all other terms being known. The resulting cubic equation is solved by trial and error, adjusting trial depth values until two consecutive trials agree within 0.025 foot. Special output is printed in the event EMSPVL encounters data not leading to a solution (3, pp. 174-175).

By using a freeboard equalling in feet (20, p. 291)

$$Frbd = 2.0 + 0.025\, VD^{\frac{1}{3}}, \tag{16}$$

WLHT1 is estimated from the flow depth just calculated by the above energy equation, and WLHTD1 is calculated from a flow depth calculated in STLBAS. The total wall concrete is calculated by dividing the chute into the crest, transition, and main chute sections. The concrete volume in each section is estimated by

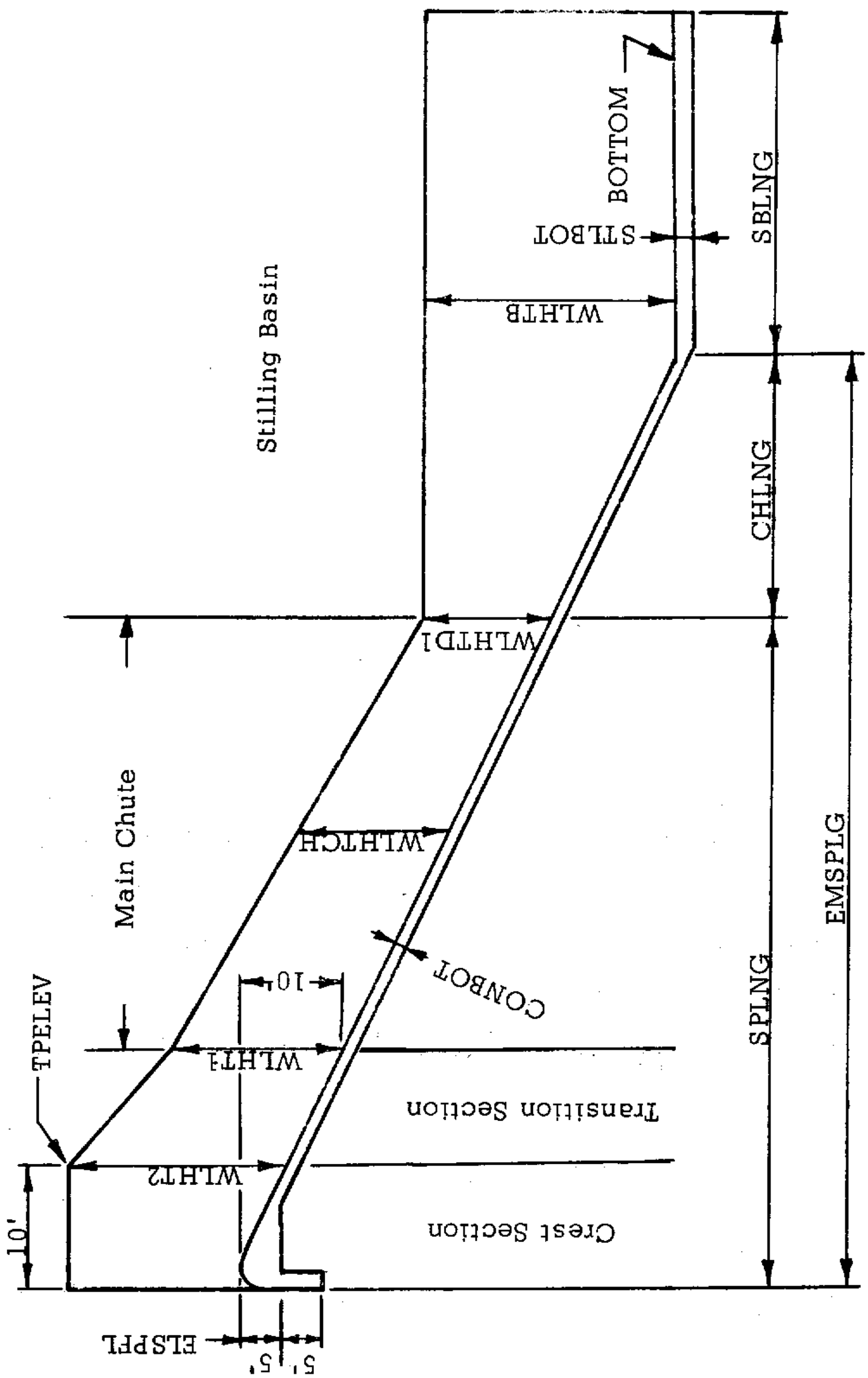



Figure 6. Emergency Spillway Profile
(Not to scale)

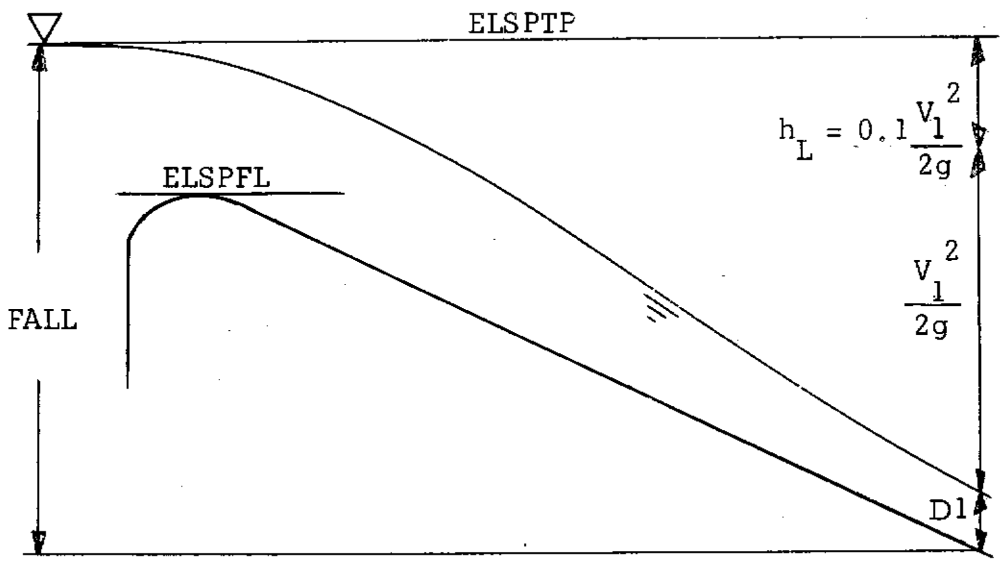



Figure 7. Emergency Spillway Water Surface Profile

summoning RETWAL to obtain the volume per unit length for the maximum (L), minimum (S), and mean (M) wall heights and applying the prismoidal formula

$$A = (L + 4M + S)/6 \tag{17}$$

to get an overall average (A) to multiply by the wall length. The sum of the wall concrete volumes in the three sections are summed to get CWAL. The volume of concrete in the channel bottom (CBOT) is the product of channel length and bottom thickness. The total concrete volume is then the sum of wall and bottom volumes.

The rock and earth excavation volumes require computation of both approach channel and spillway channel excavations. The approach channel to the spillway is cut primarily in earth, while the spillway channel is cut in the hillside rock, which is overlain with earth.

The cross-sectional area of the approach channel varies from a minimum of zero at the upstream end to a maximum at the weir crest section. The bottom of the approach channel intersects the weir crest section at a distance five feet below the weir crest. In order to determine the area of the approach channel at the crest section (APCHAR) it is necessary to locate the point at which the cut slope above the channel bottom intersects the surface of the hillside, on either side of the approach channel. These points (4 and 13 on Figure 8) are located by a trial-and-error interpolative process involving the coordinates of the hillside surface and the approach channel bottom and the cut slope ZES. When these hillside "catch" points are located, the area at the crest section is determined by dividing the total section into trapezoidal components. Computation of the volume of approach channel excavation (APCHEX) applies the average end area method going from the crest section to zero at the upstream end. The channel length read for the dam top height (3, pp. 137-138) is applied along with the prismoidal formula in computing this volume.

The outer catch point (11 on Figure 8) of the cut above the weir crest is found in the same manner as both catch points for the approach channel. The inner catch point (1 on Figure 8) is located where the hillside bedrock rises to the elevation of the dam top. This point locates the spillway crest horizontally. The area of the spillway channel (SPCRAR) at the crest section is found by the same method used for APCHAR. The spillway channel area is assumed to vary from the maximum of SPCRAR to the minimum

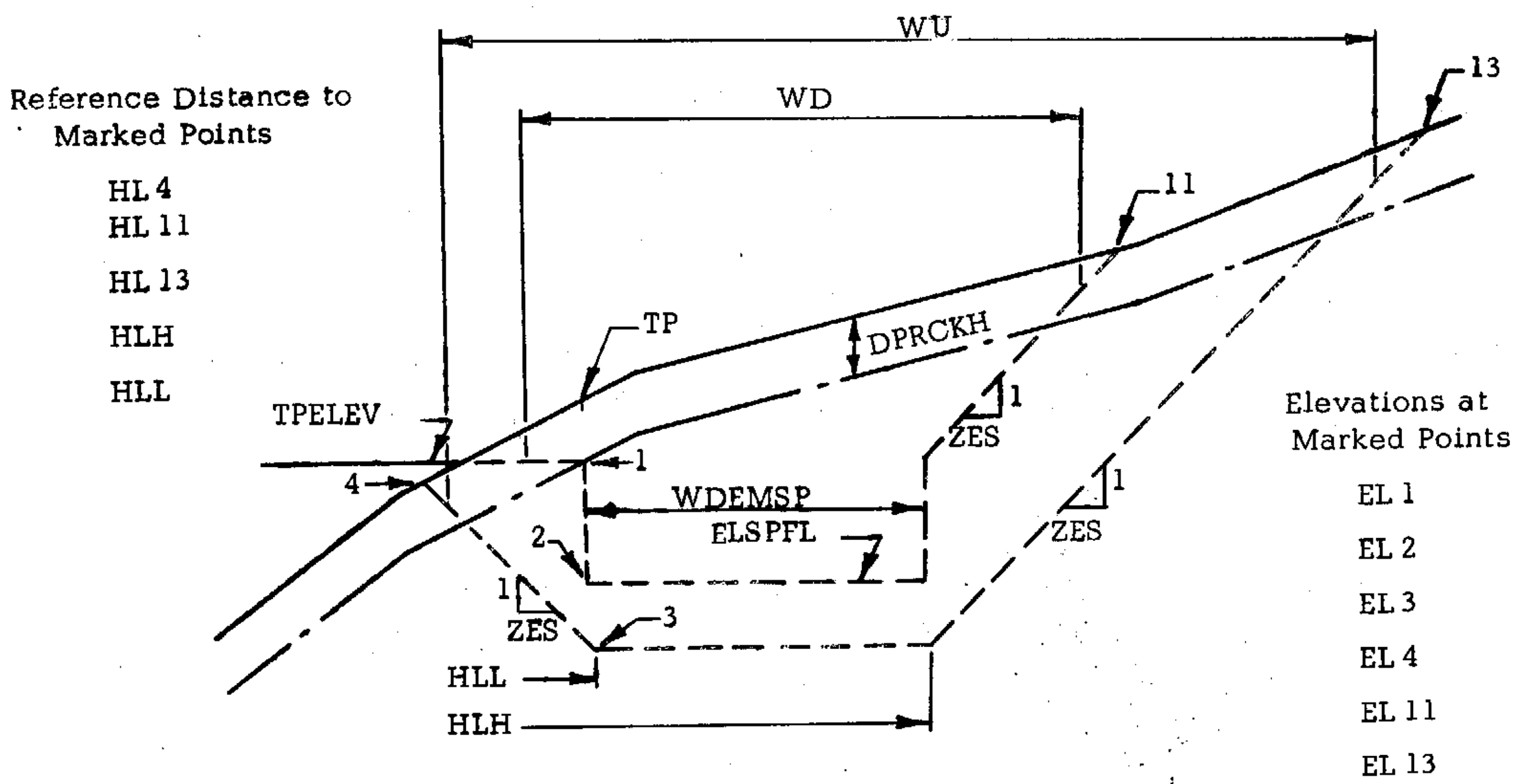



Figure 8. Emergency Spillway Cross Section (At Crest)
(Not to scale)

(WDEMSP*(WLHTD1 + DPRCKH)) at the lower end of the channel. The spillway channel excavation (CHEX) is estimated from the average-end-area formula and SPLNG (Figure 6). The total excavation volume associated with the spillway is then the sum of approach channel excavation, spillway channel excavation, and spillway concrete volume (the spillway channel excavation was computed based on measurements above the channel bottom). The earth excavation EREX is computed from the depth to rock and the surface width between the sides of the spillway channel and approach channel, and subtracted from the total excavation to give the rock excavation SPRKEX.

If logical variable DMDTLS is TRUE the volumes, lengths and catch point coordinates are printed (3, pp. 175-176). EMSPVL then returns the computed quantities to DAMBLD or SPLSIZ depending on which was the calling subroutine.

## SUBROUTINE FPCOST

### PURPOSE

Based on the relationship between flood peak and frequency established in CHFLDS for the subwatershed-stage at hand and the various economic parameters governing flood plain damage and measure cost established in CHANYZ, FPCOST selects the optimum flood damage reduction policy.

### PROCEDURE

The frequency (F) at which flooding begins in the subwatershed is determined by interpolation between flood peaks of known frequency utilizing extreme value theory as outlined in CHFLDS. The subwatershed channel capacity is first compared to the reservoir design frequency flood peak in order to determine which portion of the broken line flood frequency relationship applies (Figure 3). The mode and dispersion parameter are then computed for the proper portion of the relationship. With these parameters, FPCOST can solve directly for the frequency of the flood which peaks at the subwatershed channel capacity, the frequency at which flooding begins in the subwatershed. Subroutine CHOPTM is then summoned to determine the optimum combination of channel improvement and nonstructural measures for the subwatershed in the given stage.

The bulk of FPCOST's remaining work consists of the bookkeeping duties of saving for printout and later use if the amount of flood storage currently being considered should prove optimum the measures implemented under the optimum policy found by CHOPTM. The number (NSTAGE) of the current stage is assigned to variable LC9(NW) if the land-use adjustment alternative was employed in the subwatershed for the first time. The type of channel improvement, the number of drop structures, and the fall per drop structure are recorded in LN9(NW), ND9(NW), and FD9(NW) respectively. The cost of channel improvement implemented during the current stage is added to the accumulated costs of structural measures implemented in the subwatershed in previous stages to obtain the current value of annual cost of all structural measures implemented in the subwatershed to date (OUTPUT(4)). The current value of annual cost of all measures, structural and nonstructural, implemented in the subwatershed to date (OUTPUT(13)), is similarly determined. IMPROV is assigned a value to indicate the type of channel improvement work done in the current stage. Four channel dimensions are saved, and all changes made in the highway and railroad bridges within the subwatershed by Subroutine BRIDGE are duly recorded.

If the logical variable HOLDNG has been read TRUE to indicate that rights-of-way for future channel improvements should be purchased and held if feasible and CHANYZ has indicated that holding right-of-way is financially attractive, FPCOST conducts additional tests to determine whether such holding is in fact a wise choice. If rectangular concrete channels have been implemented within the subwatershed or if the subwatershed channels have been improved to contain a flood at least as great as the 40-year flood, it is not considered likely that further channel enlargement requiring additional right-of-way can be justified, and no rights-of-way are held. If such holding still looks promising, the right-of-way width to be held and the cost of such holding is then computed. The flood event used in determining the width of extra right-of-way to be held using an approximate formula derived from Manning's equation is the largest event in the array of potential design floods. If the right-of-way currently owned for the existing channel is sufficient for a channel containing the aforementioned flood event, additional right-of-way need not be purchased for potential future channel improvement.

If the width required for holding exceeds the width currently available, the cost of purchasing and holding the extra right-of-way is computed. If the computed cost of holding the necessary right-of-way for possible future channel improvements is as great as one-third of the current sum of the costs of flooding and implemented measures in the subwatershed, it is deemed unlikely that channel improvement will ever prove feasible, and the idea of holding right-of-way is abandoned. Otherwise, the holding of right-of-way is deemed a sound course of action and the cost of such holding is added to the accumulated annual cost of measures implemented in the subwatershed through the current stage.

FPCOST next writes a summary of the measures implemented in the subwatershed in the current stage, along with the costs of such measures (3, pp. 160-161). The summary contains the frequency at which flooding begins; the design flood frequency and flood peak for structural measures and the cost of the improvements; the frequency, peak, and cost associated with implemented land-use adjustment; the frequency, peak, and cost associated with implemented flood proofing; the annual cost of residual flooding in the subwatershed; the cost of uncertainty associated with the residual flooding; and the total annual cost of all measures implemented in the subwatershed through the present stage and all earlier stages. These values are contained in OUTPUT (1-13).

If any channel improvements were implemented in the stage, Subroutine STROUT is summoned to print a summary of the improvements, including data on channel widths, linings, and drop structures (3, pp. 162-163). If any location measures were adopted, the area (acreage) of the restricted land-use is computed and written. If flood proofing was employed, the acreage flood proofed is computed and written.

Upon completing this work, Subroutine FPCOST returns control to CHANYZ.

## SUBROUTINE HYDCOM

### PURPOSE

HYDCOM is called by RSHYDR to combine a local inflow hydrograph for a given subwatershed with the flood hydrograph routed to the subwatershed mouth from upstream subwatersheds. The combined hydrograph is used for estimating flood peaks in the subwatershed flood plain and to continue the routing into the next downstream subwatershed.

PROCEDURE

The hydrograph routed in CHRTE to the downstream end of a given subwatershed (HYDOUT) is a 50-element hydrograph with flow elements spaced at a time interval of HYDINT hours. HYDINT is specified in the input data and used for spacing hydrograph elements in all routing along the main stream.

The local inflow hydrograph (HYDIN) describing flow originating within the given subwatershed is a 20-element hydrograph with its peak at element number N1. However, the time interval between elements of the local inflow hydrograph depends upon the time to peak (TPW) for the local subwatershed as developed in RSHYDR based upon its area and hydrologic characteristics. HYDCOM determines the time spacing between the elements of HYDIN as TPW/N1 hours.

Because the time intervals between elements of the local and incoming hydrographs are not the same, the local inflow hydrograph elements cannot be added directly to the incoming hydrograph elements. HYDCOM must interpolate between elements of the local inflow hydrograph to determine the flows corresponding to the 50 elements of the incoming hydrograph. Because the peak of the local inflow hydrograph will seldom occur simultaneously with any of the elements of the incoming hydrograph, the local peak is always added to the nearest element of the incoming hydrograph to insure that the peak in a very sharp local inflow hydrograph will not be severely reduced by the process of interpolation.

In the event the local inflow hydrograph is of shorter duration than the 50-element hydrograph to which it is to be added, HYDCOM extends it by use of a recession constant. The first element beyond the normal local hydrograph is determined as the product of HYDIN(20) and the recession constant (RK24) calculated for HYDINT hours. Each of the following elements is then determined as the product of the previous element and the recession constant until a sufficient number of elements have been developed to extend the local inflow hydrograph to the end of the incoming 50-element hydrograph.

If so instructed, HYDCOM prints the 50 elements of the combined hydrograph HYDOUT (3, p. 165). Control is returned from HYDCOM to RSHYDR.

## SUBROUTINE PLACEA

### PURPOSE

PLACEA is a two-way arithmetic interpolation procedure used to determine multipliers for estimating the values of the mean annual and 200-year flood peaks and average flood flows as functions of the levels of urbanization and channelization. The multipliers are determined by linear interpolation from two-dimensional read arrays (Q05, Q43, V05, V43) based on known values of U and C.

### PROCEDURE

The values brought to PLACEA in position X(11,11) are one of Q05(11,11), Q43(11,11), V05(11,11) or V43(11,11). Q43 contains the ratios of the mean annual flood peak from one square mile for 121 combinations of urbanization and channelization levels to the mean annual flood peak from one square mile of drainage area with U = 0.0 and C = 0.0 (4). Q43(1,1) equals 1.0 (U = C = 0.0). All other values of Q43 are greater than 1.0 because tributary urban development and channel improvement both tend to increase flood peaks. Q05 brings a similar array of ratios for the 200-year flood. V43 and V05 bring the ratios for the average flows during the mean annual and 200-year flood hydrographs respectively.

Along with one of the four above arrays, the fraction of the tributary area in urban development (UU) and the fraction of the tributary channel length which has been improved (CC) are brought to the subroutine. With these values, PLACEA conducts a two-dimensional linear interpolation in the array and returns the interpolated ratio as QR to the calling subroutine, usually RSHYDR.

## SUBROUTINE PRNSP

### PURPOSE

Subroutine PRNSP designs and estimates construction quantities associated with a pipe spillway of the type shown on Figure 9. The spillway is designed to pass the design flood (routed peak outflow for flood of design frequency) based on pipe control and a head equal to the difference in elevation between the emergency spillway crest and the tailwater. The spillway includes an entrance tower including the desired entrance facilities as specified through the cost data (UCTRK), a horizontal pipe through the base of the dam section, and an impact stilling basin.

### PROCEDURE

PRNSP begins by calculating the design head (HDPRSP) from the difference in upstream (ELSPFL) and downstream (TWELEV) water surface elevations and the required pipe length (PLNGT) from the dam height determined in DAMSIZ. The length of the spillway pipe (PLNGT) is the sum of the lengths of the vertical and horizontal sections of the pipe. The vertical section extends

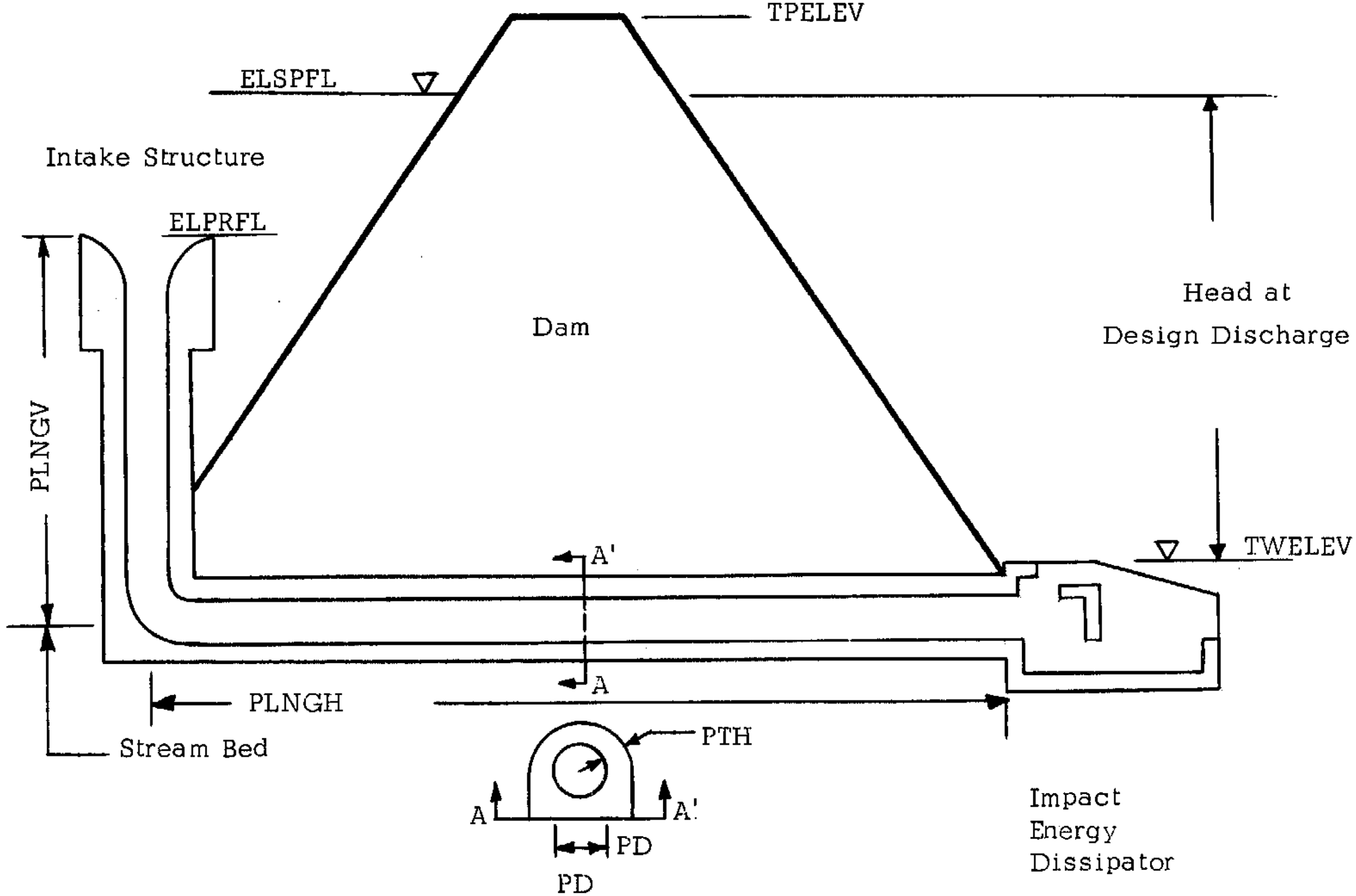



Figure 9. Principal Spillway
(Not to Scale)

from the spillway inlet elevation (ELPRFL) to the bottom of the original stream channel, and the horizontal section extends through the entire base of the dam.

An initial pipe diameter (PD) of 0.25 foot is assumed, its capacity is calculated, and PD is increased by increments of 0.25 foot until a diameter sufficient to pass the design discharge is reached. The discharge at each trial diameter is computed by application of the energy equation using the Darcy-Weisbach expression to estimate head loss. More specifically,

$$Q = 0.7854\, PD^2 * 64.4((ELSPFL-TWELEV)/(1.25 + (FPIPE)(PLNGT)/PD))^{\frac{1}{2}}. \tag{18}$$

The necessary concrete pipe thickness (PTH) is computed by a "rule of thumb" as approximately one-fortieth of the product of the pipe diameter and the square root of the effective head on the pipe. The outside cross-section of the pipe is thickened to a rectangular section along the lower half of the circumference to provide strength and a more stable foundation (Figure 9). The concrete volume (PRCON) in the pipe is then computed as the product of the length of the pipe and the cross-sectional area.

The concrete volume (CONID) of an impact dissipator is then estimated from design dimensions derived by the Bureau of Reclamation (20, p. 306) as

$$CONID = 0.158 * DRQ + 1.7. \tag{19}$$

The size of the opening at the spillway entrance (TRAREA) is computed as DRQ/(0.6 * TRV). This size is used as an index for estimating the cost of the entrance in excess of the cost of the pipe. Items which may be included in the unit cost (UCTRK) (3, p. 152) include the extra cost of the entrance tower above the cost of the pipe and the costs of the trashrack, the antivortex device, any gates used, and associated structural work.

The design values calculated in PRNSP are printed out if so specified (3, pp. 176-177) and then returned to Subroutine DAMBLD or SPLSIZ.

SUBROUTINE RDDATA

PURPOSE

Subroutine RDDATA reads all input data to be used in the analysis. It also combines input data terms utilized in combination throughout the analysis to save computer time by avoiding repetitious computations.

PROCEDURE

Because each input data item is thus clearly identified in the input list of Appendix B and a complete description of the input data is provided by Cline (3, pp. 56-155), detailed description of the input data items will not be repeated here. However, the computations combining certain input variables will be discussed.

From the input values of variables L1 through L11, RDDATA fixes the values of the logical variables which determine the program options employed throughout the analysis. UNC is set TRUE if uncertainty costs are to be evaluated, PTF, LTF, and STF are set TRUE if flood proofing, land-use adjustment and channel improvement, respectively, are to be eliminated from consideration in the analysis. TRACE and CHECK are set TRUE if the optimization process for subwatershed measures (CHOPTM) is to be traced through the interior loop computations. HOLDNG is set TRUE if the program is to consider the early purchase and holding of channel rights-of-way for possible future channel improvements, DMDTLS is set TRUE if certain design dimensions and costs associated with the construction of a dam and reservoir are to be printed as computed. HYDTLS is set TRUE if the results of certain hydrologic computations are to be printed. LOOPTR is set TRUE if a special message is to be printed as the Program enters and leaves each subroutine. NODAM is set TRUE if retention storage is to be eliminated from consideration in the analysis.

RDDATA utilizes input arrays AFCTR(3,11), AFCTRV(2,11), and AFCTRT(11) to compute values for arrays AFW(2,MW), AFV(2, MW) and AFT(MW). AFCTR contains the ratios of the mean annual and 200-year flood peaks (expressed in cubic feet per second per square mile) from the eleven drainage areas specified in AFCTR(1, 11) to the mean annual and 200-year flood peaks from one square mile of drainage area. AFCTRV contains the same set of ratios for the volumes of the mean annual and 200-year flood flows. AFCTRT(11) contains the ratios of the time to peak from the areas specified in AFCTR(1,11) to the time to peak from a drainage area of one square mile. Arrays AFW, AFV and AFT are filled with the proper peak, volume, and time ratios to correspond to the drainage areas of each of the subwatersheds in the study area. The ratios for a given subwatershed drainage area are interpolated logarithmically between the ratios for the two bracketting areas in AFCTR(1,11).

Utilizing the read values of discharge, channel capacity, area inundated, and maximum depth of flooding in each subwatershed (QK12,Q0, AK12, DK12) for some historical flood event, RDDATA computes for each subwatershed the ratio of maximum flooding depth to discharge in excess of channel capacity raised to the three-eights power K1(MW), and the ratio of acreage flooded to maximum depth of flooding K2(MW). These ratios are used in

CD1 and CD2 to determine the depth and area of flooding which result from a given discharge in a specified subwatershed.

After reading the cumulative runoff data (CUMVOL) corresponding to a drainage area (AWG) where streamflow records are available, RDDATA reduces CUMVOL to correspond to the drainage area at the considered reservoir site AW(1) by multiplying each element by the ratio of the two areas. Also, the recession constant (RK24) employed in HYDCOM is determined by raising the average runoff during the second day divided by that during the third to a power equal to the fractional part of one day contained in hydrograph routing interval HYDINT.

The cost of right-of-way is modified to correct for the difference between the rate of return earned from the land and the public discount rate (7, pp. 146-148). The correction is added to the acquisition cost.

Utilizing the input values of the project discount rate (R) used in the analysis, the private investment interest rate (RPI) for land investment in the study area, the duration in years (TIME) of each of the planning stages, and the economic life in years (TIMST) of structural measures, RDDATA computes the set of discount factors needed later in the analysis. These include CRF, the project capital recovery factor for the stage duration; CRFSM, the project capital recovery factor for the economic life of structural measures; GSF, the uniformly increasing gradient series present worth factor for TIME years; PWF and PWFR, the single-payment present worth factors for TIME years for the private and public interest rates, respectively; and SPWF and SPWFAC, the uniform annual series present worth factors for TIME years for private and public interest rates, respectively. Special formulas are provided for computation of these factors in the case of a zero project discount rate.

Values for eight factors are computed for later use in estimating the costs of the several types of structural measures. Each factor (SK1 through SK8) combines the discount factors and unit construction costs needed to estimate the cost of a specific type of structural measure. Because costs must be estimated many times throughout the analysis, a considerable savings in computational time is achieved by combining as many of the assorted constants as possible. The factors are defined in Cline's (3, Appendix B) dictionary of program variables.

In like manner, CPF, the factor which may be multiplied by the maximum depth of flooding to determine the cost of flood proofing, is computed from input flood proofing unit costs and discount factors.

The final factors computed deal with farm income and crop damage due to flooding. FIF(NW), which contains the average annual agricultural income from a composite crop acre in each subwatershed flood plain, is computed as the sum of the products of the per-acre crop income from land in each of the three basic soil categories and the fraction of the subwatershed flood plain composed of each soil category. CDF(NW), which contains the dollar damage to a composite crop acre when flooded to a minimal depth, is computed for each subwatershed as the sum of the products of the damage done to each of the three basic soil categories when flooded to a minimal depth and the fraction of the subwatershed flood plain composed of each of the three soil categories. CG(MW), which is the additional damage done to a composite crop acre per additional foot of flood depth, is computed as the sum of the products of the incremental damage to each of the three basic soil categories and the fraction of the subwatershed flood plain composed by each of the three soil categories.

Input array D(3,MW), which provides the fraction of each subwatershed flood plain in each of the three soil categories, is read in the input data (3, pp. 85-86). For the three soil categories in order from best soil to worst soil, read-in values of FIA, FIB, and FIC provide annual per-acre farm income, CDA, CDB, and CDC provide per-acre crop damage when flooded to a minimal depth, and CDAV, CDBV, and CDCV provide incremental per-acre crop damage per foot of flooding depth. The input constants listed in this paragraph are those used to develop those factors described in the previous paragraph.

With the data read and the term combining computations completed, program control returns to the central control program for continuation of the analysis.

SUBROUTINE READ

The University of Kentucky Flood Control Planning Programs require reading many arrays and single-valued items of hydrologic, topographic, and economic input data. In order to minimize the time necessary for coding this data onto punched-cards and allow more freedom in punching explanatory comments, RDDATA employs a special subroutine called READ. Numerical input data is read from punched-cards without resorting to input format specifications. This feature is presently available on the University of Kentucky Computing Center's IBM System 360/50.

In order to illustrate the use of Subroutine READ, let us suppose that it is desired to read the values of real variables ALPHA and BETA and integer variable IOTA from one or more punched-cards but that the location of the values on the cards is not known. The instruction CALL READ (ALPHA, BETA, IOTA) would cause the data cards to be scanned consecutively from left to right with the first value found being stored as ALPHA, the second as BETA, and the third as IOTA, regardless of the spacing of the values on the card or how many blank cards are passed before the data is found. However, it is necessary that there be at least one blank column between any two values. An array may be read in conveniently as

```
      DO 5 I = 1,27
    5 CALL READ (DATA(I)).
```
(20)

This instruction will cause the first 27 values encountered to be stored in array DATA(27). The 27 values may be placed on a single card or may be spread over any desired number of cards.

When an asterisk (*) is encountered in scanning a card, READ skips on to the next card, ignoring all notes punched in columns to the right of the asterisk. This feature makes it very convenient to place identifying data labels throughout the data list. This can be a delightful luxury, especially when working with large volumes of various types of data, as is the case with UKFCPP III. Many examples of such labeling can be found in the data listing of Appendix B.

It should be pointed out that READ will not accept alphanumeric data at the present time even though the data input to UKFCPP III contains no alphanumeric data.

## SUBROUTINE RESRTE

### PURPOSE

Subroutine RESRTE routes a given inflow hydrograph expressed as 50 elements each separated by HYDTIM hours through a reservoir having the characteristics of the current trial design. The discharge through the reservoir principal spillway may be regulated by a gate if so specified in the input data.

PROCEDURE

Subroutine RESRTE utilizes the standard storage routing technique based on continuity to route a given 50 element inflow hydrograph through a gated or ungated reservoir (3, pp. 224-227). Over a sufficiently short time interval, the mean inflow and outflow may be adequately evaluated as the arithmetic mean of the flows at the beginning and end of the time period. The change in reservoir storage during the interval may be expressed in terms of inflow and outflow as

$$S_2 - S_1 = t(I_1 + I_2)/2 - t(0_1 + 0_2)/2 \tag{21}$$

which may be more conveniently rearranged as

$$(S_2/t + 0_2/2) = (S_1/t - 0_1/2) + (I_1 + I_2)/2. \tag{22}$$

Thus if inflow, outflow, and storage are known at a given time and inflow is known from the hydrograph at a time interval t later, the quantity $S/t + 0/2$ may be evaluated from Eq. 22 for the later time. If I and 0 are in cubic feet per second, S is in acre-feet, and t is in hours, the term $S/t$ must be converted to $12.12\ S/t$, which also has units of cfs.

If a relationship between 0 and $S/t + 0/2$ can also be developed, the calculated value $(S_2/t + 0_2/2)$ may be used to estimate $0_2$. Since S depends on reservoir geometry and 0 depends on the head on the spillways, both are functions of reservoir water surface elevation; construction of a table of 0 vs. $S/t + 0/2$ readily follows. RESRTE computes values of 0 and $S/t + 0/2$, labeled OUTFLO(25) and STOR(25), corresponding to the reservoir surface elevations stored in array RESEL(25). The first elevation, RESEL(1), is taken as the elevation of the principal spillway inlet, ELPRFL, the minimum surface elevation for which water will flow from the reservoir. The next ten elements of RESEL are at the next even one-foot contours, the next two at two-foot intervals, the next four at five-foot intervals, the following three at ten-foot intervals, the next three at twenty-foot intervals, and the remaining two elements are spaced at intervals of forty feet. Although up to 25 elements are provided, no computations are made for elevations which exceed the maximum elevation contained in the input data (ELEVA(IMAX)).

In the routing procedure, values of $0_1$, $I_1$, $S_1$ and $I_2$ are substituted in Eq. 22 to compute for the routing interval at hand the value $(S_2/t + 0_2/2)$, called STOUT. Values of $S/t + 0/2$ have already been placed in STOR for each RESEL. A search determines between which two values of STOR the computed value of STOUT lies. The outflow (RESOUT), which corresponds to the computed value of STOUT, is interpolated linearly between the values of OUTFLO which correspond to the two elements of STOR surrounding STOUT.

Discharge potentially occurs over both the principal spillway and the emergency spillway. Hydraulic control for the emergency spillway is over a weir crest of length WDEMSP at elevation ELSPFL. If the reservoir surface elevation is greater than ELSPFL, the discharge through the emergency spillway is given by

$$QWEIR = WDEMSP*CWEIR*(RESEL - ELSPFL)^{1.5} \qquad (23)$$

Flow enters the principal spillway through an opening in the top of the entrance tower. The hydraulic control at larger heads will be that of a pipe flowing full. It will be that of a circular weir of length equal to the opening circumference (PRM) at low heads. When the principal spillway flows as a pipe, the discharge is computed as

$$QSPILL = DRQ*((RESEL - TWELEV)/HDPRSP)^{0.5} \tag{24}$$

where DRQ is the spillway design discharge and HDPRSP is the design head. When the head on the principal spillway is low enough that it flows as a circular weir, the discharge is computed as

$$QSPLWR = PRM*3.25*(RESEL - ELPRFL)^{1.5} \tag{25}$$

The smaller of QSPILL and QSPLWR governs. Outflow (OUTFLO) is the sum of principal plus emergency spillway discharges.

The gating of the principal spillway is assumed to be operated so that the principal spillway outflow is held constant at its initial value (STFLOW) for GDELAY (3, pp. 131-132) hours. Afterwards, the gates are opened wide and no longer reduce outflow. When the gates are operating, GOUTF (the sum of STFLOW and QWEIR) is used instead of OUTFLO. GSTOR based on GOUTF replaces STOR based on OUTFLO. GSTOR is calculated for each RESEL. Eq. 22 is used to estimate GSTOR, and linear interpolation is used to estimate GOUTF. After GDELAY hours, the ungated values are used as before.

The outflow hydrograph is examined as calculated to determine its peak flow (PEAK) and the time elapsed until the peak is reached (PKTIME). Afterwards, the peak reservoir water surface elevation (ELPEAK) is interpolated from OUTFLO using PEAK. Output describing the routing is printed (3, pp. 170-173) if requested. Finally, control is returned to DAMSIZ, SPLSIZ, or BUILD, the calling subroutines.

## SUBROUTINE RETWAL

### PURPOSE

Subroutine RETWAL estimates for a retaining wall of given height the volume of concrete per linear foot of wall. Retaining walls are required as sidewalls to the emergency spillway stilling basin and chute.

### PROCEDURE

RETWAL computes the proper concrete volume (CONC in C.Y. /L.F.) for a retaining wall of given height (WLHT) by interpolating from arrays CONWAL and HWAL. Should the given wall height exceed the maximum height in array HWAL, the relationship between CONWAL and HWAL is extrapolated linearly,

This procedure requires the bulk of the work in retaining wall design to be done in developing input data for HWAL and CONWAL. The type and volume of retaining wall best suited to a specific location is dictated largely by the soil pressures on the wall and the required wall height. Buttressed walls often become economical at heights exceeding 15 feet. For each wall height, a design appropriate for expected earth pressures should be completed in developing CONWAL data (6, pp. 256-268). In later Program development, it may prove feasible to program an explicite retaining wall design procedure in this subroutine.

## SUBROUTINE RSHYDR

### PURPOSE

Subroutine RSHYDR develops a complete storm hydrograph for a drainage area of specified size, specified fraction of land in urban use, and specified fraction of channels being improved. The method of development assumes all drainage areas of a given size within the study area to be homogeneous with respect to shape, rural land use, and other characteristics besides urbanization and channelization which may influence the hydrograph. Variation of these characteristics among drainage basins of different sizes can be handled by appropriate adjustment of input data read into AFCTR, AFCTRV, and AFCTRT (3, pp. 72-77).

RSHYDR develops local inflow flood hydrographs for the mean annual, 200-year, and a specified reservoir design frequency event and combines them with flood hydrographs of corresponding frequency routed down from upstream. If the existing mainstream channels in the unit are unimproved, three additional combined hydrographs are developed for improved channel conditions to be used in the design of potential mainstream channel improvement. The degree of channel improvement on the tributary channels is specified in the input data by stage (3, p. 67).

## PROCEDURE

Hydrograph development begins with estimating three basic hydrograph parameters: the peak instantaneous flow, the time elapsed from the beginning of the rise to the peak, and the flow volume measured as an average flow rate over the hydrograph duration. The remainder of the hydrograph is developed based on the estimated average flow to peak flow ratio and input data (3, pp. 78-79) providing hydrographs whose average flow to peak flow ratios cover the range of those likely to be encountered.

Flood Peaks: The development of the flood peaks for the mean annual (QF43), 200-year (QF05), and specified reservoir design frequency (QFDS) floods for a given unit begins with the magnitudes of the mean annual and 200-year peak flows from a drainage area of one square mile, QB43 and QB05, respectively. Values for QB43 and QB05 are entered as input data (3, pp. 69-71). Their magnitudes are functions of the hydrologic characteristics of the local area under study.

The flood peak for a given planning unit cannot be computed as the product of the drainage area in square miles and the corresponding flood peak from one square mile of drainage area. The ratio of peak to drainage area is significantly affected by basin size, level of urbanization, and the condition of the channels. These effects must be determined and supplied as input to the Program.

While the volume of precipitation falling upon a watershed during a given storm is approximately proportional to the drainage area of the watershed, the ratio of flood peak to drainage area decreases considerably as drainage area increases. Increased basin lag time slows watershed response and the dampening effect of channel storage upon peak flows is increased with increasing drainage area.

Input data array AFCTR relates the ratio of peak to area for the eleven areas specified in the first row of the array to the ratio of peak to area for one square mile for both the mean annual and 200-year floods (3, pp. 72-73). For the South Fork Licking River analysis, a range of drainage areas from 1.0 to 1000.0 square miles was employed.

An array AFW(2,MW) is filled (in RDDATA) with the proper factors for the subwatershed areas actually encountered in the analysis based on logarithmic interpolation between the areas contained in array AFCTR. AFW(1,MW) contains the factors for the MW subwatershed for the mean annual flood, and AFW(2,MW) contains the factors for the 200-year flood.

Two other very important subwatershed characteristics affecting flood peaks are the levels of urbanization and channelization. Urbanization can substantially increase the flood peaks from an area by decreasing infiltration and overland flow time to produce more runoff and get it into the channels faster. Channelization increases the flood peaks by reducing the dampening effect of channel storage and speeding the flows once they have entered the channels.

The effects of urbanization and channelization on the flood peaks from a drainage area of one square mile were evaluated from an analysis of California and Kentucky watersheds, using data from studies made with the Stanford Watershed Model (4). These effects are quantified in input data arrays Q43(11,11) and Q05(11,11). These arrays give the ratio of the flood peak with U and C at specified levels, to the flood peak with the values of U and C equal to 0.0. The effect on flood peak of any specific combination of urbanization and channelization (U and C between 0.0 and 1.0) is determined by PLACEA as some multiplier greater than 1.0.

The peaks of the mean annual (QF43) and 200-year (QF05) floods from a subwatershed of given area (AW(NW)) are then computed as the product of drainage area AW(NW), corresponding flood peak from one square mile QB43 or QB05, area multiplier AFW(1 or 2,NW), and urbanization-and-channelization multiplier QT43 or QT05.

In equation form

$$QF43 = AW(NW)*QB43*AFW(1,NW)*QT43, \quad (26)$$

$$QF05 = AW(NW)*QB05*AFW(2,NW)*QT05, \quad (27)$$

for the mean annual and 200-year floods, respectively.

These flood peaks are then used in computing the value of the peak of the reservoir design frequency flood QFDS for the given subwatershed. The computation is a direct interpolation between the values of QF43 and QF05, based on the Gumbel theory of extreme values, using the reduced variates (YDS, Y43, Y05) of the flow probabilities. The interpolation takes the form

$$QFDS = QF43 + (YDS-Y43)*(QF05-QF43)/(Y05-Y43). \tag{28}$$

<u>Time to Peak</u>: The time to peak is measured as the length of time from when the rate of flow at a particular point in a channel first begins to increase to the time when the rate of flow is at its maximum. The two characteristics which most affect the time to peak for a basin are the size of the drainage area and the condition of the channels. Other influencing factors are basin shape, slope, and vegetative cover; relative flood magnitude; and rainfall distribution; but these are assumed relatively constant from one drainage area to another in the analysis. An analysis of available data did not indicate a significant difference in time to peak with varying levels of subwatershed urbanization (4). Following unit hydrograph theory, time to peak has been assumed independent of frequency.

The input variable TPB specifies the time to peak, in hours, for hydrographs from a drainage area of one square mile. TPB is a function of the variables listed in the previous paragraph and should be varied in the input data with the values these variables have under typical local conditions.

The input array AFCTRT(11) expresses the ratios of the times to peak for eleven drainage areas (1 to 1000 square miles in the South Fork, Licking River study) to the time to peak from one square mile of drainage area. The ratios for the individual subwatershed areas are logarithmically interpolated from array AFCTRT and stored in array AFT(NW).

The effect of the condition of the channels is reflected in input array TP(11), which contains multipliers (all less than one) for levels of channelization from 0.0 to 1.0. For a specified level of channelization, RSHYDR interpolates in array TP to find the appropriate multiplier of the time to peak.

The time to peak in hours for the subwatershed is then computed as the product of the time to peak from one square mile with C equal to 0.0, the area factor for the subwatershed, and the interpolated channelization multiplier. In equation form

$$TPW = TPB*AFT(NW)*multiplier. \quad (29)$$

Flood Volumes: Computation of the average flows during the mean annual (VF43), 200-year (VF05), and reservoir design frequency (VFDS) floods is analogous to the computation of the corresponding flood peaks.

The volume of a flood hydrograph is defined as the average flow past a particular point between the times when the flow rate first increases measurably above the base flow rate and when the flow rate drops again to the base flow rate. This elapsed time may be estimated for specific historical hydrographs.

The average flow estimated in RSHYDR is based on the input values of the volumes of flood runoff from one square mile of drainage area for the mean annual (VB43) and 200-year (VB05) floods (3, pp. 74-75). These values, like QB43 and QB05 for the flood peaks, are functions of the local precipitation patterns and hydrologic conditions. The volume of flood runoff per square mile is also affected by the size of the drainage area, as well as by the levels of urbanization and channelization.

Input array AFCTRV(2,11), analogous to the last two rows of array AFCTR(3,11) for flood peaks, contains the multipliers relating the ratio of the volume of flood runoff for the drainage afea to the volume of flood runoff from one square mile. Array

AFV(2,MW) is analogous to array AFW(2,MW) for flood peaks. It contains the multipliers for the specific areas of the MW subwatersheds in the study.

The effects of urbanization and channelization on flood volumes is reflected in input data arrays V43(11,11) and V05(11,11) for the mean annual and 200-year floods, respectively. These arrays give the multipliers relating the flood volumes expected from a drainage area having specified values of U and C to the flood volume expected from a drainage area with U and C equal to 0.0. Given values of U and C, RSHYDR summons PLACEA to interpolate in arrays V43 and V05 to obtain the multipliers for the mean annual (VT43) and 200-year (VT05) floods. The average flood flows for each subwatershed are then computed as

$$VF43 = AW(NW)*VB43*AFV(1,NW)*VT43, \qquad (30)$$

$$VF05 = AW(NW)*VB05*AFV(2,NW)*VT05, \qquad (31)$$

for the mean annual and 200-year floods. The volume of the reservoir design frequency flood for each subwatershed is then computed as

$$VFDS = VF43 + (YDS-Y43)(VF05-VF43)/(Y05-Y43), \qquad (32)$$

where YDS, Y43, and Y05 are again the reduced variates of the corresponding flood frequencies.

Shaping the Hydrograph: The procedure for shaping a given hydrograph begins with known values for the peak flows (QF43, QF05, QFDS), average flood flows (VF43, VF05, VFDS), and time to peak (TPW).

The input array HYDBAS(5,21) contains five basic hydrograph shapes of 20 elements each. The five shapes range from "very sharp" to "very flat" and are developed from an analysis of single storm hydrograph shapes characteristic of the area under study (4). The "sharpness" of a given hydrograph is indicated by the ratio of its average flow to the peak flow. This "sharpness ratio" for each of the five basic hydrograph shapes is contained in element 21 of each of the five rows of array HYDBAS. The remaining 20 elements in each row are the "ordinates" of the five basic shapes. The peak element in each row has a value of 1.0, and the remaining nineteen elements are fractions less than 1.0.

RSHYDR searches the input data for the peak element of the hydrograph (N1). The hydrograph base time is computed as 20/N1 times the time to peak. The peak element in each of the five hydrographs must be the same.

The ratio of the average flow to peak flow (VF43/QF43 for example) is calculated for the particular hydrograph to be shaped. This value is then compared to element 21 in each of the five rows of array HYDBAS to determine which two of the five basic shapes enclose the shape of the given hydrograph. If the sharpness ratio of the given hydrograph lies beyond either extreme of the five basic shapes, the shape of the given hydrograph is taken as the nearest extreme shape. The flow elements are then computed for the given hydrograph (HYDTP) as products of the peak flow and the proper 20 fractions of the peak, as interpolated from the two surrounding basic shapes.

This procedure is followed by RSHYDR in developing the mean annual, 200-year, and reservoir design frequency flood hydrographs (local inflow) for a given subwatershed. If the subwatershed channels are unimproved, then RSHYDR also develops an additional set of three hydrographs for the subwatershed under improved channel conditions after calculating an appropriate increase in the value of C.

Combination of Routed and Developed Local Inflow Hydrograph: Except for the watershed tributary to the reservoir site, RSHYDR supervises the combination of the developed local inflow hydrographs with the hydrographs routed downstream through the mainstream channel from upstream. The actual combination of the hydrographs is performed by HYDCOM.

The time interval (HYDINT) between the flow elements of the routed hydrographs is specified in the input data and is usually taken as some integral multiple of one hour. The developed local inflow hydrographs are expressed in 20 elements with the time interval being 0.05 of the hydrograph base time. However, the combined hydrographs and thus the routed hydrographs are 50-element hydrographs, spaced at time interval HYDINT.

HYDCOM converts the odd and variable interval of the local inflow hydrographs to the constant even interval of the routed hydrographs and then sums the flow elements at each interval. The result is a set of combined routed and local hydrographs, based on the time interval of the routed hydrographs.

If the logical variable HYDTLS is declared TRUE by the input data, RSHYDR and HYDCOM print out all combined hydrographs and the parameters (3, pp. 168-169) used in developing the hydrographs.

## SUBROUTINE SPLSIZ

### PURPOSE

Once the amount of flood control storage and corresponding emergency spillway crest elevation have been determined by DAMSIZ, SPLSIZ is called to determine the optimum width of emergency spillway. The optimization is based on the economic trade-off between the costs of building a higher dam or a wider spillway to accommodate the flood flows which enter the reservoir after the flood storage has been exhausted. The optimum width narrows with increased steepness of the hillside slope.

A new spillway width optimization is performed each time the analysis enters a new stage or changes spillway site within a given stage. The Program knows whether the optimization has been completed for the stage by setting WFIX(NSTAGE) TRUE once it is done. The optimum spillway width tends to increase from stage to stage with new urban development making reservoir right-of-way more expensive.

PROCEDURE

The emergency spillway width (WDEMSP) read with the input data only serves to initialize the width optimization calculations. SPLSIZ begins by multiplying the 200-year inflow hydrograph by HYDMLT to obtain the emergency spillway design flood. RESRTE is summoned to route this flood through the reservoir, using the initial input value of WDEMSP as the spillway width. Adding the specified freeboard (DMFRBD) to the peak water surface of the routed hydrograph (ELSPTP) gives the initial dam top elevation, TPELEV. Subroutines DAMVOL, STLBAS, EMSPVL, PRNSP and DMCOST are then employed to compute the construction quantities and resultant cost of a dam with the specified height and emergency spillway width.

The initial value of WDEMSP is then divided by 1.2, and the cost calculation is repeated. If the narrower spillway results in a smaller total dam cost, division by 1.2 continues and the calculations are repeated until a higher total dam cost is found. The value of WDEMSP associated with the minimum dam cost is selected as the optimum.

If the narrower spillway tried first increases the total dam cost, WDEMSP is multiplied by 1.44; and the cost calculations are repeated. Multiplying by 1.2 and cost estimation is then repeated until a minimum is found. The value of WDEMSP is then noted and saved.

When reoptimization is required by a new stage or new spillway site, the last optimal value of WDEMSP rather than the read value is used for initialization. After the first stage, only increases in WDEMSP are tried. Special output (3, pp. 183-184) is printed to record widths tried as well as that found optimum. Control returns to DAMSIZ when the analysis is complete.

## SUBROUTINE STLBAS

### PURPOSE

A stilling basin is required at the downstream end of the emergency spillway chute to reduce the outflow velocity to a level which will not cause excessive scour. STLBAS designs and figures quantities for a hydraulic jump basin (20, pp. 299-301), but it does not go into the detail of dimensioning or figuring quantities for chute or baffle blocks. Quantities computed are the volumes of excavation (SBEX) and concrete (SBCONC).

### PROCEDURE

The necessary length of the emergency spillway from its crest to the stilling basin (Figure 6) is determined by interpolating in arrays LGEMSP and ELEVA with the elevation of the top of the dam, TPELEV.

STLBAS next determines by trial and error the stilling basin bottom elevation (BOTTOM) for which the basin flow depth, after the hydraulic jump, is approximately the same as the tailwater depth. BOTTOM is initially assumed as ELEVA(1), the elevation of the valley floor, and then adjusted by trial until the basin depth after the jump is within six inches of the tailwater elevation.

For each trial BOTTOM elevation, the supercritical depth D1 at which flow from the spillway channel enters the basin is computed from the energy equation based on an energy loss equal to one-tenth the increase in velocity head. The conjugate depth D2 in the basin is then computed by the standard equation for a hydraulic jump in a horizontal rectangular channel. If the conjugate energy line elevation is not within six inches of the read tailwater elevation (TWELEV), the basin bottom elevation (BOTTOM) is adjusted by the difference of the basin flow depth and the tailwater depth.

Once the proper basin bottom elevation has been determined, the basin design is completed. The length (SBLNG) is computed as four times the flow depth D2 (20, p. 298). The height of the basin walls (WLHTB) is computed as D2 plus one-tenth the sum of the velocity head of the incoming flow and D2 (20, p. 301).

The quantities estimated in STLBAS extend from the point where the wall height first begins to increase upstream from the stilling basin (Figure 6) to the downstream end of the stilling basin. This includes length CHLNG of the chute which must be calculated based on the difference in wall height and longitudinal chute slope. Wall volumes are computed using RETWAL, and bottom concrete is estimated using a uniform thickness. Earth excavation is calculated by assuming the chute to be below the ground surface at the stilling basin to be at ELEVA(1).

If requested through DMDTLS, certain design dimensions and quantities are printed (3, pp. 174-175). Control is returned to either DAMBLD or SPLSIZ.

SUBROUTINE STR

PURPOSE

For a given subwatershed with specified subwatershed conditions, STR selects the least costly type of channel improvement to accommodate a specified flood discharge (QS) and determines the resulting design dimensions and cost.

PROCEDURE

The types of channel improvements to be considered are specified by the values read into array LINING(MW) (3, pp. 99-101). An integer ranging from 0 to 4 is read for each subwatershed. A value of 4 specifies that only concrete-lined rectangular channels are to be considered; 3 specifies only concrete-lined trapezoidal channels; 2 specifies unlined trapezoidal channels with drop structures; 1 specifies unlined trapezoidal channels without drop structures, and 0 specifies that all four of the above channel types shall be investigated to determine the least expensive.

The first action of STR is to compute the per-acre cost of right-of-way (RC) in the subwatershed if it has not previously been computed for the current stage. The right-of-way cost is computed as the sum of the per-acre value of the land and the average per-acre value of urban structures on the land. The value of structures is reduced when needed to account for the effect of land use adjustment. In the event the subwatershed channels are thus far unimproved, the per-acre urban structure value is reduced by a factor of three because of the ability of the planner to adjust channel alignment to bypass expensive buildings.

Given the specified design discharge QS, BRIDGE is summoned to determine which highway and railroad bridges in the subwatershed are adequate and which bridges must be enlarged or replaced.

If the existing subwatershed channels are concrete-lined rectangular channels; however, any further channel improvements would not increase the bridge span. Therefore, no replacement or enlargement of existing bridges would be necessary. For such subwatersheds, BRIDGE is not summoned.

Execution of STR next branches to special sections of the subroutine if only lined trapezoidal or lined rectangular channels are to be examined. Otherwise, STR first examines unlined channel types. It begins with determination of the channel dimensions necessary to pass the design discharge (QS). Employing the Manning relationship for open channels and beginning with the minimum ratio of channel bottom width to channel depth (BDMIN), the required depth of flow is calculated. If necessary, the ratio of width to depth is increased by increments of 0.5 until the required channel depth becomes less than the maximum allowable depth (HMAX) or until the width to depth ratio exceeds the maximum allowable ratio (BDMAX). These limiting criteria are specified in the input data.

From the calculated depth (H) and the read slope of the subwatershed channel, the expected tractive force on the channel bed is computed and compared to the input value of allowable tractive force for the subwatershed channel (TF). If the computed tractive force exceeds the allowable, drop structures must be employed to reduce the effective slope of the subwatershed channel. STR branches to a design including drop structures. If the tractive force is within the allowable limits, STR computes the bottom width, top width, cross sectional area, and right-of-way width required by a channel which can accommodate the design discharge. From quantities based on the difference between these final dimensions and the original channel dimensions, the cost (CS) of enlarging the channel is computed. If the channel was originally unimproved, the minimum excavation is taken as 20 percent of the cross sectional area.

If the original channel was unimproved and if only unlined channel improvements were to be considered, control returns to CHOPTM. If all channel types were to be considered, the subroutine branches to consider lined channels in case they should prove cheaper.

If the subwatershed channel entered the current stage improved but unlined, STR considers the possibility of lining the original channel as an alternative to enlarging it and leaving it unlined. This alternative is economical where the right-of-way required by channel enlargement is very expensive. It is in part justified by the reduction in flood damages effected by the substantial increase in channel capacity. STR computes the dimensions and then the total increased capacity (QLINED) of the original channel if lined. Next, STR summons CD1 first to compute average annual flooding and uncertainty costs residual to the original unlined channel and again to compute the flooding and uncertainty costs residual to the original channel if lined. To each residual damage is added the corresponding construction cost. The two resulting sums are compared. Whichever alternative has the smaller total cost is adopted for the subwatershed as optimum, and STR returns control to CHOPTM.

The next section is entered when STR finds an unlined channel to be unstable and wishes to increase channel stability by adding drop structures. Channel stability is improved by increasing the ratio of bottom width to depth by multiples of 1.05 and reducing the slope by multiples of 0.95 until a tractive force within the allowable limit is obtained. After obtaining the required reduction in channel slope, the final dimensions of the necessary unlined channel are computed. The total drop in energy line which must be provided at drop structures is then computed. The number of necessary drop structures and the vertical fall at each are determined by a requirement that the fall at any one drop structure not exceed five feet. Then, the cost of constructing new drop structures and channels or enlarging existing drop structures and channels is computed, basing drop structure cost on the U. S. Soil Conservation Service Type "C" drop structure (19).

If only unlined channels with drop structures are to be considered and the original subwatershed channel is unimproved, STR considers the possibility of lining the existing channel rather than enlarging the unlined channel and installing larger drop structures.

The procedure used to examine the use of trapezoidal lined channels is analogous to that for unlined channels. The depth required by the design flow based on BDMIN is computed. If the required depth exceeds HMAX, the width to depth ratio is increased until the required channel depth is less than the maximum allowable depth or until the width to depth ratio exceeds the allowable maximum. However, the Manning rougness used in the Manning relationship is that for a concrete lined rather than unlined channel. The final channel dimensions are then determined and the cost of constructing the trapezoidal lined channel computed. If the cost exceeds that found for an improved unlined section, the improved unlined section is accepted as the optimum improvement.

If the existing subwatershed channel is trapezoidal and lined, STR estimates the cost of enlarging the channel to accommodate the design discharge. The enlargement is accomplished by maintaining the same basic lined section but increasing the top of lining elevation as needed.

In considering rectangular lined channels, the ratio of width to depth is set permanently at BDMIN to minimize right-of-way purchases. The required flow depth is computed directly. The required channel dimensions are determined, and the cost of constructing a lined rectangular channel of those dimensions is computed. Unless LINING is read 4, rectangular lining is rejected in favor of trapezoidal lining if it proves more costly.

When an existing lined rectangular channel must be enlarged in order to accommodate the design discharge, the existing channel is deepened but not widened. Thus, no additional right-of-way need be purchased; and the reconstruction cost is limited to raising the height of the two sidewalls by the required amount.

With the optimum type of channel improvement thus selected and its cost determined, STR returns control to CHOPTM.

## SUBROUTINE STROUT

### PURPOSE

STROUT prints a summary of the optimum state of improvement for a given subwatershed in a given stage. It also prints a summary of right-of-way held for future channel construction.

### PROCEDURE

When the channel enters the stage improved or when improvements are included in the optimum flood damage reduction policy for a given subwatershed in a given stage as developed by Subroutines FPCOST and CHOPTM, FPCOST calls upon STROUT to print summary of channel dimensions (3, pp. 161-163). Also printed is the type of channel and the type of work done on the channel in the current stage.

If right-of-way along the channel can economically be held for possible future channel improvements, a summary of the holding information is also printed (3, pp. 164-166).

These summary tables complete the function of STROUT, and control is therefore returned to FPCOST.

## SUBROUTINE UCFIX

### PURPOSE

UCFIX computes the discounted average annual values of urbanization and channelization in a given subwatershed over the design life of the dam and reservoir being considered. These average values of urbanization and channelization are used in the hydrologic computations employed in sizing the reservoir to be built in the stage when in-stage reservoir benefits first exceed discounted average annual project cost.

### PROCEDURE

The Program considers a reservoir justified when discounted average annual benefits in the current stage exceed the cost. Because of the construction difficulty of enlarging an existing reservoir, it is sized based on discounted average conditions over the design life of the project. UCFIX determines these discounted average annual conditions using the project discount rate (R).

Urbanization is assumed to increase by a uniform annual amount during each stage from the beginning to the end value read into UTOTR and remain constant at the final value thereafter (Figure 10). Using gradient series factor GSF, the average annual value of urbanization during each TIME-year stage is found for TIMST years beyond the stage in which reservoir construction is being considered. With uniform series present worth factor SPWFAC, each of the stage annual averages is discounted to the beginning of that stage. With single payment present worth factor

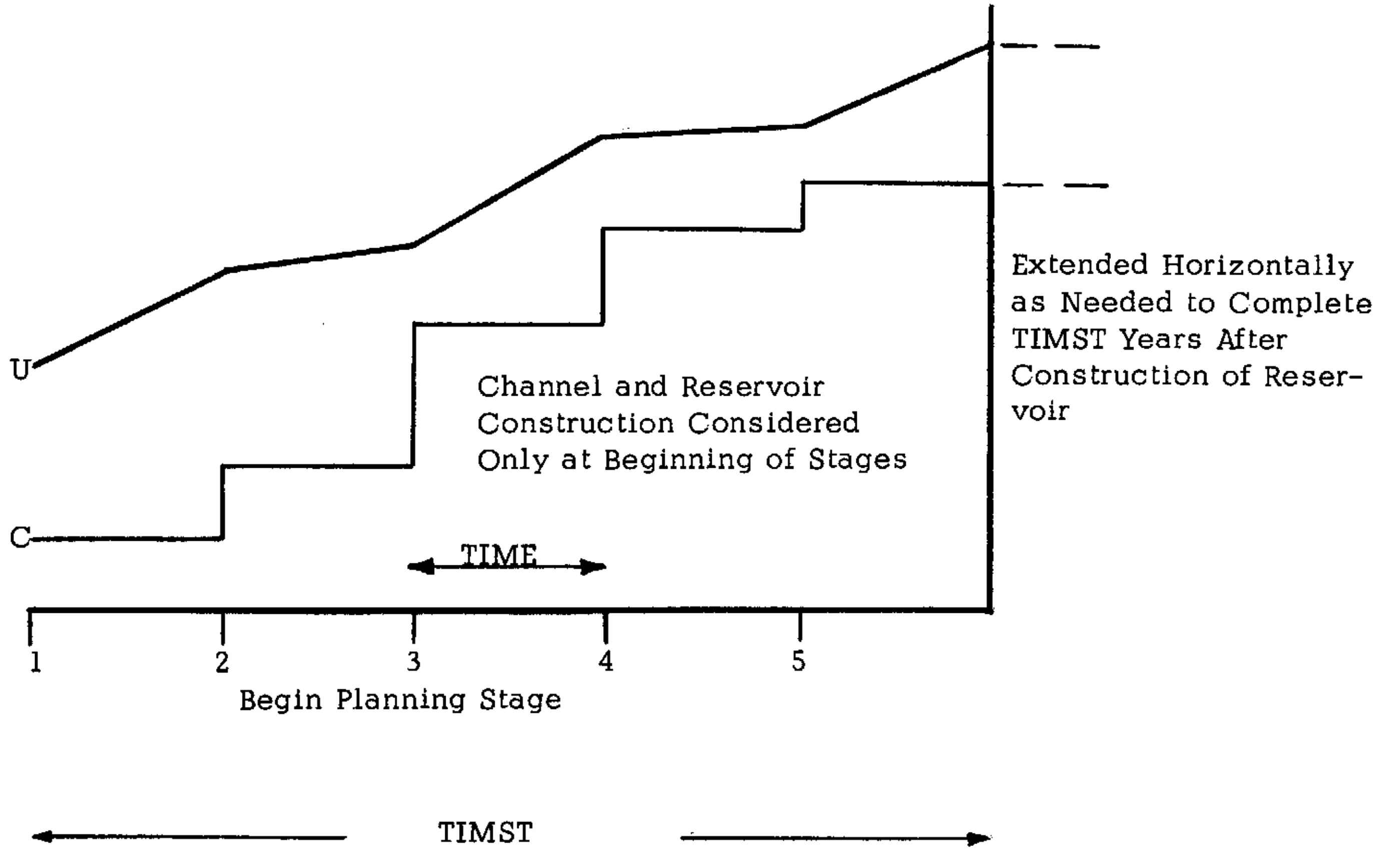



Figure 10. Time Variation of Subwatershed Urbanization and Channelization

PWFR, each of these stage values is discounted to the beginning of the stage in which a reservoir is being considered. Using capital recovery factor CRFSM, this total value of urbanization is spread over the TIMST years of reservoir life. This gives the discounted annual urbanization (UT) taken into RSHYDR to estimate flood peaks and volumes.

The computation of discounted average annual channelization (CT) is analogous. However, channelization is considered to be constant during each stage rather than to increase within the stage as does urbanization. In other words, channel improvement is assumed to only be installed at stage beginnings.

With discounted averages UT (a fraction) and CT (in miles) computed, control is returned to the calling Subroutine, BUILD or CHANYZ.

## Chapter III

## RESULTS OF SOUTH FORK LICKING RIVER STUDY

### DESCRIPTION OF STUDY AREA

Program III was tested for a selected flood-problem area along the South Fork of the Licking River in northeastern Kentucky (Figure 11). The South Fork of the Licking River joins the Licking River at Falmouth, Kentucky, approximately 60 miles above the confluence of the Licking and Ohio Rivers. The study area extends upstream along the South Fork from Falmouth to its origin at the confluence of Stoner and Hinkston Creeks, then upstream along Hinkston Creek to the selected reservoir site 87.4 miles above Falmouth. The dam site was selected by the U. S. Army Corps of Engineers as being the most promising for flood control in the South Fork of the Licking River basin, and no other sites were evaluated in the course of this study.

The study area encompasses portions of Pendleton, Harrison, Bourbon, and Nicholas counties (Figure 12). These are predominately agricultural counties, with the flood plain being used almost exclusively for agricultural purposes. Population centers extending into the flood plain are at Falmouth (1960 pop. 2600) and Morgan (pop. 50) in Pendleton County, Berry (pop. 300) and Cynthiana (pop. 5600) in Harrison County, and Ruddles Mills (pop. 75) and Millersburg (pop. 900) in Bourbon County. These communities are almost entirely supported by agricultural activity in the surrounding areas. All significant urban growth in the study area in the next fifty years is expected

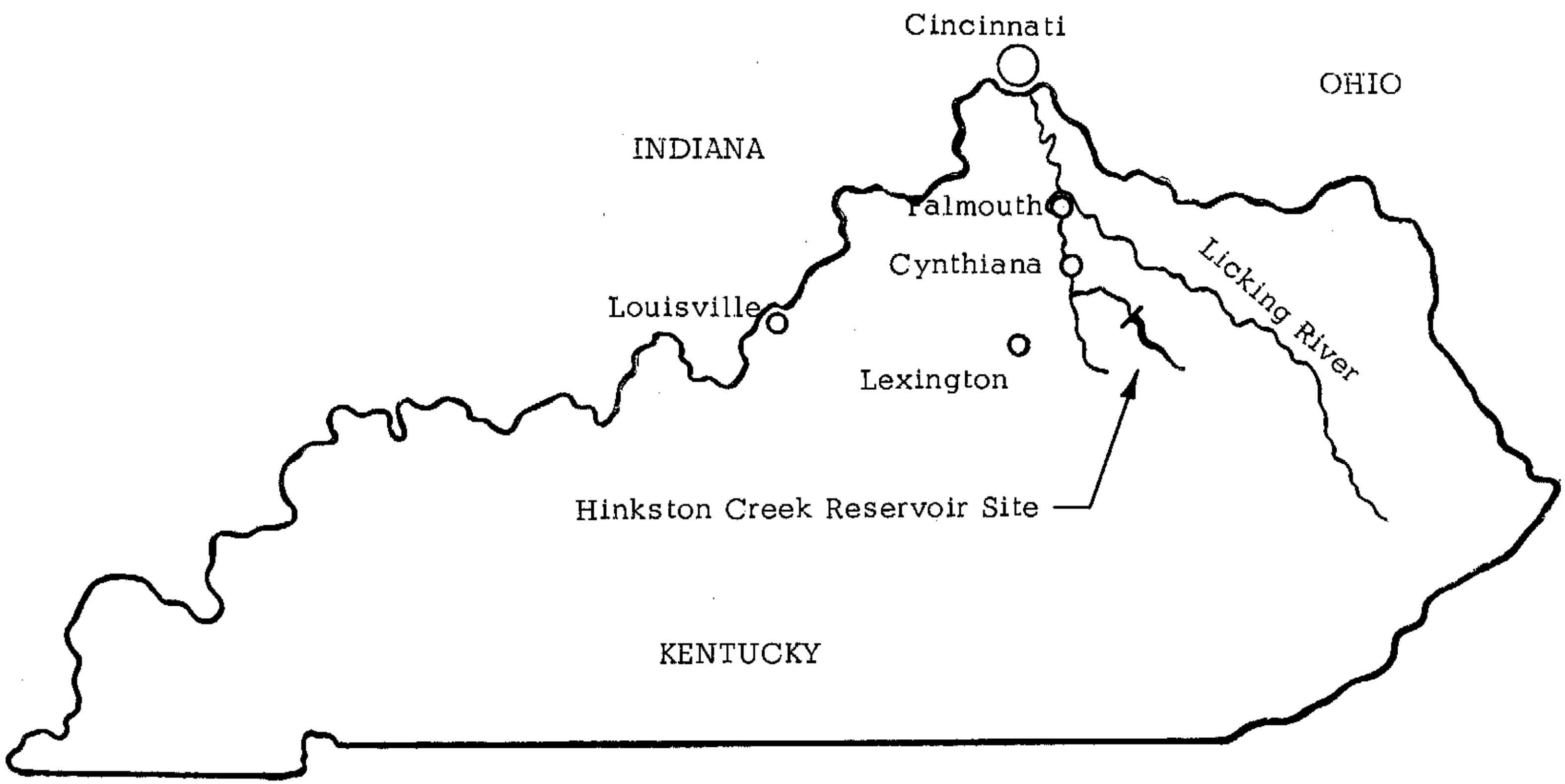



Figure 11. General Location Map

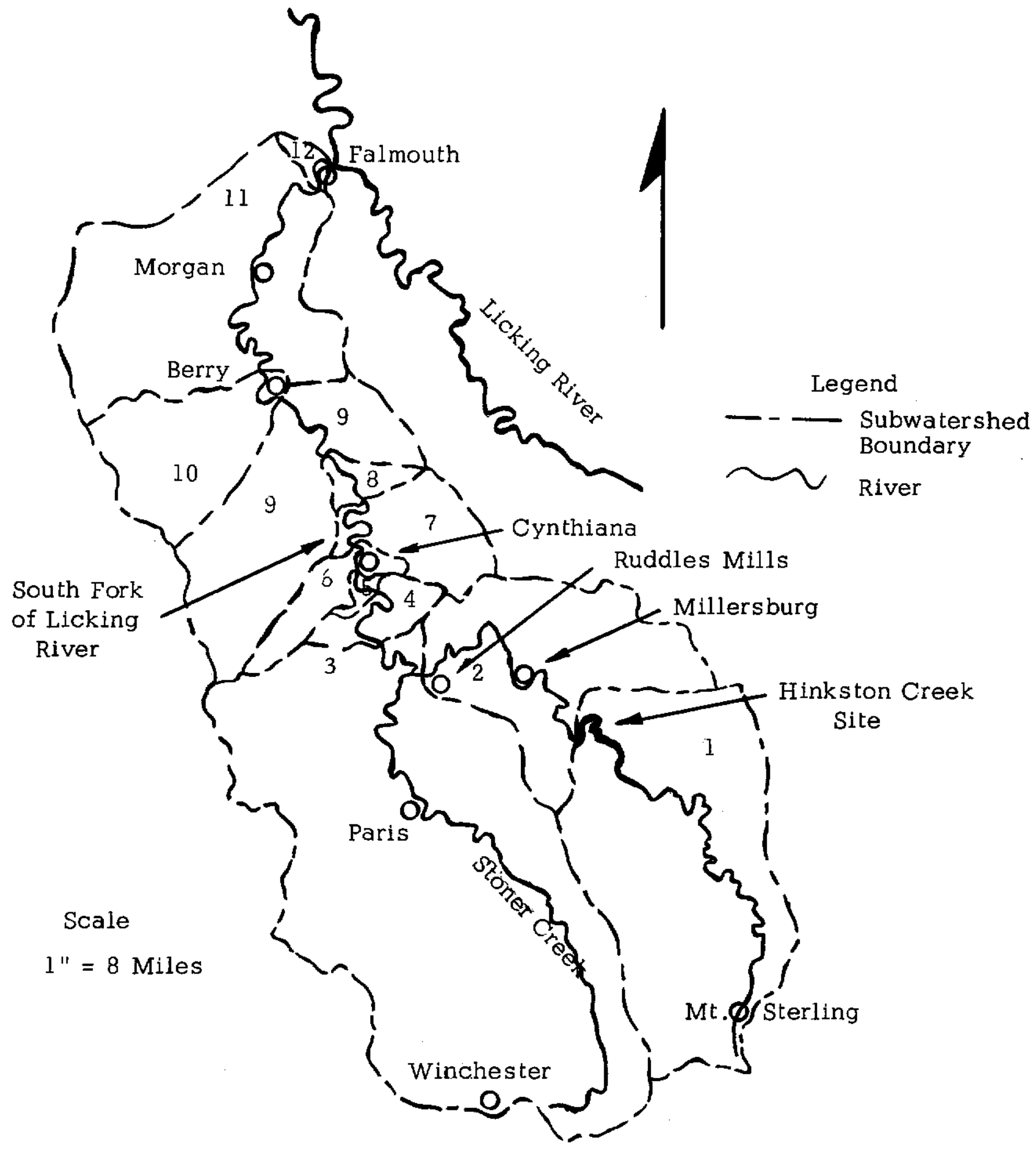



Figure 12. Specific Location Map

to be confined to the immediate vicinities of Falmouth, Cynthiana and Millersburg. The area as a whole was predicted for this study to maintain a relatively constant fraction of the total population and employment of the Ohio River Basin (1, pp. 8, 19-21) and would thus experience a net economic growth of approximately 50 percent in the years from 1970 to 2010.

The terrain of the area may be described as gently rolling to fairly hilly, with the valleys somewhat steeper and narrower above the mouth of Hinkston Creek than below. The South Fork drains 927 square miles at Falmouth, 621 square miles at Cynthiana, and 544 square miles at the confluence of Hinkston and Stoner Creeks. Hinkston Creek drains 260 square miles above Stoner Creek and 174 square miles at the selected dam site.

Flooding in the study area is confined primarily to downstream from the dam site along Hinkston Creek and the South Fork of the Licking River. Thus, the study corresponds to "Main Stream Analysis" or "Case 2" as defined by Cline (3, pp. 39-40), for application of Program III. Although the optimum policy could be determined with only one application of the Program, several runs were made in this study in order to evaluate alternative policies of selecting combinations of measures. Flood damages in the study area are primarily to crops except at Cynthiana and Falmouth, where residences and commercial establishments are periodically inundated. The major flood at Falmouth in 1964 was caused primarily by the Licking River rather than the South Fork. The authorized Falmouth Reservoir on the Licking River would protect Falmouth from further disastrous flooding from the Licking. This study does not evaluate flooding at Falmouth from the Licking River, but only from the South Fork.

## ASSEMBLY OF DATA

The basic collection process used in developing input data for the Program is described by Cline in great detail (3, pp. 56-155). The procedures he describes were followed for the Licking River to develop the data described in Appendix B.

Using the U.S.G.S. 7 1/2-minute topographic maps of the study area, the flood plain downstream from the selected dam site to Falmouth was divided into 11 reaches within each of which the flooding situation is essentially homogeneous throughout the length of the reach (3, pp. 34-35). The configuration of the planning units (subwatersheds) is shown in Figure 12.

Topographic information such as drainage areas, subwatershed channel lengths, and channel slopes was measured from the topographic maps. Most of the necessary dam and reservoir design, crop damage, and unit cost data were provided by the Hydraulics and Project Planning Branches of the U. S. Army Corps of Engineers, Louisville District. Hydrologic data were obtained from the U.S.G.S. streamflow records and the studies on the effects of urbanization and channelization on flood hydrographs completed by Dempsey (4). Land value data were assembled from property tax assessments provided by the offices of the county tax assessors in Pendleton, Harrison, and Bourbon counties. Urbanization and land value projections for the study area were based upon population projections from the Ohio River Comprehensive Survey (1, pp. 8, 19-21) for the Licking-Kentucky-Salt River Basin Area.

## EVALUATION OF EXISTING FLOOD HAZARD

The existing flood hazard in the study area was evaluated by applying Program III with no reservoir, channel improvements, flood proofing, or land-use management considered. Thus, the Program computed the average annual flood damages and uncertainty costs for each subwatershed in each stage. The no-measure flooding cost, along with the mean annual and 200-year flood peaks, are shown by subwatershed for Stage 1 on Table 1. Table 2 represents the no-measure flooding cost for the entire study area for each of the five ten-year planning stages. A combination of flood control measures can be justified if the sum of its cost and residual flood damages is less than the no-measure cost totals. Whether or not the uncertainty costs should be included in the total to be reduced is a policy decision which should be made prior to commencing the analysis.

It will be observed from Table 2 that total flooding cost increases steadily throughout the entire planning period. The major portion of the increase may be attributed to increasingly intensive development of the flood plain at Cynthiana and Falmouth.

## EVALUATION OF FLOOD DETENTION STORAGE

Flood detention storage was first studied alone in order that the increased economic efficiency afforded by considering downstream channel improvements, flood proofing, and land-use management in combination with the reservoir might be more clearly illustrated. Flood storage is not necessarily economically justified just because it produces a reduction in flood damage exceeding its cost. It must also produce a greater net reduction in flood cost than any other combination of measures. This study considered flood detention storage both with and without additional conservation storage.

TABLE 1

STAGE 1 FLOOD PEAKS AND COSTS
WITH NO MEASURES IMPLEMENTED

| Unit | Costs in $/Year | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|
| | Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 1 | - | - | - | 9554[1] | 18731[1] |
| 2 | 39096 | 5516 | 44612 | 8467 | 18022 |
| 3 | 7479 | 2690 | 10169 | 21789 | 44244 |
| 4 | 12035 | 8218 | 20253 | 21869 | 44555 |
| 5 | 3234 | 2247 | 5481 | 21950 | 44763 |
| 6 | 101258 | 25727 | 126985 | 22855 | 46588 |
| 7 | 10546 | 4348 | 14894 | 23149 | 47776 |
| 8 | 11449 | 1069 | 12518 | 23337 | 48251 |
| 9 | 19914 | 5885 | 25799 | 23892 | 49735 |
| 10 | 4522 | 1800 | 6322 | 24359 | 51306 |
| 11 | 61382 | 16681 | 78063 | 26621 | 54829 |
| 12 | 119702 | 102406 | 222108 | 26795 | 54856 |
| Total | 390617 | 176587 | 567204 | - | - |

[1] Inflow to dam site

TABLE 2

STAGE COSTS OF FLOODING FOR STUDY AREA
WITH NO MEASURES IMPLEMENTED

| Stage | Costs in $/Year | | |
|---|---|---|---|
| | Flooding | Uncertainty | Total |
| 1 | 390617 | 176587 | 567204 |
| 2 | 414282 | 190794 | 605076 |
| 3 | 438984 | 205795 | 644779 |
| 4 | 463940 | 221219 | 685159 |
| 5 | 490140 | 237546 | 727686 |

## EVALUATION OF RESERVOIR CONTAINING ONLY FLOOD DETENTION STORAGE

A run of Program III was made with no reservoir conservation storage, downstream channel improvements, flood proofing, or land-use management considered.

Flood detention storage could not be economically justified under these conditions, since the total cost of the reservoir and residual downstream flooding was greater than the no-measure cost of flooding for every stage and every reservoir design flood considered. Only two reservoir design floods, the mean annual and 5-year floods, were considered within the Program in each stage because the Program automatically abandons the reservoir alternative after two consecutive unsuccessful trial designs in any given stage if the second has less net benefit than the first. Although a single-purpose flood control reservoir could not be justified, the results of the trials are summarized on Tables 3 through 6.

Tables 3 and 5 show subwatershed flooding and uncertainty costs and flood peaks in Stage 1 for reservoir designs to control the mean annual and 5-year floods, respectively. Detention storage was found to actually increase flood peaks in the two most downstream subwatersheds due to the effect of reservoir releases after the flood coinciding with peaks from the uncontrolled watershed. Tables 4 and 6 show trial reservoir costs, residual flooding and uncertainty costs and downstream (beyond Falmouth) flood control benefits for each stage for trial reservoir designs to control the mean annual and 5-year floods, respectively. Very little reduction in residual flood damage was achieved by going to more flood storage because the lesser amount was able to delay the Hinkston Creek peak sufficiently to separate it from the uncontrolled peak in most subwatersheds. Comparison of Tables 4 and 6 shows that

TABLE 3

STAGE 1 FLOOD PEAKS AND COSTS
WITH DETENTION STORAGE RESERVOIR
TO CONTROL THE MEAN ANNUAL FLOOD

| | Costs in $/Year | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|
| Unit | Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 1 | - | - | - | 1566[1] | 8826[1] |
| 2 | 32283 | 4496 | 36799 | 7269 | 14172 |
| 3 | 3834 | 2210 | 6044 | 18383 | 36566 |
| 4 | 5307 | 5494 | 10801 | 18949 | 37687 |
| 5 | 1395 | 1486 | 2863 | 19005 | 37775 |
| 6 | 71774 | 23517 | 95291 | 19977 | 39800 |
| 7 | 6365 | 3673 | 10038 | 20460 | 41345 |
| 8 | 10315 | 978 | 11293 | 20673 | 41942 |
| 9 | 14203 | 5672 | 19875 | 21491 | 44082 |
| 10 | 3993 | 1645 | 5638 | 23272 | 47653 |
| 11 | 62664 | 16901 | 79565 | 26909 | 55203 |
| 12 | 127099 | 105256 | 232355 | 27088 | 55623 |
| Total | 339232 | 171310 | 510542 | - | - |

[1] Reservoir outflow

TABLE 4

STAGE COSTS OF FLOODING IN STUDY AREA
WITH DETENTION STORAGE (9282 ACRE-FEET)
RESERVOIR TO CONTROL THE MEAN ANNUAL FLOOD

| | Costs in $/Year | | | | |
|---|---|---|---|---|---|
| Stage | Reservoir | Flooding | Uncertainty | Downstream Benefits | Net |
| 1 | 154037 | 339232 | 171310 | 8226 | 656353 |
| 2 | 165831 | 361148 | 185494 | 9095 | 703378 |
| 3 | 179851 | 384168 | 200499 | 10048 | 754470 |
| 4 | 196857 | 407603 | 215926 | 11110 | 809276 |
| 5 | 218160 | 432289 | 232256 | 12280 | 870425 |

TABLE 5

STAGE 1 FLOOD PEAKS AND COSTS
WITH DETENTION STORAGE RESERVOIR
TO CONTROL 5-YEAR FLOOD

| | Costs in $/Year | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|
| Unit | Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 1 | - | - | - | 1435[1] | 6935[1] |
| 2 | 32205 | 4563 | 36768 | 7275 | 14124 |
| 3 | 3803 | 2191 | 5994 | 18366 | 36237 |
| 4 | 5212 | 5431 | 10643 | 18935 | 37454 |
| 5 | 1379 | 1455 | 2834 | 18993 | 37608 |
| 6 | 71564 | 23395 | 94959 | 19963 | 39573 |
| 7 | 6340 | 3660 | 10000 | 20450 | 41218 |
| 8 | 10314 | 972 | 11286 | 20664 | 41795 |
| 9 | 14166 | 5653 | 19819 | 21481 | 43948 |
| 10 | 3996 | 1647 | 5643 | 23272 | 47606 |
| 11 | 62613 | 16945 | 79558 | 26909 | 55155 |
| 12 | 127441 | 105283 | 232724 | 27088 | 55576 |
| Total | 339033 | 171195 | 510228 | - | - |

[1] Reservoir outflow

TABLE 6

STAGE COSTS OF FLOODING IN STUDY AREA
WITH DETENTION STORAGE (11700 ACRE-FEET)
RESERVOIR TO CONTROL THE 5-YEAR FLOOD

| | Costs in $/Year | | | | |
|---|---|---|---|---|---|
| Stage | Reservoir | Flooding | Uncertainty | Downstream Benefits | Net |
| 1 | 173583 | 339033 | 171195 | 9684 | 674127 |
| 2 | 185532 | 360981 | 185384 | 10706 | 721191 |
| 3 | 200461 | 383999 | 200357 | 11826 | 772991 |
| 4 | 218396 | 407477 | 215800 | 13073 | 828600 |
| 5 | 240853 | 432217 | 232152 | 14448 | 890774 |

the total study area costs are greater in every stage for the 5-year detention storage reservoir than for the mean annual detention storage reservoir. Comparison of Tables 2 and 4 shows that the mean annual flood detention reservoir project yielded study-area costs considerably greater than the costs of no-measure flooding in each stage. Detention storage came nearest to being justified in Stage 1 when it missed by some $89,150/year.

It should be pointed out here that this study made no attempt to quantify secondary or intangible flood control benefits, but it was rather confined to reductions in direct and indirect annual flood damages and uncertainty costs. However, there is no reason why such benefits could not be included if desired. Some such benefits are achieved through the reduction of the secondary and intangible consequences of flooding. These benefits could be incorporated into the analysis by assigning a higher value to the basic unit damage factors. Thus COEFDM could be increased in proportion to the ratio of urban secondary benefits to urban flood damage reductions. The crop damage factors (CDA, CDB, CDC, CDAV, CDBV, and CDCV) could be adjusted in accord with crop secondary benefits. Other secondary benefits are achieved through the expenditure of project construction funds. These benefits could be incorporated into the analysis by modifying the contingency cost multipliers (CSM and CSMD) to convert to adjusted economic rather than financial cost.

## EVALUATION OF DETENTION STORAGE AND CONSERVATION STORAGE COMBINED

It is often desirable to include additional storage for such beneficial purposes as recreation, low flow augmentation, or water supply in reservoirs to be constructed primarily for flood control. If storage for such purposes is economically justified, it must produce benefits at least as great as the additional cost incurred by including the conservation storage in the reservoir.

However, the inclusion of conservation storage in a reservoir causes some reduction in downstream flood peaks by the effect of surcharge storage, and this reduction in flood peaks should not be credited to the flood detention storage. Program III requires that if a given value (XTRSTR) of conservation storage is to be included in a reservoir, a study must be made outside the Program to show that the conservation storage may be assigned benefits at least sufficient to cover the cost of building a reservoir to provide the conservation storage alone. However, Program III could be used to evaluate surcharge storage benefits from such a reservoir. Therefore, Program III first computes the cost of constructing a reservoir to provide the given amount of conservation storage and the cost of residual flooding in the downstream subwatersheds. If flood detention storage is economically justified, then the incremental cost of enlarging the reservoir to include flood detention storage must be less than the reduction in flood damages which the flood detention storage produces.

A run of Program III was made with conservation storage set at 21000 acre-feet, with no downstream channel improvements, flood proofing, or land use management considered. For each stage the Program first computed the cost of constructing a reservoir to provide only the conservation storage and the cost of residual downstream flooding, then tried including flood detention storage to see if the sum of reservoir cost and residual downstream flooding was less than that for the conservation storage reservoir. Table 7 shows the cost by subwatershed in stage 1, and Table 8 shows total cost by stage associated with the conservation

TABLE 7

STAGE 1 FLOOD PEAKS AND COSTS
WITH CONSERVATION STORAGE RESERVOIR

| Unit | Costs in $/Year | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|
| | Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 1 | - | - | - | 3887[1] | 8576[1] |
| 2 | 33847 | 5082 | 38929 | 7047 | 13890 |
| 3 | 3899 | 2257 | 6156 | 18324 | 37405 |
| 4 | 5962 | 6109 | 12071 | 18836 | 38443 |
| 5 | 1660 | 1751 | 3411 | 18855 | 38484 |
| 6 | 74033 | 25088 | 99121 | 19877 | 40558 |
| 7 | 6469 | 3768 | 10237 | 20310 | 41945 |
| 8 | 10544 | 1050 | 11594 | 20560 | 42602 |
| 9 | 14482 | 5860 | 20342 | 21354 | 44601 |
| 10 | 4093 | 1697 | 5790 | 23153 | 47263 |
| 11 | 63150 | 17088 | 80238 | 26786 | 54815 |
| 12 | 144523 | 121301 | 265824 | 26969 | 55238 |
| Total | 362662 | 191051 | 553713 | - | - |

[1] Reservoir outflow

TABLE 8

STAGE COSTS OF CONSERVATION STORAGE
(21000 ACRE-FEET) RESERVOIR AND RESIDUAL FLOODING

| Stage | Costs in $/Year | | | |
|---|---|---|---|---|
| | Reservoir | Flooding | Uncertainty | Total |
| 1 | 197436 | 362662 | 191051 | 751149 |
| 2 | 212912 | 370193 | 195800 | 778985 |
| 3 | 231228 | 384149 | 202597 | 817974 |
| 4 | 252613 | 387415 | 206455 | 846483 |
| 5 | 280134 | 402301 | 213699 | 896134 |

storage reservoir. Tables 9 and 10 show the same types of cost for the reservoir including both 21000 acre-feet of conservation storage and flood detention storage to control the mean annual flood.

In Stages 1 and 2, inclusion of flood detention storage to control the mean annual flood yielded combined reservoir and flooding costs in excess of that for conservation storage alone. However, in Stage 3 the total cost of the multipurpose reservoir and residual flooding fell below that for the conservation storage reservoir. Thus flood detention storage sufficient to control the mean annual flood was economically justified on an incremental basis, and construction of the multipurpose reservoir in Stage 3 could be justified if $231,228 (the annual cost of the conservation storage reservoir) annual benefits could be credited to the conservation storage reservoir. Of this total, $58,033 result from surcharge storage flood benefits.

A flood-control benefit-cost analysis for the combined reservoir project in Stage 3 is shown on Table 11. It should be emphasized that this reservoir is only justified by using projected economic growth as of 1990 and only then after more effective flood damage reduction measures are ignored. Design details for the selected multipurpose reservoir are shown on Table 13, and costs are summarized on Table 12.

In order to confirm the "U" shape of the total cost curve and thus insure that detention storage would not be economically justified at higher levels of protection, a run of Program III was made with the 100-year flood as the minimum reservoir design flood (MRDF = 9). Conservation storage of 21000 acre-feet was included as before. Again, downstream channel improvements, flood proofing, and land-use management were not considered. Tables 14 and 15 summarize the 100-year detention storage reservoir.

TABLE 9

STAGE 1 FLOOD PEAKS AND COSTS
WITH CONSERVATION STORAGE AND
MEAN ANNUAL FLOOD STORAGE RESERVOIR

| | Costs in $/Year | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|
| Unit | Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 1 | - | - | - | 1647[1] | 5612[1] |
| 2 | 33446 | 5113 | 38559 | 6996 | 13828 |
| 3 | 3631 | 2143 | 5774 | 18024 | 36199 |
| 4 | 5158 | 5732 | 10890 | 18587 | 37425 |
| 5 | 1449 | 1651 | 3100 | 18640 | 37589 |
| 6 | 71415 | 24380 | 97795 | 19629 | 39554 |
| 7 | 6215 | 3660 | 9875 | 20119 | 41176 |
| 8 | 10447 | 1026 | 11473 | 20336 | 41740 |
| 9 | 14113 | 5748 | 19861 | 21162 | 43869 |
| 10 | 4076 | 1695 | 5771 | 23112 | 47252 |
| 11 | 62970 | 17080 | 80050 | 26744 | 54799 |
| 12 | 143799 | 121119 | 264918 | 26927 | 55223 |
| Total | 356719 | 189347 | 546066 | - | - |

[1]Reservoir outflow

TABLE 10

STAGE COSTS FOR CONSERVATION STORAGE
(21000 ACRE-FEET) AND MEAN ANNUAL FLOOD
STORAGE (12665 ACRE-FEET) RESERVOIR

| | Costs in $/Year | | | | | |
|---|---|---|---|---|---|---|
| | Reservoir | | | | Downstream | |
| Stage | Total | Flood Control | Flooding | Uncertainty | Benefits | Net |
| 1 | 230500 | 33064 | 356719 | 189347 | 22843 | 753723 |
| 2 | 247273 | 34361 | 364151 | 194151 | 25244 | 780331 |
| 3* | 270410 | 39182 | 371843 | 199156 | 27874 | 813535 |

*Flood detention storage justified in Stage 3

TABLE 11

FLOOD CONTROL BENEFIT-COST SUMMARY
FOR MULTIPURPOSE RESERVOIR

| | |
|---|---|
| COSTS | |
| Multipurpose Reservoir | $270410/year |
| Conservation Reservoir | $231228/year |
| Separable to Flood Control | $ 39182/year |
| BENEFITS | |
| Conservation Reservoir | |
| Flooding and Uncertainty | $586746/year |
| Multipurpose Reservoir | |
| Flooding and Uncertainty | $570999/year |
| Flood Damage Reduction | $ 15747/year |
| Downstream Benefits | $ 27874/year |
| Total Flood Control Benefits | $ 43621/year |

BENEFIT-COST RATIO FOR FLOOD CONTROL

B/C = $43621/$39182 = 1.11

TABLE 12

RESERVOIR COST SUMMARY

| | | | |
|---|---|---|---|
| Dam Embankment | $ 430856 | | |
| Emergency Spillway | $ 464761 | | |
| Stilling Basin | $ 324464 | | |
| Principal Spillway | $ 230536 | | |
| Reservoir Clearing | $ 130793 | | |
| Total Construction | | $1581410 | |
| Engineering and Contingencies | $ 790703 | | |
| Subtotal | | | $2372113 |
| Right of Way (4745 Acres) | $2041564 | | |
| Acquisition | $ 489975 | | |
| Relocation | $1593713 | | |
| Subtotal | | | $4125251 |
| Total Installation Cost | | | $6497364 |
| Annual Capital Recovery | $ 258549 | | |
| Annual Reservoir Maintenance | $ 11861 | | |
| Total Annual Cost | $ 270410 | | |

TABLE 13

DAM DESIGN DETAILS

| | |
|---|---|
| STORAGE | |
| Sediment | 4355 Acre-Feet |
| Conservation | 21000 Acre-Feet |
| Flood | 12665 Acre-Feet |
| Total | 38020 Acre-Feet |
| ELEVATIONS | |
| Principal Spillway | 805.8 Feet |
| Emergency Spillway | 811.6 Feet |
| Safety Flood Crest | 821.5 Feet |
| Top of Dam | 826.5 Feet |
| DISCHARGES | |
| Principal Spillway Design Flow | 1631 CFS |
| Emergency Spillway Design Flow | 22580 CFS |
| DAM CONSTRUCTION QUANTITIES | |
| Volume of Dam | 172580 Cubic Yards |
| Cutoff Trench Volume | 26418 Cubic Yards |
| Riprap Volume | 5725 Cubic Yards |
| STILLING BASIN | |
| Bottom Elevation | 749.83 Feet |
| Supercritical Flow Depth | 1.70 Feet |
| Subcritical Flow Depth | 19.97 Feet |
| Concrete Volume | 7078 Cubic Yards |
| Excavation Volume | 19782 Cubic Yards |
| EMERGENCY SPILLWAY | |
| Total Spillway Excavation | 165252 Cubic Yards |
| Spillway Rock Excavation | 118973 Cubic Yards |
| Spillway Earth Excavation | 46279 Cubic Yards |
| Spillway Concrete Volume | 6054 Cubic Yards |
| Distance from Crest to Basin | 662 Feet |
| Approach Channel Crest Area | 9271 Square Feet |
| Approach Channel Length | 400 Feet |
| Spillway Width | 207 Feet |
| Spillway Crest Area | 6735 Square Feet |
| Spillway Slope | 0.05 Feet/Feet |
| Mean Wall Height | 3.13 Feet |

TABLE 13 - - Continued

| | | |
|---|---|---|
| EMERGENCY SPILLWAY | | |
| Catch Points of Hillside Cut | | |
| | Distance | Elevation |
| Inner | 981.64 | 828.78 |
| Outer | 1292.94 | 853.72 |
| PRINCIPAL SPILLWAY | | |
| Head | | 41 Feet |
| Flowrate | | 1631 CFS |
| Pipe Diameter | | 8.00 Feet |
| Pipe Concrete | | 924 Cubic Yards |
| Impact Dissipator Concrete | | 250 Cubic Yards |
| Trashrack Area | | 874 Square Feet |

Comparison of Table 15 with Table 8 shows the 100-year detention storage program to be more costly than the conservation storage program in every stage.

## EVALUATION OF DOWNSTREAM MEASURES WITHOUT RESERVOIR

In order to determine the best flood-control program excluding reservoir detention storage, three separate runs of the Program were made. One run considered only channel improvements, one considered only flood proofing and land-use management, and one considered channel improvements, flood proofing and land-use management used jointly.

## EVALUATION OF CHANNEL IMPROVEMENT USED ALONE

Tables 16 and 17 summarize the results of the run of Program III with channel improvements as the only flood control measure considered. Construction in Stage 1 of an unlined trapezoidal channel to contain the 10-year flood at Cynthiana and an unlined trapezoidal channel at Falmouth to contain the

TABLE 14

STAGE 1 FLOOD PEAKS AND COSTS
WITH CONSERVATION STORAGE AND
100-YEAR FLOOD STORAGE

| Unit | Costs in $/Year: Flooding | Uncertainty | Total | Flood Peaks in CFS: Mean Annual | 100-Year | 200-Year |
|---|---|---|---|---|---|---|
| 1 | - | - | - | 2256[1] | 3158[1] | 3558[1] |
| 2 | 33127 | 5096 | 38223 | 6953 | 12721 | 13729 |
| 3 | 3629 | 2150 | 5779 | 17973 | 33677 | 36394 |
| 4 | 5158 | 5744 | 10902 | 18517 | 34716 | 37536 |
| 5 | 1441 | 1649 | 3090 | 18557 | 34812 | 37651 |
| 6 | 70765 | 24459 | 95224 | 19558 | 36673 | 39654 |
| 7 | 6147 | 3641 | 9788 | 20032 | 38024 | 41173 |
| 8 | 10403 | 1031 | 11434 | 20246 | 38524 | 41716 |
| 9 | 13986 | 5727 | 19713 | 21078 | 40454 | 43845 |
| 10 | 4078 | 1695 | 5773 | 23119 | 43679 | 47253 |
| 11 | 63007 | 17085 | 80092 | 26752 | 50677 | 54803 |
| 12 | 143980 | 121166 | 265146 | 26937 | 51055 | 55227 |
| Total | 355721 | 189443 | 545164 | - | - | - |

[1] Reservoir outflow

TABLE 15

STAGE COSTS FOR CONSERVATION STORAGE
(21000 ACRE-FEET) AND 100-YEAR FLOOD
STORAGE (21474 ACRE-FEET) RESERVOIR

| Stage | Costs in $/Year: Reservoir | Flooding | Uncertainty | Downstream Benefit | Net |
|---|---|---|---|---|---|
| 1 | 247061 | 355721 | 189443 | 28161 | 764064 |
| 2 | 264443 | 363142 | 194248 | 31120 | 790713 |
| 3 | 288125 | 370846 | 199290 | 34360 | 823901 |
| 4 | 314765 | 378615 | 204467 | 37967 | 859880 |
| 5 | 350258 | 386734 | 209937 | 41940 | 904989 |

TABLE 16

SUMMARY OF CHANNEL IMPROVEMENTS
IN STAGE 1 WHERE CHANNEL IMPROVEMENTS
ARE ONLY MEASURES CONSIDERED

| | Costs in $/Year | | | | | | | Flood Peaks in CFS | |
|---|---|---|---|---|---|---|---|---|---|
| Unit | Frequency Flooding Begins | Channel Design Frequency | Channel Design Capacity | Cost of Channels | Residual Flooding | Uncertainty | Total | Mean Annual | 200-Year |
| 2 | 99.38 | 0.0 | 4000 | 0.0 | 39096 | 5516 | 44612 | 8467 | 18022 |
| 3 | 71.13 | 0.0 | 18000 | 0.0 | 7479 | 2690 | 10169 | 21789 | 44244 |
| 4 | 35.79 | 0.0 | 23000 | 0.0 | 12035 | 8218 | 20253 | 21869 | 44555 |
| 5 | 36.31 | 0.0 | 23000 | 0.0 | 3234 | 2247 | 5481 | 21950 | 44763 |
| 6 | 93.08 | 10.0 | 31384 | 38668 | 7189 | 11125 | 56982 | 22974 | 46711 |
| 7 | 64.52 | 0.0 | 20000 | 0.0 | 10597 | 4354 | 14951 | 23200 | 47768 |
| 8 | 100.00 | 0.0 | 7000 | 0.0 | 11468 | 1067 | 12535 | 23378 | 48248 |
| 9 | 80.94 | 0.0 | 18000 | 0.0 | 19971 | 5877 | 25848 | 23922 | 49684 |
| 10 | 70.29 | 0.0 | 20000 | 0.0 | 4616 | 1768 | 6384 | 24403 | 51280 |
| 11 | 87.95 | 0.0 | 19000 | 0.0 | 62345 | 16765 | 79110 | 26843 | 54687 |
| 12 | 28.92 | 0.5 | 55235 | 23776 | 1843 | 11892 | 37511 | 27158 | 55236 |
| Total | - | - | - | 62444 | 179873 | 71519 | 313836 | - | - |

TABLE 17

STAGE SUMMARY OF COSTS FOR PROGRAM
INVOLVING ONLY CHANNEL IMPROVEMENTS

| Stage | Costs in $/Year | | | |
|---|---|---|---|---|
| | Channels | Flooding | Uncertainty | Total |
| 1 | 62444 | 179873 | 71519 | 313836 |
| 2 | 62444 | 185810 | 74819 | 323073 |
| 3 | 62444 | 192207 | 78295 | 332946 |
| 4 | 62444 | 198732 | 81804 | 342980 |
| 5 | 62444 | 205668 | 85500 | 353612 |

200-year flood, at a combined cost of $62444/year, reduces total project costs considerably below the cost of any other program thus far tried. Annual savings over unrestricted flooding range from some $253,400/year in Stage 1 to some $374,100/year in Stage 5. Comparison of Table 16 with Table 1 shows that channelization in Subwatershed 6 causes slight changes in the flooding pattern in Subwatersheds 7-11.

## EVALUATION OF FLOOD PROOFING AND LAND USE MANAGEMENT

To evaluate the effectiveness of the optimum combined program of downstream flood proofing and land-use management (nonstructural measures), a run of Program III was made with no reservoir and no channel improvement considered. Tables 18 and 19 summarize the costs for this program. Although this nonstructural program does reduce total costs below those for no-measure flooding, it yields a total cost considerably higher than that for channel improvements alone. The higher total cost is caused by the large economic advantage found for channel improvement in Subwatershed

TABLE 18

STAGE 1 SUMMARY OF FLOOD PROOFING
AND LAND-USE MANAGEMENT WHERE ONLY
NONSTRUCTURAL MEASURES ARE CONSIDERED*

| Unit | BEG | QO | L | QL | AL | CL | P | QP | AP | CP | CF | CU | CT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 99.38 | 4000 | 43.0 | 8461 | 532 | 532 | 1.0 | 16613 | 786 | 13146 | 8483 | 3096 | 25257 |
| 3 | 71.13 | 18000 | - | - | - | - | 1.0 | 40932 | 674 | 3037 | 3409 | 1376 | 7822 |
| 4 | 35.79 | 23000 | - | - | - | - | - | - | - | - | 12035 | 8218 | 20253 |
| 5 | 36.31 | 23000 | 20.0 | 26404 | 178 | 178 | 1.0 | 41398 | 335 | 2687 | 1136 | 1104 | 5105 |
| 6 | 93.08 | 15000 | 43.0 | 22840 | 218 | 218 | 0.5 | 46587 | 368 | 43595 | 13438 | 9599 | 66850 |
| 7 | 64.10 | 20000 | - | - | - | - | 2.0 | 40498 | 827 | 4861 | 4464 | 2496 | 11821 |
| 8 | 100.00 | 7000 | - | - | - | - | 0.5 | 48250 | 361 | 3351 | 3578 | 573 | 7502 |
| 9 | 80.66 | 18000 | - | - | - | - | 1.0 | 45923 | 1145 | 8436 | 7357 | 2841 | 18634 |
| 10 | 69.94 | 20000 | - | - | - | - | 2.0 | 43343 | 276 | 2118 | 1694 | 994 | 4806 |
| 11 | 87.02 | 19000 | - | - | - | - | 1.0 | 50327 | 3275 | 24412 | 22336 | 8056 | 54804 |
| 12 | 27.89 | 30000 | 20.0 | 32274 | 388 | 388 | - | - | - | - | 113487 | 97037 | 210912 |
| Totals | - | - | - | - | 1316 | 1316 | - | - | 8047 | 105643 | 191417 | 135390 | 433766 |

*Meaning of headings is defined on Table 20

TABLE 19

STAGE SUMMARY OF COSTS OF FLOOD PROOFING AND LAND USE MANAGEMENT WHEN USED ALONE

| Stage | Costs in $/Year | | | | |
|---|---|---|---|---|---|
| | Proofing | Management | Flooding | Uncertainty | Total |
| 1 | 105643 | 1316 | 191417 | 135390 | 433766 |
| 2 | 106544 | 2054 | 191041 | 134423 | 434062 |
| 3 | 107554 | 7487 | 190646 | 133435 | 439122 |
| 4 | 108561 | 16815 | 190184 | 132395 | 447955 |
| 5 | 114783 | 20897 | 191013 | 132229 | 458922 |

12 (Falmouth). Channel improvement was found to have a much smaller economic advantage in Subwatershed 6 (Cynthiana). The The cost is equal to or less than that with channel improvement throughout the rest of the flood plain.

## EVALUATION OF CHANNEL IMPROVEMENT, FLOOD PROOFING AND LAND USE MANAGEMENT USED IN COMBINATION

To evaluate the effectiveness of combined downstream structural and nonstructural measures, a run of Program III was made with all downstream measures but no reservoir considered. Table 20 summarizes the stage by stage results of this combined program. Stage by stage cost totals are summarized on Table 21. Comparison of Table 21 with all other stage-summary tables shows this to be by far the best program tried. In Stage 1 this program yields total costs which are some $62,900/year less than if the channel improvement program is not supplemented by nonstructural measures and some $316,300/year less than the cost of no-measure flooding.

TABLE 20

SUMMARY OF CHANNEL IMPROVEMENT, FLOOD PROOFING, AND LAND USE MANAGEMENT WHERE ALL DOWNSTREAM MEASURES ARE CONSIDERED. FLOOD RETENTION STORAGE WAS ALSO CONSIDERED BUT COULD NOT BE JUSTIFIED*

| Unit | BEG | QO | S | QS | CS | L | QL | AL | CL | P | QP | AP | CP | CF | CU | CT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STAGE 1 | | | | | | | | | | | | | | | | |
| 2 | 99.38 | 4000 | - | - | - | 43.0 | 8461 | 532 | 532 | 1.0 | 16613 | 786 | 13146 | 8483 | 3096 | 25257 |
| 3 | 71.13 | 18000 | - | - | - | - | - | - | - | 1.0 | 40932 | 674 | 3037 | 3409 | 1376 | 7822 |
| 4 | 35.79 | 23000 | - | - | - | - | - | - | - | - | - | - | - | 12035 | 8218 | 20253 |
| 5 | 36.31 | 23000 | - | - | - | 20.0 | 26404 | 178 | 178 | 1.0 | 41398 | 335 | 2687 | 1136 | 1104 | 5105 |
| 6 | 93.08 | 15000 | 10.0 | 31384 | 38668 | 6.0 | 34063 | 146 | 146 | - | - | - | - | 7081 | 10968 | 56863 |
| 7 | 64.52 | 20000 | - | - | - | - | - | - | - | 2.0 | 40507 | 827 | 4862 | 4480 | 2497 | 11839 |
| 8 | 100.00 | 7000 | - | - | - | - | - | - | - | 0.5 | 48247 | 361 | 3351 | 3583 | 572 | 7506 |
| 9 | 80.94 | 18000 | - | - | - | - | - | - | - | 1.0 | 45884 | 1144 | 8427 | 7374 | 2838 | 18638 |
| 10 | 70.29 | 20000 | - | - | - | - | - | - | - | 2.0 | 43337 | 276 | 2118 | 1754 | 978 | 4850 |
| 11 | 87.95 | 19000 | - | - | - | - | - | - | - | 1.0 | 50580 | 3285 | 24560 | 22607 | 8087 | 55255 |
| 12 | 28.92 | 30000 | 0.5 | 55235 | 23776 | - | - | - | - | - | - | - | - | 1843 | 11892 | 37511 |
| Total | | | | | 62444 | | | 856 | 856 | | | 7688 | 62188 | 73785 | 51626 | 240899 |
| STAGE 2 | | | | | | | | | | | | | | | | |
| 2 | 99.40 | 4000 | - | - | - | 43.0 | 8469 | 532 | 532 | 1.0 | 16617 | 786 | 13174 | 8453 | 3043 | 25202 |
| 3 | 71.21 | 18000 | - | - | - | - | - | - | - | 1.0 | 40937 | 674 | 3037 | 3418 | 1374 | 7830 |
| 4 | 35.85 | 23000 | - | - | - | - | - | - | - | - | - | - | - | 12656 | 8638 | 21294 |
| 5 | 36.37 | 23000 | - | - | - | 20.0 | 26414 | 178 | 178 | 1.0 | 41405 | 335 | 2690 | 1120 | 1036 | 5024 |

*Meaning of headings is defined at end of table.

TABLE 20 -- Continued

| Unit | BEG | QO | S | QS | CS | L | QL | AL | CL | P | QP | AP | CP | CF | CU | CT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STAGE 2 | | | | | | | | | | | | | | | | |
| 6 | 10.03 | 31384 | 10.032 | 31384 | 38668 | 6.0 | 34079 | 146 | 640 | - | - | - | - | 7131 | 11053 | 57492 |
| 7 | 64.66 | 20000 | - | - | - | - | - | - | - | 2.0 | 40522 | 827 | 4946 | 4509 | 2524 | 11979 |
| 8 | 100.00 | 7000 | - | - | - | - | - | - | - | 0.5 | 48259 | 361 | 3425 | 3608 | 583 | 7616 |
| 9 | 81.06 | 18000 | - | - | - | - | - | - | - | 1.0 | 45897 | 1144 | 8614 | 7429 | 2878 | 18921 |
| 10 | 70.42 | 20000 | - | - | - | - | - | - | - | 2.0 | 43351 | 276 | 2201 | 1788 | 1004 | 4994 |
| 11 | 88.06 | 19000 | - | - | - | - | - | - | - | 1.0 | 50598 | 3285 | 24966 | 22735 | 8172 | 55873 |
| 12 | 0.50 | 55235 | 0.502 | 55235 | 23776 | 0.5 | 55255 | 66 | 66 | - | - | - | - | 1990 | 12880 | 38712 |
| Total | | | | | 62444 | | | 922 | 1416 | | | 7688 | 63053 | 74837 | 53185 | 254935 |
| STAGE 3 | | | | | | | | | | | | | | | | |
| 2 | 99.41 | 4000 | - | - | - | 43.0 | 8478 | 533 | 2444 | 1.0 | 16622 | 786 | 13203 | 8422 | 2987 | 27056 |
| 3 | 71.31 | 18000 | - | - | - | - | - | - | - | 1.0 | 40946 | 674 | 3038 | 3427 | 1373 | 7838 |
| 4 | 35.92 | 23000 | - | - | - | - | - | - | - | - | - | - | - | 13337 | 9095 | 22433 |
| 5 | 36.44 | 23000 | - | - | - | 20.0 | 26425 | 178 | 178 | 1.0 | 41413 | 335 | 2693 | 1102 | 964 | 4937 |
| 6 | 10.07 | 31384 | 10.068 | 31384 | 38668 | 10.0 | 31420 | 29 | 363 | - | - | - | - | 7579 | 11738 | 58348 |
| 7 | 64.82 | 20000 | - | - | - | - | - | - | - | 2.0 | 40538 | 827 | 5030 | 4538 | 2552 | 12120 |
| 8 | 100.00 | 7000 | - | - | - | - | - | - | - | 0.5 | 48273 | 361 | 3529 | 3643 | 587 | 7769 |
| 9 | 81.19 | 18000 | - | - | - | - | - | - | - | 1.0 | 45912 | 1145 | 8876 | 7503 | 2934 | 19313 |
| 10 | 70.57 | 20000 | - | - | - | - | - | - | - | 2.0 | 43367 | 276 | 2285 | 1822 | 1030 | 5137 |
| 11 | 88.17 | 19000 | - | - | - | - | - | - | - | 1.0 | 50618 | 3286 | 25373 | 22864 | 8258 | 56494 |
| 12 | 0.50 | 55235 | 0.503 | 55235 | 23776 | 0.5 | 55276 | 86 | 467 | - | - | - | - | 2043 | 13341 | 39627 |
| Total | | | | | 62444 | | | 826 | 3452 | | | 7690 | 64027 | 76280 | 54869 | 261072 |

TABLE 20 -- Continued

| Unit | BEG | QO | S | QS | CS | L | QL | AL | CL | P | QP | AP | CP | CF | CU | CT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STAGE 4 | | | | | | | | | | | | | | | | |
| 2 | 99.43 | 4000 | - | - | - | 43.0 | 8487 | 533 | 5556 | 1.0 | 16627 | 786 | 13233 | 8390 | 2929 | 30108 |
| 3 | 71.41 | 18000 | - | - | - | - | - | - | - | 1.0 | 40954 | 674 | 3039 | 3437 | 1371 | 7847 |
| 4 | 35.99 | 23000 | - | - | - | - | - | - | - | - | - | - | - | 14023 | 9554 | 23577 |
| 5 | 36.52 | 23000 | - | - | - | 20.0 | 26437 | 178 | 178 | 1.0 | 41421 | 335 | 2696 | 1083 | 888 | 4846 |
| 6 | 10.10 | 31384 | 10.105 | 31384 | 38668 | - | - | - | - | - | - | - | - | 7984 | 12299 | 58951 |
| 7 | 64.98 | 20000 | - | - | - | - | - | - | - | 2.0 | 40555 | 828 | 5114 | 4568 | 2579 | 12261 |
| 8 | 100.00 | 7000 | - | - | - | - | - | - | - | 0.5 | 48288 | 361 | 3633 | 3677 | 612 | 7922 |
| 9 | 81.33 | 18000 | - | - | - | - | - | - | - | 1.0 | 45927 | 1145 | 9139 | 7577 | 2991 | 19707 |
| 10 | 70.72 | 20000 | - | - | - | - | - | - | - | 1.0 | 47358 | 293 | 2665 | 1736 | 880 | 5281 |
| 11 | 88.28 | 19000 | - | - | - | - | - | - | - | 1.0 | 50638 | 3287 | 25780 | 22994 | 8343 | 57118 |
| 12 | 0.51 | 55235 | 0.505 | 55235 | 23776 | 0.5 | 55298 | 101 | 1571 | - | - | - | - | 2084 | 13742 | 41173 |
| Total | | | | | 62444 | | | 812 | 7305 | | | 7709 | 65299 | 77553 | 56188 | 268789 |
| STAGE 5 | | | | | | | | | | | | | | | | |
| 2 | 99.45 | 4000 | - | - | - | - | - | - | - | 1.0 | 16632 | 786 | 18120 | 10192 | 4223 | 32535 |
| 3 | 71.51 | 18000 | - | - | - | - | - | - | - | 1.0 | 40962 | 674 | 3040 | 3446 | 1370 | 7856 |
| 4 | 36.06 | 23000 | - | - | - | 20.0 | 26341 | 580 | 612 | - | - | - | - | 14378 | 9770 | 24761 |
| 5 | 36.60 | 23000 | - | - | - | 15.0 | 27981 | 205 | 1517 | 1.0 | 41430 | 335 | 2712 | 1066 | 835 | 6130 |
| 6 | 10.14 | 31384 | 10.144 | 31384 | 38668 | - | - | - | - | - | - | - | - | 8188 | 12592 | 59448 |
| 7 | 65.16 | 20000 | - | - | - | - | - | - | - | 2.0 | 40572 | 828 | 5232 | 4608 | 2619 | 12459 |
| 8 | 100.00 | 7000 | - | - | - | - | - | - | - | 0.5 | 48303 | 361 | 3737 | 3712 | 627 | 8076 |
| 9 | 81.48 | 18000 | - | - | - | - | - | - | - | 1.0 | 45944 | 1145 | 9402 | 7653 | 3048 | 20102 |
| 10 | 70.88 | 20000 | - | - | - | - | - | - | - | 1.0 | 47374 | 293 | 2759 | 1765 | 900 | 5424 |
| 11 | 88.40 | 19000 | - | - | - | - | - | - | - | 1.0 | 50659 | 3288 | 26189 | 23127 | 8429 | 57745 |

TABLE 20 -- Continued

| Unit | BEG | QO | S | QS | CS | L | QL | AL | CL | P | QP | AP | CP | CF | CU | CT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STAGE 5 | | | | | | | | | | | | | | | | |
| 12 | 0.51 | 55235 | 0.507 | 55235 | 23776 | 0.5 | 55321 | 114 | 3185 | - | - | - | - | 2116 | 14110 | 43187 |
| Totals | | | | | 62444 | | | 899 | 5314 | | | 7710 | 71191 | 80251 | 58523 | 277723 |

Definition of Headings

BEG: Frequency of incipient flooding in percent.
QO: Existing channel capacity in cfs.
S: Channel improvement design frequency in cfs.
QS: Channel improvement design flow in cfs.
CS: Annual cost of channel improvement in dollars.
L: Land-use adjustment design flood frequency in percent.
QL: Land-use adjustment design flood peak in cfs.
AL: Area of restricted land use in acres.
CL: Annual cost of land-use adjustment in dollars.
P: Flood proofing design flood frequency in percent.
QP: Flood proofing design flood peak in cfs.
AP: Area in which buildings are flood proofed in acres.
CP: Annual cost of flood proofing in dollars.
CF: Annual residual flood damage in dollars.
CU: Annual residual uncertainty cost in dollars.
CT: Total (CS + CL + CP + CF + CU) annual cost in dollars.

TABLE 21

STAGE SUMMARY FOR DOWNSTREAM MEASURES

| Stage | Costs in $/Year | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Channels | Proofing | Management | Flooding | Uncertainty | Total |
| 1 | 62444 | 62188 | 856 | 73785 | 51626 | 250899 |
| 2 | 62444 | 63053 | 1416 | 74837 | 53185 | 254935 |
| 3 | 62444 | 64027 | 3452 | 76280 | 54869 | 261072 |
| 4 | 62444 | 65299 | 7305 | 77553 | 56188 | 268789 |
| 5 | 62444 | 71191 | 5314 | 80251 | 58523 | 277723 |

## EVALUATION OF DETENTION STORAGE, CHANNEL IMPROVEMENT, FLOOD PROOFING AND LAND USE MANAGEMENT COMBINED

A final run of Program III was made to test the effectiveness of all measures used in combination. The Program first computed the cost of a 21000 acre-foot conservation storage reservoir, then selected the optimum combination of channels, flood proofing and land use management for the residual downstream flooding. The optimum downstream program selected was the same as the downstream program selected when reservoir storage was not considered, except for the relatively small reduction in flood damages caused by the effects of surcharge storage. When flood detention storage was added, it could not be justified by an effected further reduction in flood damages. Thus, reservoir detention storage could not be economically justified at the Hinkston Creek damsite.

## THE OPTIMUM FLOOD CONTROL PROGRAM FOR THE STUDY AREA

The optimum (least cost) flood control policy for the South Fork Licking River study area is that dynamic program shown on Table 20. The program consists of channel improvements at Cynthiana and Falmouth (units 6 and 12) and various combinations of flood proofing and land-use management throughout the 11 subwatersheds downstream of the considered Hinkston Creek reservoir site. Table 22 shows design criteria for the channels found optimum at Cynthiana and Falmouth.

It must be emphasized that this "optimum" policy should not be adopted for application in the study area without first making field checks to refine the input data beyond the level of accuracy used for this study. In particular, the channel cross-sections should be carefully determined by actual field measurements, the depth-area flooded relationship should be more precisely determined, actual soil testing should be done to accurately determine the subwatershed channel tractive forces, and a more exhaustive study of crop income patterns for the area should be made. These data were assembled for this study in a much less rigorous manner than should be employed in a practical application of the Program. The Program can be rerun with refined input data as it is obtained to determine the effects of the changes.

TABLE 22

DESIGN DETAILS OF CHANNEL IMPROVEMENTS IN OPTIMUM PROGRAM FOR UNITS 6 AND 12

| | Unit 6 (Cynthiana) | Unit 12 (Falmouth) |
|---|---|---|
| Channel Type | Trapezoidal, Unlined | Trapezoidal, Unlined |
| Cross-Sectional Area* | 5814 Square Feet | 4321 Square Feet |
| Top Width | 272 Feet | 211 Feet |
| R/W Width | 317 Feet | 256 Feet |
| Depth | 24.7 Feet | 24.8 Feet |
| Capacity | 31384 cfs | 55235 cfs |
| Design Frequency | 10-Year | 200-Year |
| Cost | $38668/Year | $23776/Year |
| When Built | Stage 1 | Stage 1 |
| When Enlarged | Never | Never |

*Section is larger at Cynthiana because of flatter hydraulic slope.

## Chapter IV

## CONCLUSION

This report has endeavored to describe the nature and basic logic of a digital computer program developed as part of this study and called the University of Kentucky Flood Control Planning Program III and to present a sample study illustrating the Program's application to find the economic course of action in response to an existing flood problem. For a given reach of flood plain divided into planning units and a selected reservoir site, Program III selects the economically efficient (least-cost) combination of structural and nonstructural measures and residual flooding. The aim of Program III is not to prepare the final design of specific measures; it is rather to help isolate those combinations of measures which show the greatest promise of economic efficiency and should be investigated in greater detail through the collection of more exhaustive field data.

In order to evaluate changes with time in flood hazard and flood plain conditions, the analysis may be based on up to five planning stages of specified duration. The multi-stage approach is predicated on the corollary of the economic efficiency criterion that flood control measures are best installed when first justified by currently expected flood damages. Projections extended over a shorter period of time allow periodic updating of planning data to reflect actual changes in the flood plain and tributary watershed. A right-of-way holding option is available to allow early purchase so delays in construction will not result in excessive cost at a later date. This stage-planning approach helps to eliminate the inherent inefficiency in project designs based on uncertain long-range projections and the economic waste of committing excessive capital before realizing commensurate benefits.

The greatest advantage of preliminary flood control planning by digital computer lies in the opportunity afforded the planner for examining in a very short time many more alternative combinations of measures than can be considered by conventional analysis. Program III currently analyzes up to ten alternative levels of protection by reservoir detention storage, channel improvement, flood proofing and land-use management. Several thousand combinations are therefore compared in selecting the optimum.

A complete analysis of the South Fork, Licking River, flood plain in conjunction with the potential Hinkston Creek damsite was made with a single run of Program III in only 45 minutes of IBM 360/50 computer time, representing a cost of approximately $250. Since the input data required by the Program is essentially the same as that required for conventional analysis, the cost of the computer analysis consists of computer time cost plus the cost of the time required to assemble data into a form usable by the computer. The total of several hundred dollars compares with many thousand dollars using conventional methods.

For the South Fork, Licking River, study the Program quickly showed that reservoir detention storage at the Hinkston Creek site is not economically feasible unless benefits from conservation storage justify the major portion of the cost of the project. It further showed that the key structural measures in an efficient program were channel improvements at Cynthiana and Falmouth, and that these improvements should be currently supplemented by flood proofing in units 2,3,5,7,8,9,10, and 11 and land use management in units 2,4,5,6, and 12 (Figure 12).

Procedures for measure design and benefit-cost analysis are well established for structural measures but much less so for nonstructural measures. As techniques for nonstructural measure design and evaluation are refined, they can be incorporated into Program III without changing its basic structure. Continued refinement of the preliminary design procedures used by the Program for structural measures can make the Program increasingly more useful in planning.

It must be emphasized that Program III represents only a starting point in flood control planning by digital computer and makes no pretense of being the last word. Review of the Program by public agencies and all others involved in flood control planning is strongly encouraged, and all suggestions will be genuinely appreciated.

## APPENDIX A

### UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III

```
C    CENTRAL CONTROL DECK
C   UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C   PROGRAM DETERMINES THE OPTIMUM COMBINATION OF STRUCTURAL ( RESERVOIR
C   STORAGE AND CHANNEL IMPROVEMENTS ) AND NONSTRUCTURAL ( FLOOD PROOFING
C   AND LAND USE MANAGEMENT ) MEASURES FOR FLOOD CONTROL.
C VERSION OF JANUARY 8, 1968
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),QO(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),TO(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 WO(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      DIMENSION DQCK(16)
      LOGICAL CH8,CH9,CHANEL,HOLDNG,KNBOT,LL,LOOPTR,LTF,PP,PTF,RSBLT,
     1RTEST,SS,STF,WFIX
```

```
      REAL LC
C   READS INPUT DATA
      CALL RDDATA
C   INITIALIZE FOR NO RESERVOIR AT BEGINNING.
      RSBLT = .FALSE.
      KNBOT = .FALSE.
      COSTOM = 0.0
      DO 30 I = 1, 5
   30 WFIX(I) = .FALSE.
C   INITIALIZE LOOP CONTROL FOR FLOOD DAMAGE ANALYSIS.
      ITOP=16
      FTOP=9.210
C   INITIALIZE KDF FOR DETERMINING IN FPCOST THE FREQUENCY AT WHICH
C   FLOODING BEGINS WITH NO RESERVOIR
      KDF = 1
C   DETERMINES WHICH TYPES OF MEASURES TO BE CONSIDERED
      PP=PTF
      LL=LTF
      SS=STF
C   INITIALIZE SUBWATERSHED CONDITIONS.
      DO 107 I=2,MW
      LOC(I)=-1
      ADDCS(I)=0.
      IHOLD(I)=0
      WO(I)=0.0
      TO(I)=0.0
      NDT(I)=0
      FDA(I)=0.0
      DO 107 J=9,11
  107 CAP(I,J)=0.
C   PROBABILITY OF OCCURRENCE OF 16 FLOODS SPECIFIED FOR USE IN COMPUTING
C     ANNUAL DAMAGES
   99 DQCK(1)=0.0005
      DQCK(2)=0.003
      DQCK(3)=0.0075
      DQCK(4)=0.015
      DQCK(5)=0.025
      DQCK(6)=0.035
      DQCK(7)=0.05
      DQCK(8)=0.07
      DQCK(9)=0.09
      DQCK(10)=0.125
      DQCK(11)=0.175
      DQCK(12)=0.25
      DQCK(13)=0.35
      DQCK(14)=0.5
      DQCK(15)=0.7
      DQCK(16)=0.9
C   GUMBEL FACTORS - 16 SPECIFIED FLOODS
      DO 97 I=1,16
      PN=1.0-(DQCK(I))
      TEMP=1.0/ALOG(1.0/PN)
```

```
   97 Y(I)=ALOG(TEMP)
C  GUMBEL FACTORS - POTENTIAL DESIGN FLOODS
   98 DO 109 I=1,NDF
      PN=1.00-(DF(I))
      TEMP=1./ALOG(1./PN)
  109 YY(I)=ALOG(TEMP)
C  DETERMINING WHICH CHANNELS WERE IMPROVED PRIOR TO START OF ANALYSIS
      DO 111 NW=1,MW
      IF(SIC(NW) .GE. LC(NW))  GO TO 110
      CHANEL(NW)=.FALSE.
      GO TO 111
  110 CHANEL(NW)=.TRUE.
C  FIX THE DIMENSIONS OF CHANNELS WHICH WERE IMPROVED PRIOR TO THE START
C        OF THE PLANNING PERIOD FOR THE PURPOSE OF ESTIMATING THE COST
C        OF CHANNEL ENLARGEMENT.  EVEN IF THE CRITERIA USED IN BUILDING
C        THE EXISTING CHANNEL DO NOT CONFORM TO THOSE USED IN THIS
C        PROGRAM, THIS SUBROUTINE CAUSES ALL COSTS TO BE BASED ON THE
C        SAME DESIGN CRITERIA.
      CALL CHFIX(AO,BDMAX,BDMIN,HMAX,LINING,LOOPTR,MANNR,MANNT,MANNU,
     1NW,QO,S,TO,WO,ZT,ZU)
  111 CONTINUE
C  CALCULATE LOCATION COST IN EACH SUBWATERSHED-STAGE UNLESS IT
C  IS NOT NEEDED.
      IF (.NOT. LTF .OR. HOLDNG)  CALL CALCLU(CHECK,CLEN,CLOC,CRF,FIF,
     1FRU,GSF,IPP,LOOPTR,MW,NSTEMX,PWF,SPWF,TIME,USUBW,VALUE)
C  INITIALIZE SUBWATERSHED CHANNEL PROPERTIES.
      DO 1000 NW=2,MW
      A9(NW)=AO(NW)
      A8(NW)=AO(NW)
      DO 1001 K = 1,11
      CA9(NW,K)=CAP(NW,K)
 1001 CA8(NW,K)=CAP(NW,K)
      CH9(NW)=CHANEL(NW)
      CH8(NW)=CHANEL(NW)
      FD9(NW)=0.0
      FD8(NW)=0.0
      LN9(NW)=LINING(NW)
      LN8(NW)=LINING(NW)
      IHLD9(NW)=0
      IHLD8(NW)=0
      LC9(NW)=-1
      LC8(NW)=-1
      ADDC9(NW)=0.0
      ADDC8(NW)=0.0
      ND9(NW)=0
      ND8(NW)=0
      Q8(NW)=QO(NW)
      Q9(NW)=QO(NW)
      T9(NW)=TO(NW)
      T8(NW)=TO(NW)
      W9(NW)=WO(NW)
      W8(NW)=WO(NW)
```

```
      WT9(NW)=0.0
      WT8(NW)=0.0
 1000 WT(NW)=0.0
C  LOOP FOR STAGE BY STAGE ANALYSIS.
      DO 100 NSTAGE=1,NSTEMX
C  SUBWATERSHED CHANNEL PROPERTIES ALREADY INITIALIZED FOR FIRST STAGE
      IF(NSTAGE .EQ. 1) GO TO 102
C  SET SUBWATERSHED CHANNEL PROPERTIES AT OPTIMUM FOUND IN ANALYSIS OF
C  PREVIOUS STAGE.
      DO 101 NW=2,MW
      AO(NW)=A8(NW)
      DO 103 J=1,11
  103 CAP(NW,J)=CA8(NW,J)
      CHANEL(NW)=CH8(NW)
      FDA(NW)=FD8(NW)
      LINING(NW)=LN8(NW)
      IHOLD(NW) = IHLD8(NW)
      LOC(NW)=LC8(NW)
      ADDCS(NW)=ADDC8(NW)
      NDT(NW)=ND8(NW)
      QO(NW)=Q8(NW)
      IF(CHANEL(NW)) SIC(NW) = LC(NW)
      TO(NW)=T8(NW)
      WO(NW)=W8(NW)
  101 WT(NW)=WT8(NW)
  102 WRITE(6,150) NSTAGE
  150 FORMAT(1H1, 5X,31HBEGINNING THE ANALYSIS OF STAGE,I2)
C  ENTER ANALYSIS FOR OPTIMUM COMBINATION OF FLOOD-CONTROL STORAGE AND
C     SUBWATERSHED MEASURES WITHIN STAGE.
      CALL BUILD
  100 CONTINUE
      STOP
      END


      SUBROUTINE BRIDGE(CAP,CHANEL,HE,HN,LC,LOOPTR,NSTAGE,NW,Q,RE,RN,
     1USUBW)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C          VERSION OF NOVEMBER  1, 1966
C  DETERMINES NUMBER OF BRIDGES TO BE ENLARGED OR REPLACED.  EXISTING
C        BRIDGES WHICH BECOME TOO SMALL ARE REPLACED.  BRIDGES BUILT IN
C        PROGRAM ARE ENLARGED.  HIGHWAY BRIDGES BUILT TO SERVE NEW URBAN
C        DEVELOPMENT ARE ENLARGED AS NECESSARY, BUT INITIAL CONSTRUCTION
C        COST IS NOT CHARGED TO FLOOD CONTROL.
C  Q IS THE CURRENT REQUIRED CHANNEL CAPACITY
      DIMENSION CAP(15,11),CHANEL(15),LC(15),USUBW(15,6)
      REAL LC
      LOGICAL CHANEL,LOOPTR
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE BRIDGE ENTERED)
C  FORGET OLD VALUES
```

```
      HA=0.
      RE = 0.
      HE =0.
      RN = 0.
      HN = 0.
C  COUNT ADEQUATE (HA) AND INADEQUATE (HN) HIGHWAY BRIDGES.  INADEQUATE
C  HIGHWAY BRIDGES ARE TO BE REPLACED.
      DO 1 J=1,6
      IF(CAP(NW,J) .LT. 0.)  GO TO 2
      IF(CAP(NW,J) .GE. Q)  GO TO 10
      HN = HN+1.
      GO TO 1
   10 HA=HA+1.
    1 CONTINUE
C  COUNT RAILWAY BRIDGES NEEDING REPLACEMENT (RN)
    2 DO 3 J=7,8
      IF(CAP(NW,J) .LT. 0.)  GO TO 4
      IF(CAP(NW,J) .GE. Q)  GO TO 3
      RN = RN+1.
    3 CONTINUE
C  NUMBER OF BRIDGES BUILT IN PROGRAM TO BE EXTENDED
    4 IF(CAP(NW,11) .GT.0. .AND. CAP(NW,11) .LT. Q)  GO TO 5
      GO TO 6
    5 HE = CAP(NW,9)
      RE = CAP(NW,10)
    6 IF(NSTAGE .EQ. 1) GO TO 1312
C  ESTIMATE NUMBER OF HIGHWAY CROSSINGS WHICH WILL BE BUILT FOR FUTURE
C          URBANIZATION BUT BEFORE THE BEGINNING OF THE STAGE UNDER
C          ANALYSIS
      IF(USUBW(NW,NSTAGE) .LT. .25) GO TO 1312
      IF(USUBW(NW,NSTAGE) .LT. .50)  GO TO 7
      NBR = LC(NW)*3.0 + 0.5
      GO TO 8
    7 NBR = LC(NW)*2.0 + 0.5
    8 BRN = NBR
      IF(.NOT. CHANEL(NW))  GO TO 9
      IF (BRN .GT. HN+HE+HA) HE=BRN-(HN+HA)
      GO TO 1312
    9 IF (BRN .GT. HN+HE+HA) HN=BRN-(HE+HA)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE BRIDGE LEFT)
      RETURN
      END


      SUBROUTINE BUILD
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 12, 1968
C    FOR  1. A GIVEN STAGE
C         2. A FLOOD PLAIN DIVIDED INTO MW-1 SUBWATERSHEDS
C         3. A GIVEN RESERVOIR SITE
```

```
C  THE ECONOMICALLY OPTIMUM SIZE OF FLOOD RETENTION RESERVOIR IS
C  DETERMINED AND SPECIFIED BY DESIGN FLOOD FREQUENCY.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),TO(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      LOGICAL BLDNOW,CH8,CH9,CHANEL,HYDTLS,LOOPTR,NODAM,NOXTR,RBIG,
     1RESIN,RONE,RSBLT,RSFLD,RTEST,STF
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,24HSUBROUTINE BUILD ENTERED)
C  RESERVOIR MUST BE JUSTIFIED BY FLOOD THREAD WITHIN STAGE BEFORE BEING
C        SIZED FOR AVERAGE FLOOD THREAT OVER PROJECT LIFE.  CHANGING
C        VALUES OF "U" AND "C" CAUSE THE FLOOD THREAT TO CHANGE WITH
C        TIME.
      RBIG = .FALSE.
C  INITIALIZE COST IN FLOOD PLAIN.
      COSTFP = 0.0
C  ABBREVIATED INITIALIZATION WHERE RESERVOIR CONSTRUCTION IS NOT TO BE
C    CONSIDERED.
      IF (.NOT. NODAM) GO TO 497
      BNFDST = 0.0
      KDF = 0
      GO TO 499
C  FIRST ANALYZE WITHOUT NEW RESERVOIR (MAY HAVE BEEN CONSTRUCTED IN A
C  PREVIOUS STAGE).
```

```
  497 RTEST = .FALSE.
C  UNDER "BLDNOW", BOTH OPTIONS INCLUDE NON-FLOOD-CONTROL STORAGE UNTIL
C        FLOOD STORAGE IS PROVED INFEASIBLE IN CURRENT STAGE.  FLOOD
C        STORAGE MUST BE JUSTIFIED BY FLOOD DAMAGE REDUCTION IN ADDITION
C        TO THAT ACHIEVED BY NON-FLOOD-CONTROL STORAGE.
      NOXTR = .FALSE.
C  SIZE RESERVOIR FOR AVERAGE FLOOD THREAT OVER PROJECT LIFE IF REQUIRED
C  TO BUILD IN FIRST STAGE TO ACHIEVE OTHER PROJECT PURPOSES.
      IF(XTRSTR .GT. 0.0 .AND. .NOT. RSBLT .AND. BLDNOW) RBIG = .TRUE.
C  SET OR RESTORE INITIAL CONDITIONS FOR RESERVOIR NOT YET BUILT.
      IF(RSBLT) GO TO 499
C  NOT YET ANALYZING CURRENT OR SUBSEQUENT STAGE AFTER INSTALLING
C  RESERVOIR BUILT FOR PROJECT LIFE.
      RONE = .FALSE.
C  NO FLOOD STORAGE IN RESERVOIR.
      RSFLD = .FALSE.
C  NO RESERVOIR FLOOD DESIGN FREQUENCY.
      KDF = 0
      KDFG = 0
      ISTAGE = 0
C  POINT OF RETURN FOR STAGE ANALYSIS OR FOR SIZING JUSTIFIED RESERVOIR.
C  DEVELOP HYDROGRAPHS FOR AREA TRIBUTARY TO RESERVOIR SITE.
  499 RESIN = .TRUE.
      NW = 1
C  FIX AVERAGE "U" AND AVERAGE "C" OVER PROJECT LIFE IF NEEDED.
      IF (RBIG) CALL UCFIX(CRFSM,CTOTR,GSF,HYDTLS,LOOPTR,NSTAGE,NSTEMX,
     1NW,PCT,PUT,PWFR,SPWFAC,TIME,TIMST,UTOTR)
      CALL RSHYDR(AFT(NW),AFV(1,NW),AFV(2,NW),AFW(1,NW),AFW(2,NW),
     1AW(NW),CHANEL(NW),GSF,HYD05,HYD05N,HYD43,HYD43N,HYDBAS,HYDDS,
     2HYDDSN,HYDINT,HYDTLS,KDF,LC(NW),LOOPTR,NDF,NW,PCT,PUT,Q05,Q43,
     3QB05,QB43,RBIG,RESIN,RK24,SIC(NW),STF,TCL(NW),CTOTR(NW,NSTAGE),
     4TIME,TP,TPB,TPW,UTOTR(NW,NSTAGE),UTOTR(NW,NSTAGE+1),V05,V43,VB05,
     5VB43,VF05,VF43,VFDS,YY)
C  SKIP RESERVOIR ANALYSIS WHERE NOT NEEDED.
      IF (NOXTR .OR. NODAM) GO TO 502
C  SKIP BUILDING RESERVOIR FOR NON-FLOOD-CONTROL STORAGE ALONE WHERE NOT
C  PART OF THE ANALYSIS.
      IF (XTRSTR .EQ. 0.0 .OR. COSTDM .NE. 0.0) GO TO 501
C  DESIGN DAM FOR EXTRA STORAGE ALONE AND SAVE THOSE DESIGN VALUES
C  REQUIRED IF LATER TRIAL DESIGNS DO NOT PROVE JUSTIFIED.
      CALL DAMBLD
      GDRQ =DRQ
      GELFDB = ELFDBG
      GELSPF = ELSPFL
      GELPRF = ELPRFL
      GFLDST = FLDSTR
      GCSTDM = COSTDM
      GELF43 = ELFB43
      GELF05 = ELFB05
      RSBLT = .TRUE.
C  NO ROUTING IF RESERVOIR NOT BUILT.
  501 IF(.NOT.RSBLT) GO TO 502
```

```
C  ROUTE MEAN ANNUAL AND 200-YEAR FLOODS TO DETERMINE EFFECTS OF
C  NON-FLOOD-CONTROL STORAGE ON HYDROGRAPH.
      IF(HYDTLS) WRITE(6,1320) ELFB43
 1320 FORMAT(10X,43HROUTING MEAN ANNUAL FLOOD THROUGH RESERVOIR/15X,
     1 8HELFDBG =,F8.2)
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB43,ELPEAK,ELPRFL,ELSPFL,0.0,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYD43N,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
      IF(HYDTLS) WRITE(6,1321) ELFB05
 1321 FORMAT(10X,40HROUTING 200-YEAR FLOOD THROUGH RESERVOIR/15X,
     1 8HELFDBG =,F8.2)
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB05,ELPEAK,ELPRFL,ELSPFL,0.0,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYD05N,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
C  ROUTE RESERVOIR DESIGN FLOOD IF NOT ONE OF THE ABOVE TWO FREQUENCIES.
      IF(.NOT. RSFLD .OR. KDF .EQ. 1 .OR. KDF .EQ. NDF) GO TO 502
      IF(HYDTLS) WRITE(6,1322) ELFDBG
 1322 FORMAT(10X,38HROUTING DESIGN FLOOD THROUGH RESERVOIR/15X,
     1 8HELFDBG =,F8.2)
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFDBG,ELPEAK,ELPRFL,ELSPFL,0.0,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYDDSN,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
C  EVALUATE THE MOST ECONOMICAL COURSE OF ACTION IN EACH SUBWATERSHED
C  FLOOD PLAIN AND TOTAL ALL COSTS.
  502 CALL CHANYZ
C  CORRECT DOWNSTREAM FLOOD BENEFITS FOR NEW DEVELOPMENT IN FLOOD PLAIN
C  SINCE LAST STAGE.
      IF (RONE .AND. .NOT. RTEST) GO TO 131
      BNFDST = 0.0
      GO TO 132
C  CORRECT DOWNSTREAM BENEFITS WHEN ANALYZING A STAGE AFTER CONSTRUCTION
C  OF RESERVOIR.
  131 IF (NSTAGE .NE. ISTAGE) BNFDST = BNFDST*DMBNF(NSTAGE)/DMBNF(NSTAGE
     1-1)
C  TOTAL COST IN FLOOD PLAIN AND OF DAM NET OF DOWNSTREAM BENEFITS.
  132 COSTFM = COSTFP + COSTDM - BNFDST
      WRITE(6,1367) COSTFP,COSTDM,BNFDST,COSTFM
 1367 FORMAT(10X,27HSUMMARY FOR RESERVOIR TRIAL/15X,20HFLOOD PLAIN COST
     1= $,F10.2/15X,14HRESERVOIR COST,3X,3H= $,F10.2/15X,20HDOWNSTRM BEN
     2EFIT = $,F10.2/15X,10HTOTAL COST,7X,3H= $,F10.2)
C  SAVE CURRENT SUBWATERSHED ACTION IF BEST THUS FAR.
   10 DO 21 NW=2,MW
      A8(NW)=A9(NW)
      DO 20 J=1,11
   20 CA8(NW,J)=CA9(NW,J)
      CH8(NW)=CH9(NW)
      FD8(NW)=FD9(NW)
      LN8(NW)=LN9(NW)
      IHLD8(NW)=IHLD9(NW)
      LC8(NW)=LC9(NW)
      ADDC8(NW)=ADDC9(NW)
      ND8(NW)=ND9(NW)
      Q8(NW)=Q9(NW)
      T8(NW)=T9(NW)
      W8(NW)=W9(NW)
```

```
   21 WT8(NW)=WT9(NW)
C  NO MORE ANALYSIS NEEDED IF RESERVOIR NOT TO BE CONSIDERED.
      IF (NODAM) GO TO 1312
C  RETURN TO "11" IF CAME TO "10" WHILE TESTING RESERVOIR.
      IF(RTEST) GO TO 11
C  RETURN IF ANALYZING FLOOD PLAIN AFTER BUILDING RESERVOIR IN CURRENT
C  OR PREVIOUS STAGE.
      IF (RONE) GO TO 1312
      RONE = .TRUE.
      RTEST = .TRUE.
C  ANALYZE RESERVOIRS CONTAINING FLOODS SPECIFIED IN ARRAY DF(),
C  BEGINNING WITH MINIMUM ALLOWABLE RESERVOIR DESIGN FLOOD DF(MRDF)
      KDF = MRDF - 1
 1010 KDF = KDF + 1
      FRES = 1.0/DF(KDF)
      WRITE(6,1250) FRES
 1250 FORMAT(1H1,28HANALYSIS FOR RETURN PERIOD =,F6.2,1X,5HYEARS)
C  DEVELOP RESERVOIR DESIGN HYDROGRAPHS.
      RESIN = .TRUE.
      NW = 1
      IF (RBIG) CALL UCFIX(CRFSM,CTOTR,GSF,HYDTLS,LOOPTR,NSTAGE,NSTEMX,
     1NW,PCT,PUT,PWFR,SPWFAC,TIME,TIMST,UTOTR)
      CALL RSHYDR(AFT(NW),AFV(1,NW),AFV(2,NW),AFW(1,NW),AFW(2,NW),
     1AW(NW),CHANEL(NW),GSF,HYD05,HYD05N,HYD43,HYD43N,HYDBAS,HYDDS,
     2HYDDSN,HYDINT,HYDTLS,KDF,LC(NW),LOOPTR,NDF,NW,PCT,PUT,Q05,Q43,
     3QB05,QB43,RBIG,RESIN,RK24,SIC(NW),STF,TCL(NW),CTOTR(NW,NSTAGE),
     4TIME,TP,TPB,TPW,UTOTR(NW,NSTAGE),UTOTR(NW,NSTAGE+1),V05,V43,VB05,
     5VB43,VF05,VF43,VFDS,YY)
C  DESIGN DAM AND RESERVOIR.
      CALL DAMBLD
C  ROUTE MEAN ANNUAL, 200-YEAR, AND DESIGN FLOOD(IF NOT EQUAL TO ONE OF
C  OTHER TWO) THROUGH RESERVOIR.
      IF (HYDTLS) WRITE(6,1320) ELFB43
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB43,ELPEAK,ELPRFL,ELSPFL,GDELAY,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYD43N,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
      IF (HYDTLS) WRITE(6,1321) ELFB05
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB05,ELPEAK,ELPRFL,ELSPFL,GDELAY,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYD05N,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
      IF (KDF .EQ. 1 .OR. KDF .EQ. NDF) GO TO 504
      IF (HYDTLS) WRITE(6,1322) ELFDBG
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFDBG,ELPEAK,ELPRFL,ELSPFL,GDELAY,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYDDSN,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
C  REINITIALIZE FACT OF CHANNEL IMPROVEMENT
  504 DO 5045 NW = 1, MW
 5045 CH9(NW) = CHANEL(NW)
C  EVALUATE THE MOST ECONOMICAL COURSE OF ACTION IN EACH SUBWATERSHED
      CALL CHANYZ
C  ESTIMATE BENEFITS DOWNSTREAM FROM END OF FORMAL ANALYSIS FROM DATA
C  RELATING BENEFIT TO STORAGE.
      DO 505 I = 2, 10
      IF(DMBN(1,I).GT.FLDSTR) GO TO 506
  505 CONTINUE
```

```
      BNFDST = DMBN(2,10)
      GO TO 507
  506 BNFDST = DMBN(2,I-1)+(DMBN(2,I)-DMBN(2,I-1))*(FLDSTR-DMBN(1,I-1))/
     1(DMBN(1,I) - DMBN(1,I-1))
  507 BNFDST = BNFDST*DMBNF(NSTAGE)
      COSTSM = COSTFP + COSTDM - BNFDST
      WRITE(6,1367) COSTFP, COSTDM,BNFDST,COSTSM
C    COSTSM = CURRENT TRIAL COST
C    COSTFM = BEST TRIAL COST
C    COSTFT = LAST TRIAL COST
C   RESERVOIR SO COSTLY ON FIRST TRIAL THAT THERE IS NO HOPE OF ECONOMIC
C     JUSTIFICATION.
      IF(KDF.EQ.1.AND.COSTSM.GT.2.0*COSTFM) GO TO 1312
C   RESERVOIR WORSE THAN LAST TRIAL SO NO NEED TO CONTINUE EXCEPT ON
C   FIRST TRIAL.
      IF(KDF.GE.2.AND.COSTSM.GT.COSTFT) GO TO 1001
C   TRY A SECOND DESIGN FREQUENCY EVEN IF FIRST WAS NOT JUSTIFIED.
      IF(COSTSM .GT. COSTFM) GO TO 11
C   IF DESIGN FOR AVERAGE FLOOD THREAT OVER PROJECT LIFE PROVES GOOD,
C   SAVE THOSE DESIGN VALUES REQUIRED IF LATER TRIAL DESIGNS DO NOT PROVE
C   JUSTIFIED AND WRITE COST SUMMARY FOR DAM.
      IF(RBIG .OR. (NSTEMX .EQ. 1)) GO TO 12
C   IF RESERVOIR CONSTRUCTION HAS PROVED JUSTIFIED BY BENEFITS REALIZED
C   DURING STAGE, RETURN TO SIZE RESERVOIR BY BENEFITS REALIZED
C   DURING PROJECT LIFE.
      RBIG = .TRUE.
      WRITE(6,1330)
 1330 FORMAT(10X,37HRESERVOIR JUSTIFIED BUT MUST BE SIZED)
      KDF = 0
      RTEST = .FALSE.
      COSTDM = 0.0
      RONE = .FALSE.
      GO TO 499
C    A FLOOD CONTROL RESERVOIR IS JUSTIFIED AND ITS DIMENSIONS ARE SAVED
   12 COSTFM = COSTSM
      KDFG = KDF
      GDRQ = DRQ
      GELFDB = ELFDBG
      GELSPF = ELSPFL
      GELPRF = ELPRFL
      GFLDST = FLDSTR
      GCSTDM = COSTDM
      GELF43 = ELFB43
      GELF05 = ELFB05
      GBNF = BNFDST
      ISTAGE = NSTAGE
      WRITE(6,510) NSTAGE,FRES,COSTDM,COSTFP,BNFDST,COSTFM
  510 FORMAT(///15X,36HCONSTRUCTION OF A RESERVOIR IN STAGE,1X,I2,2X,
     144HTO CONTAIN A FLOOD HAVING A RETURN PERIOD OF,1X,F9.2,1X,5HYEARS
     2,/25X,11HCOST OF DAM,5X,3H= $,F9.0,/25X,19HDOWNSTREAM COST = $,
     3F9.0/25X,19HDWNSTRM BENEFIT = $,F9.0/25X,10HTOTAL COST,6X,3H= $,
     4F9.0)
```

```
      RSBLT = .TRUE.
      RSFLD = .TRUE.
      GO TO 10
C   SAVE COST FOR LAST TIME THROUGH.
   11 COSTFT = COSTSM
C   GO TO NEXT BIGGER DESIGN FLOOD IF NOT AT BIGGEST.
 1000 IF(KDF.LT.NDF) GO TO 1010
      GO TO 1312
C   ENTER WITH COST INCREASING OVER THAT FOR LAST DESIGN FREQUENCY.
C    COSTSM .GT. COSTFT
C   SET DIMENSIONS IF HAVE A NON-FLOOD-CONTROL RESERVOIR.
 1001 IF(RSBLT .AND. .NOT. RSFLD) GO TO 1003
C   RETURN IF NOT SIZING RESERVOIR FOR PROJECT LIFE OR IF NO RESERVOIR
C   WITH FLOOD STORAGE BUILT (NO DIMENSIONS TO SET).
      IF(.NOT. RBIG .OR. .NOT. RSFLD) GO TO 1004
C   SET DIMENSION FOR BEST RESERVOIR DESIGN FOUND.
 1003 DRQ = GDRQ
      ELFDBG = GELFDB
      ELSPFL = GELSPF
      ELPRFL = GELPRF
      FLDSTR = GFLDST
      COSTDM = GCSTDM
      ELFB43 = GELF43
      ELFB05 = GELF05
      RBIG = .FALSE.
      KDF = KDFG
      BNFDST = GBNF
      RTEST = .FALSE.
C   ELIMINATE NON-FLOOD-CONTROL RESERVOIR IF NOT REQUIRED.
      IF (.NOT. BLDNOW .AND. .NOT. RSFLD) GO TO 713
C   RETURN TO ANALYZE EFFECT OF RESERVOIR BUILT FOR PROJECT LIFE ON
C   FLOODING WITHIN STAGE.
      IF(NSTEMX .EQ. 1) GO TO 1312
      GO TO 499
C   INITIALIZATION FOR ELIMINATING NON-FLOOD-CONTROL RESERVOIR.
  713 RSBLT = .FALSE.
      NOXTR = .TRUE.
      COSTDM = 0.0
      IF(NSTEMX .EQ. 1) GO TO 1312
      GO TO 499
C   INITIALIZATION FOR NEXT STAGE IF NO RESERVOIR BUILT.
 1004 KDF = 0
      COSTDM = 0.0
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,21HSUBROUTINE BUILD LEFT)
 1002 RETURN
      END


      SUBROUTINE CALCLU(CHECK,CLEN,CLOC,CRF,FIF,FRU,GSF,IPP,LOOPTR,MW,
     1NSTEMX,PWF,SPWF,TIME,USUBW,VALUE)
```

```
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 15, 1967
C  CALCULATES LOCATION COST PER ACRE FOR EACH SUBWATERSHED IN EACH STAGE
C         AND MAKES SURE THAT LOCATION COST WILL INCREASE AS THE
C         SUBWATERSHED BECOMES MORE URBANIZED.
      DIMENSION CLOC(15,5),FIF(15),FRU(11),USUBW(15,6),VALUE(15,6)
      LOGICAL CHECK,LOOPTR
      REAL IA,IPP
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE CALCLU ENTERED)
C  FILLS ARRAY OF PER ACRE LOCATION ADJUSTMENT COST FOR ALL SUBWATERSHED
C  STAGES.
      DO 3 NSTAGE=1,NSTEMX
      DO 3  NW = 2,MW
     0UN=USUBW(NW,NSTAGE)+(GSF*(USUBW(NW,NSTAGE+1)-USUBW(NW,NSTAGE)))/TI
     1ME
      IF (UN .LT. 1.00) GO TO 1
      FUQ=FRU(11)
      GO TO 2
    1 UR=10.0*UN+1.0
      I=UR
      UQ=I
      FUQ=FRU(I)+(UQ-UR)*(FRU(I)-FRU(I+1))
    2 IA=FUQ*FIF(NW)
     0CLUT=   CRF*(VALUE(NW,NSTAGE)-PWF*VALUE(NW,NSTAGE+1)-SPWF*(IA+IPP*
     1UN))
      IF (CLUT.LT.0.0) CLUT=0.0
    3 CLOC(NW,NSTAGE)=CLUT+CLEN
      IF (NSTEMX.EQ.1) GO TO 1312
C   IF IT IS HIGHER, REDUCES SUBWATERSHED VALUE TO THAT IN NEXT STAGE
      DO 4  NW = 2,MW
      DO 4 NRS=2,NSTEMX
      NRT=NSTEMX+1-NRS
    4 IF(CLOC(NW,NRT).GT. CLOC(NW,NRT+1)) CLOC(NW,NRT)=CLOC(NW,NRT+1)
      IF (.NOT. CHECK) GO TO 1312
      WRITE (6,80)
   80 FORMAT (1H1,15X,56HLOCATION ADJUSTMENT COST IN $/ACRE BY SUBWATERS
     1HED-STAGE/10X,2HNW,2X,7HSTAGE 1,2X,7HSTAGE 2,2X,7HSTAGE 3,2X,7HSTA
     2GE 4,2X,7HSTAGE 5)
      DO 70 NW = 2,MW
   70 WRITE (6,60) NW,(CLOC(NW,NSTAGE), NSTAGE=1,NSTEMX)
   60 FORMAT (10X,I2,5(2X,F7.2))
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE CALCLU LEFT)
      RETURN
      END


      SUBROUTINE CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,
     1Q0,QP,QS,QX,R,UN,UNC,VA,VLAGST,VLURST)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
```

```
C VERSION OF JANUARY 8, 1968
C  EVALUATES AVERAGE ANNUAL VALUES FOR FLOOD DAMAGE AND UNCERTAINTY
C     DAMAGE FOR CASES WHERE LAND USE ADJUSTMENT IS NOT INVOLVED.
C  FLOOD DAMAGE IS EVALUATED BY SEPARATING STRUCTURAL FROM CROP
C     DAMAGE.            CROP DAMAGE EQUALS $FA PER ACRE PLUS $GA
C     PER ACRE PER FOOT OF FLOOD DEPTH.  STRUCTURAL DAMAGE EQUALS
C     COEFDM*DEPTH*AREA*(MARKET VALUE) UNTIL THE FLOOD DEPTH IS GREAT
C     ENOUGH TO DESTROY 0.25*(MARKET VALUE).  STRUCTURAL DAMAGE THEN
C     INCREASES AT HALF THIS RATE WITH ADDITIONAL DEPTH UNTIL THE FLOOD
C     DEPTH IS GREAT ENOUGH TO DESTROY 0.75*(MARKET VALUE).  NO
C     ADDITIONAL DAMAGE IS ADDED FOR STILL GREATER DEPTHS.  DAMAGES
C     ARE SEPARATELY DETERMINED FOR AREAS IN EACH OF THE THREE DEPTH
C     RANGES AND THEN ADDED.
      DIMENSION DFQR(16),K1(15),K2(15),QO(15),QX(2,16)
      REAL K1,K2
      LOGICAL LOOPTR,UNC
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,22HSUBROUTINE CD1 ENTERED)
C  DESIGN FLOWS LESS CHANNEL CAPACITY
      QSS=QS-QO(NW)
      QPP=QP-QO(NW)
C  UNIT DAMAGE FACTORS
C     URBAN STRUCTURES WITH FLOOD PROOFING
      C1=0.1111*VLURST*UN*COEFDM
C     ADDITIONAL FOR URBAN STRUCTURES WITHOUT FLOOD PROOFING
      C2=8.0*C1
C     AGRICULTURAL STRUCTURES WITH FLOOD PROOFING
      C3=0.1111*VLAGST*(1.0-UN)*COEFDM
C     ADDITIONAL FOR AGRICULTURAL STRUCTURES WITHOUT FLOOD PROOFING
      C4=8.0*C3
C     CROP DAMAGE
      C5=FA*(1.0-UN)
      C5G = GA*(1.0-UN)
C     COMBINED STRUCTURES WITH FLOOD PROOFING
      C6=C1+C3
C     ADDITIONAL FOR COMBINED STRUCTURES WITHOUT FLOOD PROOFING
      C7=C2+C4
C  EVALUATE DAMAGES FOR 16 FLOODS BEGINNING WITH THE BIGGEST
      DO 100 J=1,ITOP
C  NO DAMAGE IF FLOOD CONTAINED IN CHANNEL
      DFQR(J)=0.0
      I = 1
      CA=C6
      CB=C5
      CBG = C5G
      IF (QSS .GE. QX(NN,J)) GO TO 100
C   EXCESS FLOW
      QXC=QX(NN,J)-QSS
C  ESTIMATE MAXIMUM DEPTH OF FLOODING
    2 DMAX=K1(NW)*QXC**0.375
C  TEST WHETHER MAXIMUM FRACTION OF MARKET VALUE DESTROYED EXCEEDS 0.25
      FMAX=COEFDM*DMAX
```

```
      AZ1=0.0
      AZ2=0.0
      AZ3=0.0
      DZ1=0.0
      DZ2=0.0
      DZ3=0.0
      IF (FMAX .LE. 0.25) GO TO 4
C   DEPTH AND AREA OF FLOODING IN ZONE 1
      DZ1=0.25/COEFDM
      GO TO 6
    4 DZ1=DMAX
    6 AZ1=K2(NW)*DZ1
C   DAMAGE IN ZONE 1
      DFQR(J) = DFQR(J) + 0.5*(CA+CBG)*DZ1*AZ1 + CB*AZ1
      IF (FMAX .LE. 0.25) GO TO 50
C   TEST WHETHER MAXIMUM FRACTION OF MARKET VALUE DESTROYED EXCEEDS 0.75
      FMAX = 0.25 + 0.5*COEFDM*(DMAX-DZ1)
      IF (FMAX .LE. 0.75) GO TO 8
C   DEPTH AND AREA OF FLOODING IN ZONE 2
      DZ2 = DZ1 + 1.0/COEFDM
      GO TO 10
    8 DZ2 = DMAX
   10 AZ2 = K2(NW)*DZ2 - AZ1
C   DAMAGE IN ZONE 2
      DFQR(J) = DFQR(J) + CA*(DZ1+0.25*(DZ2-DZ1))*AZ2+(CB+5.0*CBG)*AZ2
      IF (FMAX .LE. 0.75) GO TO 50
C   DEPTH AND AREA OF FLOODING IN ZONE 3
      DZ3 = DMAX
      AZ3 = K2(NW)*DZ3 - AZ2
C   DAMAGE IN ZONE 3
      DFQR(J) = DFQR(J) + CA*(DZ1+0.5*(DZ2-DZ1))*AZ3+(CB+5.0*CBG)*AZ3
C   NO ADDITIONAL DAMAGE IF ALL STRUCTURES IN FLOODED AREA ARE FLOOD
C     PROOFED
   50 CONTINUE
      IF (I .EQ. 2) GO TO 100
      I = 2
      IF (QPP .GE. QX(NN,J)) GO TO 100
C   RETURNS TO FIGURE ADDITIONAL DAMAGE IF FLOOD PROOFING IS OVERTOPPED
      QXC = QX(NN,J) - QSS
      CB = 0.0
      CBG = 0.0
      CA = C7
      GO TO 2
  100 CONTINUE
C    MEAN ANNUAL DAMAGE FROM FLOODS OF 16 SPECIFIED FREQUENCIES
     0CD=0.2*(DFQR(16)+DFQR(15)+DFQR(14))+0.1*(DFQR(13)+DFQR(12))+0.05*(
     1DFQR(11)+DFQR(10))+0.02*(DFQR(9)+DFQR(8)+DFQR(7))+0.01*(DFQR(6)+DF
     2QR(5)+DFQR(4))+0.005*DFQR(3)+0.004*DFQR(2)+0.001*DFQR(1)
      CU=0.0
      IF(.NOT. UNC) GO TO 1312
C    STANDARD DEVIATION OF FLOODS OF 16 SPECIFIED FREQUENCIES
     0SIGMA=SQRT(0.2*((DFQR(16)-CD)**2+(DFQR(15)-CD)**2+(DFQR(14)-CD)**2
```

```
     1)+0.1*((DFQR(13)-CD)**2+(DFQR(12)-CD)**2)+0.05*((DFQR(11)-CD)**2+(
     2DFQR(10)-CD)**2)+0.02*((DFQR(9)-CD)**2+(DFQR(8)-CD)**2+(DFQR(7)-CD
     3)**2)+0.01*((DFQR(6)-CD)**2+(DFQR(5)-CD)**2+(DFQR(4)-CD)**2)+0.005
     4*(DFQR(3)-CD)**2+0.004*(DFQR(2)-CD)**2+0.001*(DFQR(1)-CD)**2)
C    COST OF UNCERTAINTY BASED ON THOMAS UNCERTAINTY FUND
      CU=VA*SIGMA*CRFSM/SQRT(2.0*R)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,19HSUBROUTINE CD1 LEFT)
      RETURN
      END


      SUBROUTINE CD2(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,
     1Q0,QL,QP,QS,QX,R,UN,UNC,UZ,VA,VLAGST,VLURST)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  EVALUATES AVERAGE ANNUAL VALUES FOR FLOOD DAMAGE AND UNCERTAINTY
C     DAMAGE FOR CASES WHERE LAND USE ADJUSTMENT IS INVOLVED.
C  FLOOD DAMAGE IS EVALUATED BY SEPARATING STRUCTURAL FROM CROP
C     DAMAGE.          CROP DAMAGE EQUALS $FA PER ACRE PLUS $GA
C     PER ACRE PER FOOT OF FLOOD DEPTH.  STRUCTURAL DAMAGE EQUALS
C     COEFDM*DEPTH*AREA*(MARKET VALUE) UNTIL THE FLOOD DEPTH IS GREAT
C     ENOUGH TO DESTROY 0.25*(MARKET VALUE).  STRUCTURAL DAMAGE THEN
C     INCREASES AT HALF THIS RATE WITH ADDITIONAL DEPTH UNTIL THE FLOOD
C     DEPTH IS GREAT ENOUGH TO DESTROY 0.75*(MARKET VALUE).  NO
C     ADDITIONAL DAMAGE IS ADDED FOR STILL GREATER DEPTHS.  DAMAGES
C     ARE SEPARATELY DETERMINED FOR AREAS IN EACH OF THE THREE DEPTH
C     RANGES AND THEN ADDED.
      DIMENSION DFQR(16),K1(15),K2(15),Q0(15),QX(2,16)
      REAL K1,K2
      LOGICAL LOOPTR,UNC
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,22HSUBROUTINE CD2 ENTERED)
C  DESIGN FLOWS LESS CHANNEL CAPACITY
      QSS=QS-Q0(NW)
      QPP=QP-Q0(NW)
      QLL=QL-Q0(NW)
C  UNIT DAMAGE FACTORS
C     URBAN STRUCTURES WITH FLOOD PROOFING
      C1=0.1111*VLURST*UZ*COEFDM
C     ADDITIONAL FOR URBAN STRUCTURES WITHOUT FLOOD PROOFING
      C2=8.0*C1
C     AGRICULTURAL STRUCTURES WITH FLOOD PROOFING
      C3=0.1111*VLAGST*(1.0-UZ)*COEFDM
C     ADDITIONAL FOR AGRICULTURAL STRUCTURES WITHOUT FLOOD PROOFING
      C4=8.0*C3
C     CROP DAMAGE
      C5=FA*(1.0-UZ)
      C5G = GA*(1.0-UZ)
C  COMBINED STRUCTURES WITH FLOOD PROOFING
      C6=C1+C3
```

```
C    ADDITIONAL FOR COMBINED STRUCTURES WITHOUT FLOOD PROOFING
       C7=C2+C4
C   URBAN STRUCTURES WITH FLOOD PROOFING OUTSIDE THE RESTRICTED LAND USE
C   AREA
       C8 = 0.1111*VLURST*(UN-UZ)*COEFDM
C   ADDITIONAL FOR URBAN STRUCTURES WITHOUT FLOOD PROOFING OUTSIDE THE
C     RESTRICTED LAND USE AREA
       C9 = 8.0*C8
C   CORRECTION FOR AGRICULTURAL STRUCTURES DISPLACED BY URBAN STRUCTURES
C     OUTSIDE THE RESTRICTED AREA (FLOOD PROOFING)
       C10 = -0.1111*VLAGST*(UN-UZ)*COEFDM
C   CORRECTION FOR AGRICULTURAL STRUCTURES DISPLACED BY URBAN STRUCTURES
C     OUTSIDE THE RESTRICTED AREA (NO FLOOD PROOFING)
       C11 = 8.0*C10
C   CORRECTION FOR CROPS DISPLACED BY URBAN STRUCTURES OUTSIDE THE
C     RESTRICTED AREA
       C12 = -FA*(UN - UZ)
       C12G = -GA*(UN - UZ)
C   COMBINED ACCOUNTING FOR FLOOD PROOFED STRUCTURES OUTSIDE THE
C   RESTRICTION
       C13 = C8 + C10
C   COMBINED ACCOUNTING FOR STRUCTURES NOT FLOOD PROOFED OUTSIDE THE
C     RESTRICTION
       C14 = C9 + C11
C   EVALUATE DAMAGES FOR 16 FLOODS BEGINNING WITH THE BIGGEST
       DO 100 J=1,ITOP
C   NO DAMAGE IF FLOOD CONTAINED IN CHANNEL
       DFQR(J)=0.0
       CA = C6
       CB = C5
       CBG = C5G
       I = 1
       IF (QSS .GE. QX(NN,J)) GO TO 100
C    EXCESS FLOW
       QXC=QX(NN,J)-QSS
C   ESTIMATE MAXIMUM DEPTH OF FLOODING
     2 DMAX=K1(NW)*QXC**0.375
C   TEST WHETHER MAXIMUM FRACTION OF MARKET VALUE DESTROYED EXCEEDS 0.25
       FMAX=COEFDM*DMAX
       AZ1 = 0.0
       AZ2 = 0.0
       AZ3 = 0.0
       DZ1 = 0.0
       DZ2 = 0.0
       DZ3 = 0.0
       IF (FMAX .LE. 0.25) GO TO 4
C   DEPTH AND AREA OF FLOODING IN ZONE 1
       DZ1=0.25/COEFDM
       GO TO 6
     4 DZ1=DMAX
     6 AZ1=K2(NW)*DZ1
C   DAMAGE IN ZONE 1
```

```
      IF (I.NE.4.AND.I.NE.6) GO TO 7
C   SUBTRACTING OUT DAMAGES FROM AZS DEEPEST FLOODED ACRES WHICH DO NOT
C          ACCRUE BECAUSE OF LAND USE RESTRICTION
      AZ11=AZ1
      IF (AZ1.GE.AZD) GO TO 201
      AZ1=0.0
      GO TO 7
  201 AZ1=AZ11-AZD
      DZL=AZD/K2(NW)
      DFQR(J)=DFQR(J)+(0.5*(CA+CBG)*(DZ1+DZL)+CB)*AZ1
      GO TO 202
    7 DFQR(J) = DFQR(J) + 0.5*(CA+CBG)*DZ1*AZ1 + CB*AZ1
  202 CONTINUE
      IF (FMAX .LE. 0.25) GO TO 50
C   TEST WHETHER MAXIMUM FRACTION OF MARKET VALUE DESTROYED EXCEEDS 0.75
      FMAX = 0.25 + 0.5*COEFDM*(DMAX-DZ1)
      IF (FMAX .LE. 0.75) GO TO 8
C   DEPTH AND AREA OF FLOODING IN ZONE 2
      DZ2 = DZ1 + 1.0/COEFDM
      GO TO 10
    8 DZ2 = DMAX
   10 AZ2 = K2(NW)*DZ2 - AZ1
C   DAMAGE IN ZONE 2
      IF (I.NE.4.AND.I.NE.6) GO TO 203
      AZ21=K2(NW)*DZ2-AZ11
      AZ2=AZ21
      IF (AZ11.GE.AZD) GO TO 203
      IF (AZ11+AZ21.GE.AZD) GO TO 204
      AZ2=0.0
      GO TO 203
  204 DZL=AZD/K2(NW)
      AZ2=AZ11+AZ21-AZD
      DFQR(J)=DFQR(J)+(CA*(DZ1+0.25*(DZL+DZ2-2.0*DZ1))+CB+5.0*CBG)*AZ2
      GO TO 205
  203 DFQR(J) = DFQR(J) + CA*(DZ1+0.25*(DZ2-DZ1))*AZ2+(CB+5.0*CBG)*AZ2
  205 CONTINUE
      IF (FMAX .LE. 0.75) GO TO 50
C   DEPTH AND AREA OF FLOODING IN ZONE 3
      DZ3 = DMAX
      AZ3 = K2(NW)*DZ3 - AZ2
C   DAMAGE IN ZONE 3
      IF (I.NE.4.AND.I.NE.6) GO TO 206
      AZ31=K2(NW)*DZ3-AZ21
      AZ3=AZ31
      IF (AZ11+AZ21.GE.AZD) GO TO 206
      AZ3=AZ11+AZ21+AZ31-AZD
  206 DFQR(J) = DFQR(J) + CA*(DZ1+0.5*(DZ2-DZ1))*AZ3+(CB+5.0*CBG)*AZ3
C   NO ADDITIONAL DAMAGE IF ALL STRUCTURES IN FLOODED AREA ARE FLOOD
C      PROOFED
   50 CONTINUE
      IF (I .NE. 1) GO TO 60
      I = 2
```

```
      IF (QPP .GE. QX(NN,J)) GO TO 60
C   RETURNS TO FIGURE ADDITIONAL DAMAGE IF FLOOD PROOFING IS OVERTOPPED
      QXC = QX(NN,J) - QSS
      CB = 0.0
      CBG = 0.0
      CA = C7
      GO TO 2
   60 IF (I .NE. 2) GO TO 70
      I = 3
C   NO FLOODING OUTSIDE RESTRICTED AREA
      IF (QX(NN,J) .LE. QLL) GO TO 100
C   RETURNS TO FIGURE DAMAGE TO URBAN STRUCTURES (FLOOD PROOFED)
C     OUTSIDE THE RESTRICTED AREA
      QXC = QX(NN,J) - QSS
      CB = C12
      CBG = C12G
      CA = C13
      GO TO 2
   70 IF(I .NE. 3) GO TO 75
      I = 4
C   RETURNS TO REDUCE DAMAGE TOTAL BECAUSE OF RESTRICTED AREA
      IF (QSS .GE. QLL) GO TO 75
      QXCS = QLL - QSS
      AZS=K2(NW)*K1(NW)*QXCS**0.375
      AZL=K2(NW)*K1(NW)*QXC**0.375
      AZD=AZL-AZS
      CB = -C12
      CBG = -C12G
      CA = -C13
      GO TO 2
   75 IF(I .NE. 4) GO TO 80
      I = 5
C   DETERMINE IF FLOOD PROOFING IS OVERTOPPED
      IF (QPP .GT. QX(NN,J)) GO TO 100
C   RETURNS TO FIGURE DAMAGE TO URBAN STRUCTURES WITH FLOOD PROOFING
C     OVERTOPPED OUTSIDE THE RESTRICTED AREA
      QXC = QX(NN,J) - QSS
      CB = 0.0
      CBG = 0.0
      CA = C14
      GO TO 2
   80 IF(I .GE. 6) GO TO 100
      I = 6
C   RETURNS TO REDUCE DAMAGE TOTAL BECAUSE OF RESTRICTED AREA
      IF (QSS .GE. QLL) GO TO 100
      QXCS = QLL - QSS
      AZS=K2(NW)*K1(NW)*QXCS**0.375
      AZL=K2(NW)*K1(NW)*QXC**0.375
      AZD=AZL-AZS
      CA = -C14
      GO TO 2
  100 CONTINUE
```

```
C    MEAN ANNUAL DAMAGE FROM FLOODS OF 16 SPECIFIED FREQUENCIES
     0CD=0.2*(DFQR(16)+DFQR(15)+DFQR(14))+0.1*(DFQR(13)+DFQR(12))+0.05*(
     1DFQR(11)+DFQR(10))+0.02*(DFQR(9)+DFQR(8)+DFQR(7))+0.01*(DFQR(6)+DF
     2QR(5)+DFQR(4))+0.005*DFQR(3)+0.004*DFQR(2)+0.001*DFQR(1)
      CU=0.0
      IF(.NOT. UNC) GO TO 1312
C    STANDARD DEVIATION OF FLOODS OF 16 SPECIFIED FREQUENCIES
     0SIGMA=SQRT(0.2*((DFQR(16)-CD)**2+(DFQR(15)-CD)**2+(DFQR(14)-CD)**2
     1)+0.1*((DFQR(13)-CD)**2+(DFQR(12)-CD)**2)+0.05*((DFQR(11)-CD)**2+(
     2DFQR(10)-CD)**2)+0.02*((DFQR(9)-CD)**2+(DFQR(8)-CD)**2+(DFQR(7)-CD
     3)**2)+0.01*((DFQR(6)-CD)**2+(DFQR(5)-CD)**2+(DFQR(4)-CD)**2)+0.005
     4*(DFQR(3)-CD)**2+0.004*(DFQR(2)-CD)**2+0.001*(DFQR(1)-CD)**2)
C    COST OF UNCERTAINTY BASED ON THOMAS UNCERTAINTY FUND
      CU=VA*SIGMA*CRFSM/SQRT(2.0*R)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,19HSUBROUTINE CD2 LEFT)
      RETURN
      END


      SUBROUTINE CHANYZ
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  GIVEN THE OUTFLOW HYDROGRAPH FROM THE RESERVOIR ( OR PAST THE
C        RESERVOIR SITE IF THERE IS NO RESERVOIR), THE SUBROUTINE
C        PROCEEDS IN THE DOWNSTREAM DIRECTION THROUGH THE SUBWATERSHEDS
C        ONE AT A TIME TO DETERMINE THE NATURE AND THE COST OF THE
C        OPTIMUM FLOOD CONTROL POLICY IN EACH ONE.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
```

```
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      LOGICAL CH9,CHANEL,HOLDNG,HYDTLS,LOOPTR,LTF,RBIG,RESIN,RSFLD,
     1RTEST,RTRYD,STF
      REAL IA,IPP,K1,K2,LA,LC
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE CHANYZ ENTERED)
C  DETERMINE WHETHER SEPARATE HYDROGRAPHS FOR RESERVOIR DESIGN FLOODS
C  ARE NEEDED.
      IF((RTEST.OR.RSFLD).AND.(KDF.GE.2.AND.KDF.LT.NDF))RTRYD=.TRUE.
      IF(STF .AND. .NOT. CHANEL(2)) GO TO 1191
C  ESTABLISH HYDROGRAPHS WITH CHANNEL IMPROVEMENT IF THEY MAY BE
C  IMPROVED SO AS TO HAVE DESIGN FLOWS FOR BOTH NONSTRUCTURAL AND
C  STRUCTURAL MEASURE ANALYSIS.
      DO 1 J = 1, 50
      HYD43(J) = HYD43N(J)
      HYD05(J) = HYD05N(J)
      IF(.NOT.RTRYD) GO TO 1
      HYDDS(J) = HYDDSN(J)
    1 CONTINUE
C  INITIALIZE TOTAL FLOODING COST IN FLOOD PLAIN
 1191 COSTFP = 0.0
C  PROCEED DOWNSTREAM THROUGH SUBWATERSHEDS ONE AT A TIME.
      DO 1500 NW = 2,MW
C  SUBWATERSHED INITIALIZATION
      DO 106 K=1,13
  106 OUTPUT(K) = 0.0
      IHN=0
      IHE=0
      IRN=0
      IRE=0
      IMPROV=1
      RC=-1.0
C  DISCOUNTED AVERAGE URBANIZATION DURING SUBWATERSHED STAGE
      IF(.NOT.RBIG) GO TO 49
      CALL UCFIX(CRFSM,CTOTR,GSF,HYDTLS,LOOPTR,NSTAGE,NSTEMX,NW,PCT,UN,
     1PWFR,SPWFAC,TIME,TIMST,USUBW)
      GO TO 51
   49 UN=USUBW(NW,NSTAGE)+(GSF*(USUBW(NW,NSTAGE+1)-USUBW(NW,NSTAGE)))/
     1TIME
   51 IF(LOC(NW) .GT. 0)  GO TO 53
      UZ=USUBW(NW,NSTAGE)
      GO TO 54
   53 MN=LOC(NW)
      UZ=USUBW(NW,MN)
C  FACTORS FOR COMPUTING FLOOD PROOFING COST
```

```
   54 PA=CPF*(UN+VLAGST/VLURST*(1.0-UN))*K2(NW)*K1(NW)**2
      PB=CPF*(UZ+VLAGST/VLURST*(1.0-UZ))*K2(NW)*K1(NW)**2
      PC=PA-PB
C   SELECT URBANIZATION INTERVAL AND CORRESPONDING AGRICULTURAL INCOME
C   AND FLOOD DAMAGE.
      IF (UN .LT. 1.00) GO TO 948
      FUQ=FRU(11)
      GO TO 949
  948 UR=10.0*UN+1.0
      I=UR
      UQ=I
      FUQ=FRU(I)+(UQ-UR)*(FRU(I)-FRU(I+1))
  949 IA=FUQ*FIF(NW)
      FA=FUQ*CDF(NW)
      GA = FUQ*CG(NW)
      IF (LTF.AND. .NOT. HOLDNG) GO TO 7710
C   CALCULATE LOCATION COST MULTIPLE OF Q**0.375
      LA=CLOC(NW,NSTAGE)*K1(NW)*K2(NW)
C   DETERMINE WHETHER RIGHT-OF-WAY SHOULD BE HELD FOR LATER USE
      IF(.NOT. HOLDNG) GO TO 7710
      IF (CHANEL(NW)) GO TO 7711
      RBEG=VALUE(NW,NSTAGE)+VLURST*USUBW(NW,NSTAGE)/3.0
      REND=VALUE(NW,NSTAGE+1)+VLURST*USUBW(NW,NSTAGE+1)/3.0
      GO TO 7712
 7711 IF (LINING(NW).EQ.4) GO TO 7713
      RBEG=VALUE(NW,NSTAGE)+VLURST*USUBW(NW,NSTAGE)
      REND=VALUE(NW,NSTAGE+1)+VLURST*USUBW(NW,NSTAGE+1)
 7712 IF (REND.LE.RBEG*(1.0+R)**TIME) GO TO 7713
C   RIGHT-OF-WAY SHOULD BE HELD
      CHU=CLOC(NW,NSTAGE)+IA+IPP*UN-CLEN
      IF (IHOLD(NW).LE.0) GO TO 7714
      ITEMP=IHOLD(NW)
      GO TO 7710
 7714 ITEMP=NSTAGE
      GO TO 7710
C   RIGHT-OF-WAY SHOULD NOT BE HELD
 7713 CHU=0.0
      ITEMP=0
C   ROUTE HYDROGRAPHS TO THE LOWER END OF THE SUBWATERSHED.
 7710 IF(.NOT.CHANEL(NW)) CALL CHRTE(CHKN(NW),CHXN(NW),HYDINT,HYD43N,
     1LOOPTR)
      IF(.NOT. STF .OR. CHANEL(NW))
     1CALL CHRTE(CHKY(NW),CHXY(NW),HYDINT,HYD43,LOOPTR)
      IF(.NOT.CHANEL(NW)) CALL CHRTE(CHKN(NW),CHXN(NW),HYDINT,HYD05N,
     1LOOPTR)
      IF(STF .AND. .NOT. CHANEL(NW)) GO TO 449
      IF(HYDTLS) WRITE(6,1310) (HYD05(I), I = 1, 50)
 1310 FORMAT(10X,14HCHANNEL INFLOW/(10X,10F9.2))
      CALL CHRTE(CHKY(NW),CHXY(NW),HYDINT,HYD05,LOOPTR)
      IF(HYDTLS) WRITE(6,1311) (HYD05(I), I = 1, 50)
 1311 FORMAT(10X,15HCHANNEL OUTFLOW/(10X,10F9.2))
  449 IF(.NOT.RTRYD) GO TO 452
```

```
      IF(.NOT.CHANEL(NW)) CALL CHRTE(CHKN(NW),CHXN(NW),HYDINT,HYDDSN,
     1LOOPTR)
      IF(.NOT. STF .OR. CHANEL(NW))
     1CALL CHRTE(CHKY(NW),CHXY(NW),HYDINT,HYDDS,LOOPTR)
C  DEVELOP LOCAL INFLOW HYDROGRAPHS AND COMBINE WITH ROUTED HYDROGRAPHS.
  452 RESIN = .FALSE.
      IF (RBIG) CALL UCFIX(CRFSM,CTOTR,GSF,HYDTLS,LOOPTR,NSTAGE,NSTEMX,
     1NW,PCT,PUT,PWFR,SPWFAC,TIME,TIMST,UTOTR)
      CALL RSHYDR(AFT(NW),AFV(1,NW),AFV(2,NW),AFW(1,NW),AFW(2,NW),
     1AW(NW),CHANEL(NW),GSF,HYD05,HYD05N,HYD43,HYD43N,HYDBAS,HYDDS,
     2HYDDSN,HYDINT,HYDTLS,KDF,LC(NW),LOOPTR,NDF,NW,PCT,PUT,Q05,Q43,
     3QB05,QB43,RBIG,RESIN,RK24,SIC(NW),STF,TCL(NW),CTOTR(NW,NSTAGE),
     4TIME,TP,TPB,TPW,UTOTR(NW,NSTAGE),UTOTR(NW,NSTAGE+1),V05,V43,VB05,
     5VB43,VF05,VF43,VFDS,YY)
C  INITIALIZE FLOOD PEAKS.
      Q43Y = 0.0
      QDSY = 0.0
      Q05Y = 0.0
      Q43N = 0.0
      QDSN = 0.0
      Q05N = 0.0
C  SEARCH COMBINED HYDROGRAPHS FOR PEAKS.
      DO 475 J = 1,50
      IF(CHANEL(NW)) GO TO 454
      IF(HYD43N(J).GT.Q43N) Q43N = HYD43N(J)
      IF(HYD05N(J).GT.Q05N) Q05N = HYD05N(J)
  454 IF(STF .AND. .NOT. CHANEL(NW)) GO TO 455
      IF(HYD43(J).GT.Q43Y) Q43Y = HYD43(J)
      IF(HYD05(J).GT.Q05Y) Q05Y = HYD05(J)
  455 IF(.NOT.RTRYD) GO TO 475
      IF(STF .AND. .NOT. CHANEL(NW)) GO TO 456
      IF(HYDDS(J).GT.QDSY) QDSY = HYDDS(J)
  456 IF(CHANEL(NW)) GO TO 475
      IF(HYDDSN(J).GT.QDSN) QDSN = HYDDSN(J)
  475 CONTINUE
      IF(HYDTLS) WRITE(6,1344) NW,Q43N,Q43Y,Q05N,Q05Y,QDSN,QDSY
 1344 FORMAT(/10X,27HFLOOD PEAKS AT SUBWATERSHED,I3/15X,6HQ43N =,F9.2,
     11X,3HCFS/15X,6HQ43Y =,F9.2,1X,3HCFS/15X,6HQ05N =,F9.2,1X,3HCFS/
     215X,6HQ05Y =,F9.2,1X,3HCFS/15X,6HQDSN =,F9.2,1X,3HCFS/15X,6HQDSY =
     3,F9.2,1X,3HCFS)
C  DEVELOP THE RELATIONSHIP BETWEEN FLOOD PEAK AND FREQUENCY.
      CALL CHFLDS(CHANEL(NW),HYDTLS,KDF,LOOPTR,NDF,Q05N,Q05Y,Q43N,Q43Y,
     1QO(NW),QDSN,QDSY,QQ,QX,STF,Y,YY)
C  DEVELOP OPTIMUM FLOOD CONTROL POLICY FOR THE SUBWATERSHED.
      CALL FPCOST(LOOPTR)
C  ACCUMULATE SUBWATERSHED COSTS.
      COSTFP=COSTFP+OUTPUT(13)
      WRITE(6,1000) OUTPUT(13),COSTFP
 1000 FORMAT(10X,48HTOTAL COST OF MEASURES WITHIN SUBWATERSHED =    $F10.
     12/10X,48HTOTAL COST OF MEASURES ON LINE TO THIS POINT = $F10.2//)
C  SELECTS HYDROGRAPHS TO BE CARRIED DOWNSTREAM DEPENDING ON WHETHER OR
C  NOT SUBWATERSHED CHANNEL WAS IMPROVED.
```

```
      DO 2 J = 1,50
      IF(CH9(NW)) GO TO 3
      IF(STF .AND. .NOT. CHANEL(NW+1)) GO TO 2
      HYD43(J) = HYD43N(J)
      HYD05(J) = HYD05N(J)
      IF(RTRYD) HYDDS(J) = HYDDSN(J)
      GO TO 2
    3 HYD43N(J) = HYD43(J)
      HYD05N(J) = HYD05(J)
      IF(RTRYD) HYDDSN(J) = HYDDS(J)
    2 CONTINUE
 1500 CONTINUE
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE CHANYZ LEFT)
      RETURN
      END


      SUBROUTINE CHFIX(A0,BDMAX,BDMIN,HMAX,LINING,LOOPTR,MANNR,MANNT,
     1MANNU,NW,Q0,S,T0,W0,ZT,ZU)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C            VERSION OF NOVEMBER  1, 1966
C  FIX THE DIMENSIONS OF CHANNELS IMPROVED PRIOR TO THE BEGINNING OF
C         THE PLANNING PERIOD FOR THE PURPOSE OF ESTIMATING THE COST OF
C         CHANNEL ENLARGEMENT.  EVEN IF THE CRITERIA USED IN BUILDING THE
C         EXISTING CHANNEL DO NOT CONFORM TO THOSE USED IN THIS PROGRAM,
C         THIS SUBROUTINE CAUSES ALL COSTS TO BE BASED ON THE SAME
C         DESIGN CRITERIA.
      REAL MANNR,MANNT,MANNU
      DIMENSION A0(15),LINING(15),Q0(15),S(15),T0(15),W0(15)
      LOGICAL LOOPTR
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,24HSUBROUTINE CHFIX ENTERED)
      Q=Q0(NW)
      IF (LINING(NW) .GE. 3)  GO TO 5
C  FIX FOR UNLINED CHANNELS
      X=BDMIN
    3 H=((Q*MANNU*(X+2.*(SQRT(1.+ZU*ZU)))**0.667)/(SQRT(S(NW))*1.49*(X+Z
     1U)**1.667))**0.375
      IF(H .LE. HMAX .OR. X .GE. BDMAX)  GO TO 4
      X=X+0.5
      GO TO 3
    4 T0(NW)=H*(X+2.0*ZU)
      A0(NW)=0.5*H*(X*H+T0(NW))
      W0(NW)=H*(X+2.4*ZU)+30.0
      GO TO 1312
    5 IF(LINING(NW) .EQ. 4)  GO TO 6
C  FIX FOR TRAPEZOIDAL LINED CHANNELS
      X=BDMIN
  101 H=((Q*MANNT*(X+2.*(SQRT(1.+ZT*ZT)))**0.667)/(SQRT(S(NW))*1.49*(X+Z
     1T)**1.667))**0.375
```

```
      IF(H.LE. HMAX .OR. X .GE. BDMAX)  GO TO 102
      X=X+0.5
      GO TO 101
  102 TO(NW)=H*(X+2.0*ZT)
      AO(NW)=0.5*H*(X*H+TO(NW))
      WO(NW)=H*(X+2.4*ZT)+25.0
      GO TO 1312
C  FIX FOR RECTANGULAR LINED CHANNELS
    6 X=BDMIN
      H=(Q*MANNR*(X+2.0)**0.667 /(SQRT(S(NW))*1.49*X**1.667))**0.375
      TO(NW)=X*H
      AO(NW)=H*TO(NW)
      WO(NW)=TO(NW)+20.0
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,21HSUBROUTINE CHFIX LEFT)
      RETURN
      END


      SUBROUTINE CHFLDS(CHTRUE,HYDTLS,KDF,LOOPTR,NDF,Q05N,Q05Y,Q43N,
     1Q43Y,QCAP,QDSN,QDSY,QQ,QX,STF,Y,YY)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 15, 1967
C  USES Q43, QDS, Q05 TO DETERMINE THE MAGNITUDE OF THE 16 FLOODS
C        QX(2,16) USED TO ESTIMATE DAMAGES, AND OF THE NDF FLOODS
C        QQ(2,NDF) USED IN ANALYZING THE SUBWATERSHED STAGE.
      DIMENSION QQ(2,15),QX(2,16),Y(16),YY(10)
      LOGICAL CHTRUE,HYDTLS,LOOPTR,STF
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE CHFLDS ENTERED)
C ANALYSIS BASED ON DF(1) = 0.43 AND DF(NDF) = 0.005
C  CHECK NEED FOR SEPARATE GUMBEL PARAMETERS FOR SMALL FLOODS.
      IF (KDF.LE.1) GO TO 15
C  GUMBEL PARAMETERS FOR FLOODS SMALLER THAN RESERVOIR DESIGN FLOOD.
      QN = QDSN
      QY = QDSY
      YDS = YY(KDF)
   12 IF(CHTRUE) GO TO 13
      XLN = (Q43N*YDS-QN*0.579)/(YDS-0.579)
      ALN = (YDS-0.579)/(QN-Q43N)
   13 IF(STF .AND. .NOT. CHTRUE) GO TO 16
      XLY = (Q43Y*YDS-QY*0.579)/(YDS-0.579)
      ALY = (YDS-0.579)/(QY-Q43Y)
C  CHECK NEED FOR SEPARATE GUMBEL PARAMETERS FOR LARGE FLOODS.
      IF (KDF .NE. NDF) GO TO 16
      YYTEST = 10.0
      GO TO 18
   15 YDS = 0.579
      YYTEST =  -3.0
C  GUMBEL PARAMETERS FOR FLOODS LARGER THAN RESERVOIR DESIGN FLOOD.
   14 QN = Q43N
```

```
      QY = Q43Y
   16 IF(CHTRUE) GO TO 17
      XHN = (QN*5.296-Q05N*YDS)/(5.296-YDS)
      AHN = (5.296-YDS)/(Q05N-QN)
   17 IF(STF .AND. .NOT. CHTRUE) GO TO 18
      XHY = (QY*5.296-Q05Y*YDS)/(5.296-YDS)
      AHY = (5.296-YDS)/(Q05Y-QY)
C CALCULATE FLOWS IN EXCESS OF CHANNEL CAPACITY BY FREQUENCY
   18 IF (KDF.GE.2.AND.KDF.LT.NDF) YYTEST = YY(KDF)
      IF(CHTRUE) GO TO 30
      DO 28 I = 1,16
      IF(Y(I).GT.YYTEST)   QX(1,I) = Y(I)/AHN + XHN - QCAP
      IF(Y(I).LE.YYTEST)   QX(1,I) = Y(I)/ALN + XLN - QCAP
      IF(QX(1,I).LT.0.0) QX(1,I) = 0.0
   28 CONTINUE
      IF(STF .AND. .NOT. CHTRUE) GO TO 33
   30 DO 32 I = 1,16
      IF(Y(I).GT.YYTEST)   QX(2,I) = Y(I)/AHY + XHY - QCAP
      IF(Y(I).LE.YYTEST)   QX(2,I) = Y(I)/ALY + XLY - QCAP
      IF(QX(2,I).LT.0.0) QX(2,I) = 0.0
   32 CONTINUE
C CALCULATE DESIGN FLOOD FLOWS
   33 IF(CHTRUE) GO TO 40
      DO 38 I = 1,NDF
      IF (I .GE. KDF .AND. KDF .NE. NDF) QQ(1,I)=YY(I)/AHN + XHN
      IF (I .LT. KDF .OR. KDF .EQ. NDF) QQ(1,I)=YY(I)/ALN + XLN
   38 CONTINUE
      IF(STF .AND. .NOT. CHTRUE) GO TO 43
   40 DO 42 I = 1,NDF
      IF (I .GE. KDF .AND. KDF .NE. NDF) QQ(2,I)=YY(I)/AHY + XHY
      IF (I .LT. KDF .OR. KDF .EQ. NDF) QQ(2,I)=YY(I)/ALY + XLY
   42 CONTINUE
C  WRITE FLOOD PEAKS.
   43 IF(.NOT.HYDTLS) GO TO 1312
      IF(CHTRUE) GO TO 44
      WRITE(6,1350) (QQ(1,I), I = 1, NDF)
 1350 FORMAT (10X,25HDESIGN FLOOD PEAKS IN CFS/15X,10F10.1)
   44 IF(.NOT. STF .OR. CHTRUE)
     1WRITE(6,1350) (QQ(2,I), I = 1, NDF)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE CHFLDS LEFT)
      RETURN
      END


      SUBROUTINE CHOPTM(LOOPTR)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  PROCEDURE FOR OPTIMIZING CHANNEL IMPROVEMENT IN CONJUNCTION WITH
C           NONSTRUCTURAL MEASURES WITHIN A GIVEN SUBWATERSHED-STAGE
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
```

```
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),QO(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),TO(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 WO(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLONG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      REAL L,LA,ND
      LOGICAL CHANEL,CHECK,LG,LINED,LINEX,LL,LOOPTR,PG,PP,RTEST,SG,SS,
     1TRACE,UNC
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE CHOPTM ENTERED)
C  PREVENTS REJECTION OF FLOOD PROOFING WITHOUT TESTING FLOODS BIGGER
C       THAN RESERVOIR DESIGN FLOOD
      RKDF = KDF
C  SETS INITIAL VALUES FOR SUBWATERSHED STAGE
C  DESIGN CHANNEL DIMENSIONS AND KIND
      ST=0.0
      ND=0.0
      FD=0.0
      HN=0.0
      HE=0.0
      RN=0.0
      RE=0.0
      T=0.0
      W=0.0
      A=0.0
      NDTEMP = NDT(NW)
      FDTEMP = FDA(NW)
      ATEMP=0.
      HETEMP=0.
      HTEMP=0.
      RTEMP=0.
      RETEMP=0.
      STEMP=0.
      TTEMP=0.
      WTEMP=0.
      LGTEMP=LINING(NW)
      QP=QO(NW)
      QL=QO(NW)
      QS=QO(NW)
      CTT=0.
C  SETS WHETHER DOWNSTREAM COSTS HAVE BEEN CALCULATED AND LOCATION,
```

```
C   STRUCTURAL, AND FLOOD PROOFING MEASURES HAVE BEEN PROVED TO BE
C   ECONOMICAL DURING THE SUBWATERSHED STAGE.
      LINEX=.FALSE.
      LG=.FALSE.
      SG=.FALSE.
      PG=.FALSE.
      OUTPUT(1)=F
      IF(CHANEL(NW))  OUTPUT(2)=F
      OUTPUT(3)=QO(NW)
C   CALCULATE DAMAGES DUE TO UNRESTRICTED FLOODING BY USE OF SUBROUTINE C
      NN=1
      IF(CHANEL(NW))  NN=2
      CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,QO,QP,
     1QS,QX,R,UN,UNC,VA,VLAGST,VLURST)
      CF=CD+CU
      CT=CF
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      IF(CHECK) WRITE(6,1007) NW,(OUTPUT(I),I=1,13)
 1007 FORMAT(1X,I2,2HBG,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
      IF(CT .LE. 0.)  GO TO 1000
C   DETERMINE THE OPTIMUM LEVEL OF FLOOD PROOFING
      IF(PP)  GO TO 207
      PT=1.
      DO 206 IP=1,NDF
      IF(TRACE) WRITE(6,1001) NW
 1001 FORMAT (1X,I2,3H  P)
      P=DF(IP)
      IF(F .LT. P)  GO TO 206
      QP=QQ(1,IP)
      IF(CHANEL(NW))  QP=QQ(2,IP)
      CP=    PA*(QP-QS)**0.75
      IF(CP .LE. 0.)  GO TO 207
      IF(CP .GT. CT)  GO TO 200
      GO TO 201
  200 PP=.TRUE.
      GO TO 207
  201 PG=.TRUE.
      NN=1
      IF(CHANEL(NW))  NN=2
      CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,QO,QP,
     1QS,QX,R,UN,UNC,VA,VLAGST,VLURST)
C   EXPERIENCE HAS SHOWN PROOFING WILL NOT MAKE IT LATER ON IF IT MISSES
C   THE FIRST TWO TIMES.
      IF (PT .GE. RKDF+2.0 .AND. CTT .GT. 0.0) GO TO 202
      GO TO 203
  202 IF(CTT .LT. CD+CP+CU)  GO TO 207
  203 CTT=CD+CP+CU
      IF(CTT .LT. CT)  GO TO 204
      GO TO 205
  204 CT=CTT
```

```
      OUTPUT(5)=0.0
      OUTPUT(6)=0.0
      OUTPUT(7)=0.0
      OUTPUT(8)=P
      OUTPUT(9) =QP
      OUTPUT(10)=CP
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      IF(CHECK) WRITE(6,1002) NW,(OUTPUT(I),I=1,13)
 1002 FORMAT(1X,I2,2H P,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
  205 PT=PT+1.
  206 CONTINUE
C  DETERMINE THE OPTIMUM LEVEL OF LAND USE ADJUSTMENT
  207 IF(LL)  GO TO 220
      DO 215 IL=1,NDF
      IF(TRACE) WRITE(6,1003) NW
 1003 FORMAT (1X, I2,3H  L)
      L=DF(IL)
      IF(F .LT. L) GO TO 215
      QP=QO(NW)
      QL=QQ(1,IL)
      IF(CHANEL(NW))  QL=QQ(2,IL)
      CL=   LA*(QL-QS)**0.375
      IF(CL .GT. CT .AND. .NOT. LG)  LL=.TRUE.
      IF(CL .GT. CT)  GO TO 220
      LG=.TRUE.
      NN=1
      IF(CHANEL(NW))  NN=2
      CALL CD2(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,QO,QL,
     1QP,QS,QX,R,UN,UNC,UZ,VA,VLAGST,VLURST)
      CTT=CD+CL+CU
      IF(CTT .LT.  CT)  GO TO 208
      GO TO 2080
  208 CT=CTT
      OUTPUT(5)=L
      OUTPUT(6)=QL
      OUTPUT(7)=CL
      OUTPUT(8)=0.0
      OUTPUT(9)=0.0
      OUTPUT(10)=0.0
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      IF(CHECK) WRITE(6,1004) NW,(OUTPUT(I),I=1,13)
 1004 FORMAT(1X,I2,2H L,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
C  DETERMINE THE OPTIMUM COMBINATION OF FLOOD PROOFING AND LAND USE
C  MANAGMENT.
 2080 IF(PP)  GO TO 215
      PT=1.
      DO 214 IP=1,NDF
      IF(TRACE) WRITE(6,1005) NW
```

```
 1005 FORMAT (1X,I2,5H  L+P)
      P=DF(IP)
      IF(F .LT. P)  GO TO 214
      QP=QQ(1,IP)
      IF(CHANEL(NW))  QP=QQ(2,IP)
      CP=   PB*(QP-QS)**0.75
      IF(QP .GT. QL) CP=CP+   PC*((QP-QS)**0.375-(QP-QL)**0.375)**2
      IF(CP .LE. 0.)  GO TO 215
      IF(CP+CL .GT. CT .AND. .NOT. PG)  PP=.TRUE.
      IF(CP+CL .GT. CT)  GO TO 215
      PG=.TRUE.
      NN=1
      IF(CHANEL(NW))  NN=2
      CALL CD2(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,NN,NW,QO,QL,
     1QP,QS,QX,R,UN,UNC,UZ,VA,VLAGST,VLURST)
      IF (PT .GE. RKDF+2.0) GO TO 210
      GO TO 211
  210 IF(CTT .LT. CP+CL+CD+CU)  GO TO 215
  211 CTT=CD+CL+CP+CU
      IF(CTT .LT. CT)  GO TO 212
      GO TO 213
  212 CT=CTT
      OUTPUT(5)=L
      OUTPUT(6)=QL
      OUTPUT(7)=CL
      OUTPUT(8)=P
      OUTPUT(9)=QP
      OUTPUT(10)=CP
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      IF(CHECK) WRITE(6,1006) NW,(OUTPUT(I),I=1,13)
 1006 FORMAT(1X,I2,2HLP,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
  213 PT=PT+1.
  214 CONTINUE
      IF(LL)  GO TO 220
  215 CONTINUE
C  DETERMINE THE OPTIMUM LEVEL OF CHANNEL IMPROVEMENT
  220 IF(SS)  GO TO 1000
      DO 999 IS=1,NDF
      IIS=IS+1
      IF(TRACE) WRITE(6,1011) NW
 1011 FORMAT (1X,I2,3H  S)
      ST=DF(IS)
      IF(F .LT.ST)  GO TO 999
      QP=QQ(2,IS)
      QL=QP
      QS=QP
      CALL STR(LOOPTR)
      IF(CS .GT. CT)  GO TO 1000
C   RESIDUAL DAMAGES ALREADY CALCULATED IN "STR" IF LINED = .TRUE.
      IF (.NOT. LINED) CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,
```

```
     1LOOPTR,2,NW,Q0,QP,QS,QX,R,UN,UNC,VA,VLAGST,VLURST)
      IF(CS+CD+CU .GT. CT)  GO TO 227
      CTT=CS+CD+CU
      IF(CTT .LT. CT) GO TO 224
      GO TO 227
C  LINING OF PREVIOUSLY CONSTRUCTED CHANNELS
  224 IF (LINED)  GO TO 1200
      CT=CTT
      SG=.TRUE.
      LINEX=.FALSE.
      OUTPUT(2)=ST
      OUTPUT(3)=QS
      OUTPUT(4)=CS
      DO 225 M=5,10
  225 OUTPUT(M)=0.0
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
C  PRESERVES DIMENSIONS OF OPTIMUM CHANNEL IN ORDER TO RETURN TO THEM IF
C           SUBSEQUENT TRIAL CHANNEL DOES NOT WORK OUT.
      LGTEMP=LINING(NW)
      STEMP=ST
      NDTEMP=ND
      FDTEMP=FD
      HTEMP=HN
      HETEMP=HE
      RTEMP=RN
      RETEMP=RE
      TTEMP=T
      WTEMP=W
      ATEMP=A
      IF(CHECK) WRITE(6,1012) NW,(OUTPUT(I),I=1,13)
 1012 FORMAT(1X,I2,2H S,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
C  EVALUATE FLOOD PROOFING TO SUPPLEMENT CHANNEL IMPROVEMENT
  227 IF(IS .EQ. NDF)  GO TO 1000
      IF(PP)  GO TO 238
      PT=1.
      DO 237 IP=IIS,NDF
      IF(TRACE) WRITE(6,1013) NW
 1013 FORMAT (1X,I2,5H  S+P)
      P=DF(IP)
      QP=QQ(2,IP)
      IF (QP .LT. QS) GO TO 237
      CP=   PA*(QP-QS)**0.75
      IF(CP .LE. 0.)  GO TO 238
      IF(CP+CS .GT. CT)  GO TO 238
      CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,2,NW,Q0,QP,QS,
     1QX,R,UN,UNC,VA,VLAGST,VLURST)
      IF (PT .GE. RKDF+2.0) GO TO 228
      GO TO 229
  228 IF(CTT .LT. CD+CP+CS+CU)  GO TO 238
  229 CTT=CD+CP+CS+CU
```

```
      IF(CTT .LT. CT) GO TO 231
      GO TO 236
  231 CT=CTT
      SG=.TRUE.
      LINEX=.FALSE.
      OUTPUT(2)=ST
      OUTPUT(3)=QS
      OUTPUT(4)=CS
      OUTPUT(5)=0.0
      OUTPUT(6)=0.0
      OUTPUT(7)=0.0
      OUTPUT(8)=P
      OUTPUT(9)=QP
      OUTPUT(10)=CP
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      LGTEMP=LINING(NW)
      STEMP=ST
      NDTEMP=ND
      FDTEMP=FD
      HTEMP=HN
      HETEMP=HE
      RTEMP=RN
      RETEMP=RE
      TTEMP=T
      WTEMP=W
      ATEMP=A
      IF(CHECK) WRITE(6,1014) NW,(OUTPUT(I),I=1,13)
 1014 FORMAT(1X,I2,2HSP,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
  236 PT=PT+1.
  237 CONTINUE
C  EVALUATE LOCATION ADJUSTMENT TO SUPPLEMENT CHANNEL IMPROVEMENT
  238 IF(LL)  GO TO 999
      DO 249 IL=IIS,NDF
      IF(TRACE) WRITE(6,1015) NW
 1015 FORMAT (1X,I2,5H   S+L)
      L=DF(IL)
      QP=QS
      QL=QQ(2,IL)
      IF (QL .LT. QS) GO TO 249
      CL=    LA*(QL-QS)**0.375
      IF(CL+CS .GT. CT)  GO TO 999
      CALL CD2(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,2,NW,QO,QL,QP,
     1QS,QX,R,UN,UNC,UZ,VA,VLAGST,VLURST)
      CTT=CD+CL+CS+CU
      IF(CTT .LT. CT) GO TO 240
      GO TO 226
  240 CT=CTT
      SG=.TRUE.
      LINEX=.FALSE.
      OUTPUT(2)=ST
```

```
      OUTPUT(3)=QS
      OUTPUT(4)=CS
      OUTPUT(5)=L
      OUTPUT(6)=QL
      OUTPUT(7)=CL
      OUTPUT(8)=0.0
      OUTPUT(9)=0.0
      OUTPUT(10)=0.0
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      LGTEMP=LINING(NW)
      STEMP=ST
      NDTEMP=ND
      FDTEMP=FD
      HTEMP=HN
      HETEMP=HE
      RTEMP=RN
      RETEMP=RE
      TTEMP=T
      WTEMP=W
      ATEMP=A
      IF(CHECK) WRITE(6,1016) NW,(OUTPUT(I),I=1,13)
 1016 FORMAT(1X,I2,2HSL,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
C  EVALUATE ALL THREE TYPES OF MEASURES IN COMBINATION
  226 IF(PP)  GO TO 249
      PT=1.
      DO 2499 IP=IIS,NDF
      IF(TRACE) WRITE(6,1017) NW
 1017 FORMAT (1X,I2,7H  S+L+P)
      P=DF(IP)
      QP=QQ(2,IP)
      CP=    PB*(QP-QS)**0.75
      IF(QP .GT. QL) CP=CP+    PC*((QP-QS)**0.375-(QP-QL)**0.375)**2
      IF(CP .EQ. 0.)  GO TO 249
      IF(CP+CL+CS .GT. CT)  GO TO 249
      CALL CD2(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,2,NW,QO,QL,QP,
     1QS,QX,R,UN,UNC,UZ,VA,VLAGST,VLURST)
      IF (PT .GE. RKDF+2.0) GO TO 245
      GO TO 246
  245 IF(CTT .LT. CD+CP+CL+CS+CU)  GO TO 249
  246 CTT=CD+CP+CS+CL+CU
      IF (CTT .LT. CT) GO TO 247
      GO TO 248
  247 CT=CTT
      SG=.TRUE.
      LINEX=.FALSE.
      OUTPUT(2)=ST
      OUTPUT(3)=QS
      OUTPUT(4)=CS
      OUTPUT(5)=L
      OUTPUT(6)=QL
```

```
      OUTPUT(7)=CL
      OUTPUT(8)=P
      OUTPUT(9)=QP
      OUTPUT(10)=CP
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CT
      LGTEMP=LINING(NW)
      NDTEMP=ND
      FDTEMP=FD
      HTEMP=HN
      HETEMP=HE
      RTEMP=RN
      RETEMP=RE
      TTEMP=T
      WTEMP=W
      ATEMP=A
      IF(CHECK) WRITE(6,1018) NW,(OUTPUT(I),I=1,13)
 1018 FORMAT(1X,I2,3HSLP,    2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
  248 PT=PT+1.
 2499 CONTINUE
  249 CONTINUE
C   END OF CHANNEL IMPROVEMENT LOOPS
  999 CONTINUE
C   POINT OUTSIDE ALL MEASURE ANALYSIS LOOPS
 1000 CONTINUE
      IF (LINEX) LINED = .TRUE.
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE CHOPTM LEFT)
      RETURN
C   SET OUTPUT IF LINING PREVIOUSLY CONSTRUCTED CHANNEL
 1200 OUTPUT(3)=QLINED
      OUTPUT(4)=CS
      DO 1201 K=5,10
 1201 OUTPUT(K)=0.0
C   DETERMINE FREQUENCY OF WATER LEAVING LINED CHANNEL
      L1=1
      IF (RTEST .AND. QLINED .GT. QQ(2,KDF))L1=KDF
      L2=NDF
      IF (RTEST .AND. QLINED .LE. QQ(2,KDF)) L2=KDF
      YDIF=YY(L1)-YY(L2)
      XF=(QQ(2,L2)*YY(L1)/(YDIF))-(QQ(2,L1)*YY(L2)/(YDIF))
      AG=-YDIF/(QQ(2,L2)-QQ(2,L1))
      YF=AG*(QLINED-XF)
C   OUTPUT WITH CHANNEL OF VERY LARGE CAPACITY
      IF (YF .LT. FTOP) GO TO 1202
      OUTPUT(2)=0.0005
      OUTPUT(11)=0.0
      OUTPUT(12)=0.0
      OUTPUT(13)=CS
      GO TO 1203
C   OUTPUT WITH SMALLER CHANNEL
```

```
 1202 TEMP=EXP(-YF)
      OUTPUT(2)=   1.0-EXP(-TEMP)
      OUTPUT(11)=CD
      OUTPUT(12)=CU
      OUTPUT(13)=CTT
 1203 LGTEMP=3
      CT=OUTPUT(13)
      STEMP=OUTPUT(2)
      NDTEMP=0.0
      FDTEMP=0.0
      HTEMP=0.0
      HETEMP=0.0
      RTEMP=0.0
      RETEMP=0.0
      TTEMP=T
      WTEMP=W
      ATEMP=A
      IF(CHECK) WRITE(6,1040) NW,(OUTPUT(I),I=1,13)
 1040 FORMAT(1X,I2,2HLN,1X,2PF7.3,3(1X,2PF6.3,0PF8.0,F8.0),3F10.0)
C  RETURN TO SEE IF ENLARGING TO A GREATER DESIGN FREQUENCY IS MORE
C           ECONOMICAL THAN LINING TO A SMALLER ONE
      F=DF(IS)
      ISX=IS+2
      IF (ISX .LE. NDF) F=DF(ISX)
      LINEX = .TRUE.
      GO TO 220
      END


      SUBROUTINE CHRTE(CHK,CHX,HYDINT,HYGRAF,LOOPTR)
C   UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF MARCH 21, 1967
C   USES THE MUSKINGUM METHOD TO ROUTE HYGRAF(50) THROUGH A REACH OF
C        CHANNEL HAVING THE SPECIFIED VALUES OF THE MUSKINGUM ROUTING
C        PARAMETERS K = CHK AND X = CHX.
      DIMENSION HYGRAF(50),HYIN(50)
      LOGICAL LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,24HSUBROUTINE CHRTE ENTERED)
C  CALCULATE MUSKINGUM ROUTING VALUES: CM0, CM1, CM2
      DENOM = CHK*(1.0-CHX) + 0.5*HYDINT
      CM0 = -(CHK*CHX - 0.5*HYDINT)/DENOM
      CM1 = (CHK*CHX + 0.5*HYDINT)/DENOM
      CM2 = (CHK*(1.0-CHX) - 0.5*HYDINT)/DENOM
C  ESTABLISH HYDROGRAPH OF REACH INFLOW.
      DO 1 I = 1, 50
    1 HYIN(I) = HYGRAF(I)
C  CALCULATE HYDROGRAPH OF REACH OUTFLOW.
      DO 2 J = 2, 50
      HYGRAF(J) = CM0*HYIN(J) + CM1*HYIN(J-1) + CM2*HYGRAF(J-1)
    2 IF (HYGRAF(J) .LE. 0.0) HYGRAF(J) = HYGRAF(J-1)
```

```
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,21HSUBROUTINE CHRTE LEFT)
      RETURN
      END


      SUBROUTINE DAMBLD
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C THE SIZE AND COST OF THE DAM REQUIRED TO CONTAIN THE SPECIFIED DESIGN
C         FLOOD ARE DETERMINED.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      LOGICAL DMDTLS,KNBOT,LOOPTR,WFIX,WFX
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE DAMBLD ENTERED)
C  DETERMINE WHETHER OPTIMUM EMERGENCY SPILLWAY WIDTH HAS BEEN
C  PREVIOUSLY DETERMINED FOR THIS STAGE.
      WFX = WFIX(NSTAGE)
C  DETERMINE CREST ELEVATIONS OF PRINCIPAL SPILLWAY, EMERGENCY SPILLWAY
C  AND DAM.
      CALL DAMSIZ
```

```
      IF(.NOT.WFX) GO TO 10
      DFR = 1.0/FRES
C  ASSUME FACE OF DAM RIPRAPPED AGAINST WAVE ACTION FROM 2.0 FEET BELOW
C  TOP OF SEDIMENT STORAGE TO THE ELEVATION OF THE EMERGENCY SPILLWAY
C  DESIGN FLOOD CREST.
      ELRPTP = TPELEV - DMFRBD
      ELRPBT = ELPRFL - 2.0
      IF (XTRSTR.NE.0.0) ELRPBT = ELEVA(3)
C  DESIGN AND ESTIMATE QUANTITIES FOR DAM EMBANKMENT
      CALL DAMVOL(CTBW,LGDAM,DMDTLS,DMTPW,DPRCKV,DPRP,TPELEV,ELEVA,
     1ELRPBT,ELRPTP,IMAX,LOOPTR,VOLCT,VOLDAM,VOLRP,ZCT,ZDN,ZUP)
C  DESIGN AND ESTIMATE QUANTITIES FOR EMERGENCY SPILLWAY STILLING BASIN
      CALL STLBAS(CONBOT,CONWAL,D1,DMDTLS,ELEVA,ELSPFL,ELSPTP,GRADSP,
     1HWAL,IMAX,KNBOT,LGEMSP,LOOPTR,NWH,QEMSP,SBCONC,SBEX,SPLNG,STLBOT,
     2TPELEV,TWELEV,WDEMSP)
C  DESIGN AND ESTIMATE QUANTITIES FOR EMERGENCY SPILLWAY CREST AND CHUT
      CALL EMSPVL(CONBOT,CONWAL,D1,DMDTLS,DPRCKH,ELEVA,ELSPFL,ELSPTP,
     1SPEX,GRADSP,HLSIDE,HWAL,IMAX,LGAPCH,LOOPTR,NWH,QEMSP,SPCONC,SPLNG
     2SPRKEX,TPELEV,WDEMSP,ZCT)
C  DESIGN AND ESTIMATE QUANTITIES FOR PRINCIPAL SPILLWAY (NO SPILLWAY I
C  NO FLOOD STORAGE).
      TRAREA = 0.0
      PRCON = 0.0
      CONID = 0.0
      IF(FLDSTR.GT.0.0)CALL PRNSP(CONID,DMDTLS,DMTPW,DRQ,ELEVA(1),ELPRF
     1,ELSPFL,FPIPE,LOOPTR,PRCON,TPELEV,TRAREA,TRV,TWELEV,ZDN,ZUP)
C  ESTIMATE "COSTDM" FROM ABOVE QUANTITIES AND READ UNIT COSTS.
      CALL DMCOST(AQR,BYVERT,CONID,COSTDM,CRELOC,CRFSM,CSMD,DFR,DMDTLS,
     1ELEVA,ELSPFL,ESMD,LOOPTR,MDAM,PRCON,RESACR,RESVOL,SPRKEX,SBCONC,
     2SBEX,SEDSTR,SPCONC,SPEX,TPELEV,TRAREA,UCCLR,UCCNID,UCCT,UCDAM,
     3UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,USUBW(NW,NSTAGE),
     4VALUE(NW,NSTAGE),VLAGST,VLURST,VOLCT,VOLDAM,VOLRP)
   10 IF(LOOPTR) WRITE(6,1314)
 1314 FORMAT(10X,22HSUBROUTINE DAMBLD LEFT)
      RETURN
      END


      SUBROUTINE DAMSIZ
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C THE DAM SIZE REQUIRED TO CONTAIN THE SPECIFIED DESIGN FLOOD AND THE
C        SPECIFIED STORAGE FOR PURPOSES OTHER THAN FLOOD CONTROL
C        IS DETERMINED.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15)
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15)
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
```

```
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      DIMENSION CUMVOD(26)
      LOGICAL DMDTLS,HYDTLS,LOOPTR,RSBLT,WFIX
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE DAMSIZ ENTERED)
C   CUMULATIVE RUNOFF DATA IS JUST USED FOR FIRST APPROXIMATION OF FLOOD
C   STORAGE FOR FIRST TRIAL DESIGN.  LATER TRIAL DESIGNS CAN MAKE
C   VARIATIONS ON PREVIOUS ONES AND THEREBY BETTER ESTIMATE TRUE MARGINAL
C   CHANGES IN DOWNSTREAM FLOOD PEAKS.
      MR = MRDF + 1
      IF (KDF .GE. MR) GO TO 28
C    DETERMINE SEDIMENT STORAGE
      SEDSTR = SEDIN*TIMST*AW(1)
C    ESTIMATE REQUIRED FLOOD STORAGE FROM CUMULATIVE RUNOFF DATA
      FLDSTR = 0.0
      ID = IMPTY + 6
      RD = IMPTY
C   NO FLOOD STORAGE BUT NEED "ID" AND "RD" FOR ESTIMATING BASE FLOW.
      IF(XTRSTR.GT.0.0.AND..NOT.RSBLT) GO TO 10
      DO 2 I = 1, 26
C    CONVERT CUMULATIVE RUNOFF ARRAY DATA FROM MEAN ANNUAL VALUES WITH
C   U = C = 0.0 TO DESIGN FREQUENCY VALUES FOR KNOWN U AND C.
    2 CUMVOD(I) = CUMVOL(I)*VFDS/VF43
C    DETERMINE AVERAGE AND PEAK FLOW DURING PRESCRIBED DRAWDOWN PERIOD
      DRQA = CUMVOD(ID)
      DRQ = QRATIO*DRQA
C   ESTIMATE FLOOD STORAGE FROM CUMULATIVE RUNOFF DATA (MAXIMUM
C   ACCUMULATED INFLOW LESS OUTFLOW).
      DO 5 J = 1,8
```

```
      FJ = J
      FLDTRY = (CUMVOD(J)-DRQA)*FJ*0.495
      IF(FLDTRY.LE.FLDSTR) GO TO 10
    5 FLDSTR = FLDTRY
      DO 8 J = 9,26
      FJ = J - 6
      FLDTRY = (CUMVOD(J)-DRQA)*FJ*1.98
      IF(FLDTRY.LE.FLDSTR) GO TO 10
    8 FLDSTR = FLDTRY
C   DETERMINE TOTAL CONTROLLED STORAGE
   10 CONSTR = SEDSTR + XTRSTR + FLDSTR
C   DETERMINE STORAGE VOLUME AS A FUNCTION OF ELEVATION
      RESVOL(1) = 0.0
      DO 12 I = 2,IMAX
   12 RESVOL(I)=RESVOL(I-1)+(ELEVA(I)-ELEVA(I-1))*(RESACR(I)+RESACR(I-1)
     1)/2.0
      IF(FLDSTR.EQ.0.0) GO TO 24
C   DETERMINE ELEVATION OF TOP OF CONSERVATION STORAGE
      DO 20 I = 2,IMAX
      IF(RESVOL(I).GT.SEDSTR+XTRSTR) GO TO 22
   20 CONTINUE
   22 ELPRFL = ELEVA(I-1) + (SEDSTR + XTRSTR - RESVOL(I-1))*(ELEVA(I) -
     1ELEVA(I-1))/(RESVOL(I) - RESVOL(I-1))
C   DETERMINE ELEVATION OF TOP OF TOTAL ACTIVE STORAGE
   24 DO 25 I = 2,IMAX
      IF(RESVOL(I).GT.CONSTR) GO TO 27
   25 CONTINUE
   27 ELSPFL = ELEVA(I-1)+(CONSTR-RESVOL(I-1))*(ELEVA(I)-ELEVA(I-1))/
     1(RESVOL(I)-RESVOL(I-1))
      IF(FLDSTR.NE.0.0) GO TO 28
C  WITH NO FLOOD STORAGE, BASE FLOW IS TAKEN AS AVERAGE FLOW OVER LAST
C  TWO DAYS OF PRESCRIBED DRAWDOWN PERIOD.
      BSFL43=0.5*(CUMVOL(ID)*RD-CUMVOL(ID-2)*(RD-2.0))
      BSFL05=BSFL43*VF05/VF43
      BSFLOW=BSFL43
      IF(HYDTLS) WRITE(6,1347) BSFL43,BSFLOW,BSFL05
C  WATER SURFACE ELEVATION AT BEGINNING OF FLOOD ROUTING DETERMINED BY
C  HEAD REQUIRED TO DISCHARGE BASE FLOW THROUGH EMERGENCY SPILLWAY
C  BECAUSE NO PRINCIPAL SPILLWAY IS PROVIDED.
      ELFB43=ELSPFL+(BSFL43/(CWEIR*WDEMSP))**0.67
      ELFB05=ELSPFL+(BSFL05/(CWEIR*WDEMSP))**0.67
      ELFDBG=ELFB43
      ELPRFL = ELSPFL
      DRQ = 0.0
      GO TO 163
C  HEAD ON PRINCIPAL SPILLWAY DETERMINED BY ELEVATION OF EMERGENCY
C  EMERGENCY SPILLWAY CREST.
   28 HDPRSP = ELSPFL - TWELEV
C  IF BASE FLOWS ALREADY DETERMINED FOR MEAN ANNUAL AND 200-YEAR EVENTS,
C  NEED ONLY ADJUST BASE FLOW FOR CHANGING DESIGN STORM.
      IF (KDF.GE.MR.OR.(KDF.EQ.MRDF.AND.XTRSTR.GT.0.0)) GO TO 128
C  IF BASE FLOW IS INITIALLY ESTIMATED FOR CASE WHERE XTRSTR=0.0, IT IS
```

```
C  TAKEN EQUAL TO AVERAGE FLOW DURING DRAWDOWN PERIOD, EXCLUSIVE OF TIME
C  DURING MAIN FLOOD HYDROGRAPH.
      DO 770 N1 = 1,20
      IF (HYDBAS(1,N1).EQ.1.0) GO TO 771
  770 CONTINUE
  771 P1 = N1
      TBW = 20.0*TPW/P1
      BSFLOW = (DRQA*RD-(VFDS*TBW/24.0))/(RD-TBW/24.0)
      BSFL43 = BSFLOW*VF43/VFDS
      BSFL05 = BSFLOW*VF05/VFDS
      GO TO 129
  128 BSFLOW = BSFL05*VFDS/VF05
  129 IF(HYDTLS) WRITE(6,1347) BSFL43,BSFLOW,BSFL05
 1347 FORMAT(10X,8HBSFL43 =,F7.1,1X,3HCFS,3X,8HBSFLDS =,F7.1,1X,3HCFS,
     1 3X,8HBSFL05 =,F7.1,1X,3HCFS)
C  IF HAVE A PRINCIPAL SPILLWAY, WATER SURFACE ELEVATION AT BEGINNING OF
C  FLOOD ROUTING IS TAKEN AS THE HIGHER OF THAT DETERMINED BY PIPE
C  CONTROL OR THAT DETERMINED BY WEIR CONTROL.  IF IT IS ALREADY
C  DETERMINED FOR THE MEAN ANNUAL AND THE 200-YEAR EVENTS, NEED ONLY
C  REVISE VALUE FOR NEW DESIGN STORM.
C   PIPE CONTROL
      ELFDBG = TWELEV   + HDPRSP*(BSFLOW/DRQ)**2
      IF (KDF .GE. MR) GO TO 130
      ELFB43 = TWELEV   + HDPRSP*(BSFL43/DRQ)**2
      ELFB05 = TWELEV   + HDPRSP*(BSFL05/DRQ)**2
C   WEIR CONTROL
C  ESTIMATING WEIR LENGTH FROM PRINCIPAL SPILLWAY PIPE SIZE ESTIMATED BY
C  DARCY FORMULA.
  130 PRM=1.52*((1.0+  ZDN+ZUP)*DRQ**2)**0.2
      ELT = ELPRFL + (BSFLOW/(3.25 *PRM ))**0.67
      IF (KDF .GE. MR) GO TO 131
      ELT43=ELPRFL + (BSFL43/(3.25 *PRM ))**0.67
      ELT05=ELPRFL + (BSFL05/(3.25 *PRM ))**0.67
  131 IF(ELT.GT.ELFDBG) ELFDBG = ELT
      IF (KDF .GE. MR) GO TO 132
      IF(ELT43 .GT. ELFB43) ELFB43 = ELT43
      IF(ELT05 .GT. ELFB05) ELFB05 = ELT05
  132 CONTINUE
C  FINAL VALUE OF FLOOD STORAGE (ELEVATION OF EMERGENCY SPILLWAY CREST)
C   SET BY ROUTING DESIGN FLOOD THROUGH PRINCIPAL SPILLWAY AS SIZED FROM
C   CUMULATIVE RUNOFF DATA.  FLOW OVER EMERGENCY SPILLWAY IS PREVENTED
C   BY ZERO WEIR COEFFICIENT.
      IF (KDF.NE.1.AND.KDF.NE.NDF) GO TO 42
      IF (KDF.NE.1) GO TO 45
      DO 43 I = 1, 50
   43 HYDEM(I) = HYD43N(I)
      GO TO 40
   45 DO 44 I = 1, 50
   44 HYDEM(I) = HYD05N(I)
      GO TO 40
   42 DO 46 I = 1, 50
   46 HYDEM(I) = HYDDSN(I)
```

```
   40 CALL RESRTE(0.0,DRQ,ELEVA,ELFDBG,ELSPTP,ELPRFL,ELSPFL,0.0,HYDINT,
     1HYDTLS,IMAX,LOOPTR,HYDEM,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
   41 ELSPFL=ELSPTP
C  PRINCIPAL SPILLWAY SIZE ADJUSTED ACCORDING TO ROUTING RESULTS.
      IF(KDF.LE.MRDF) DRQ=DRQ*SQRT((ELSPFL-TWELEV)/HDPRSP)
C  FLOOD STORAGE VOLUME DETERMINED.
      DO 31 I=2,IMAX
      IF(ELEVA(I) .GT. ELSPFL) GO TO 32
   31 CONTINUE
   32 FLDSTR=RESVOL(I-1)+(ELSPFL-ELEVA(I-1))*(RESVOL(I)-RESVOL(I-1))/
     1(ELEVA(I)-ELEVA(I-1))-XTRSTR-SEDSTR
C  IF ECONOMIC STUDY TO DETERMINE THE OPTIMUM EMERGENCY SPILLWAY WIDTH
C  HAS NOT BEEN MADE FOR THIS STAGE, IT IS REQUIRED.
  163 IF(WFIX(NSTAGE)) GO TO 29
   63 CALL SPLSIZ
      GO TO 34
C  MAXIMUM FLOOD ROUTED TO DETERMINE ELEVATION OF DAM TOP UNLESS THIS
C  WAS JUST DONE IN EMERGENCY SPILLWAY WIDTH ANALYSIS.
   29 DO 30 I = 1,50
   30 HYDEM(I) = HYDMLT*HYD05N(I)
      CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB05,ELSPTP,ELPRFL,ELSPFL,0.0,
     1HYDINT,HYDTLS,IMAX,LOOPTR,HYDEM,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
      TPELEV = ELSPTP + DMFRBD
C  THE RESULTING TOP OF DAM ELEVATION IS CHECKED TO SEE IF IT IS IN
C   PROPER RANGE FOR EMERGENCY SPILLWAY SITE CURRENTLY BEING USED.  IF
C   IT IS NOT, THE SITE IS SHIFTED AND THE OPTIMUM EMERGENCY SPILLWAY
C   WIDTH IS DETERMINED FOR THE NEW SITE.  NO NEED FOR CHECK IF HAVE
C   ONLY ONE PLAUSIBLE SPILLWAY SITE.
      IF(NHILSD .EQ. 1) GO TO 60
      IF(TPELEV .GT. HBRLM) GO TO 52
      IF(IS .NE. 1) GO TO 62
      GO TO 60
   52 IF(TPELEV .GT. HBRMH) GO TO 54
      IF(IS .NE. 2) GO TO 62
      GO TO 60
   54 IF(IS .NE. 3) GO TO 62
C  ESTIMATE EMERGENCY SPILLWAY DESIGN FLOW.
   60 QEMSP = CWEIR*WDEMSP*(ELSPTP-ELSPFL)**1.5
   34 IF(DMDTLS) WRITE(6,1350)        DRQ,QEMSP,SEDSTR,XTRSTR,FLDSTR,
     1ELPRFL,ELSPFL,       ELSPTP,TPELEV
 1350 FORMAT(//40X,18HDAM DESIGN DETAILS/20X,32HPRINCIPAL SPILLWAY DESIG
     1N FLOW =,F6.0,1X,3HCFS/20X,32HEMERGENCY SPILLWAY DESIGN FLOW =,F6.
     20,1X,3HCFS//20X,18HSEDIMENT STORAGE =,12X,F8.0,1X,9HACRE-FEET/20X,
     322HCONSERVATION STORAGE =,8X,F8.0,1X,9HACRE-FEET/20X,15HFLOOD STOR
     4AGE =,15X,F8.0,1X,9HACRE-FEET//15X,10HELEVATIONS/20X,20HPRINCIPAL
     5SPILLWAY =,12X,F6.1,1X,4HFEET/20X,26HEMERGENCY SPILLWAY CREST =,6X
     6,F6.1,1X,4HFEET/20X,20HSAFETY FLOOD CREST =,12X,F6.1,1X,4HFEET/20X
     7,12HTOP OF DAM =,20X,F6.1,1X,4HFEET)
      GO TO 1312
C  WRITE WHEN SPILLWAY SITE CHANGED.
   62 WRITE(6,1375)
 1375 FORMAT(10X,40HREOPTIMIZE SPILLWAY WIDTH FOR A NEW SITE)
```

```
      GO TO 63
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE DAMSIZ LEFT)
   64 RETURN
      END


      SUBROUTINE DAMVOL(CTBW,DAMLTH,DMDTLS,DMTPW,DPROCK,DPRP,ELDMTP,
     1ELEVA,ELRPBT,ELRPTP,IMAX,LOOPTR,VOLCT,VOLDAM,VOLRP,ZCT,ZDN,ZUP)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 5, 1967
C  SUBROUTINE DAMVOL COMPUTES THE VOLUME OF FILL IN AN EARTH DAM
C        (VOLDAM), THE VOLUME OF THE CUTOFF TRENCH BENEATH THE DAM
C        (VOLCT), AND THE NECESSARY VOLUME OF RIPRAP ON THE UPSTREAM
C        FACE OF THE DAM (VOLRP).
      DIMENSION DAMLTH(25), ELEVA(25)
      LOGICAL DMDTLS,LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE DAMVOL ENTERED)
C  INITIALIZE QUANTITIES AND COMBINE VARIABLES.
      I = IMAX
      VOLDAM = 0.0
      VOLCT = 0.0
      VOLRP = 0.0
      ZM = (ZUP + ZDN)/2.
C  CANNOT PROCEED IF DATA DOES NOT GO TO TOP OF DAM
      IF(ELDMTP.GT.ELEVA(IMAX)) GO TO 1312
C  START WITH TOP CONTOUR IN DATA AND DECREMENT UNTIL COME TO TOP OF DAM
C  AND CONTINUE TO DECREMENT FIGURING VOLUMES TO THE BOTTOM OF THE DAM.
    1 I = I - 1
      IF(ELDMTP.LE.ELEVA(I)) GO TO 1
C  DAM VOLUMES ARE FIGURED BY APPLYING PRISMOIDAL FORMULA BETWEEN
C  SUCCESSIVE CONTOURS.  ASSUMES ALL CONTOURS ARE STRAIGHT AND
C  PERPENDICULAR TO THE DAM.
      IF(ELDMTP.GT.ELEVA(I+1)) GO TO 2
C  HEIGHTS FOR PORTION OF DAM WHOSE HEIGHT IS LESS THAN THE DISTANCE
C  BETWEEN THE DAM TOP AND THE FIRST CONTOUR.
      SLGTH = (ELDMTP - ELEVA(I))*(DAMLTH(I+1) - DAMLTH(I))/
     1(ELEVA(I+1) - ELEVA(I))
      HMAX = ELDMTP - ELEVA(I)
      HMIN = 0.0
      HMEAN = HMAX/2.
C  VOLUME OF CUTOFF TRENCH
      DAMLNG = DAMLTH(I) + SLGTH
      VOLCT = DAMLNG*DPROCK*(CTBW + ZCT*DPROCK)/27.0
      GO TO 3
C  HEIGHTS FOR THE SUCCESSIVE PORTIONS OF THE DAM WHOSE BOTTOM
C  ELEVATIONS LIE BETWEEN SUCCESSIVE CONTOURS.
    2 SLGTH = DAMLTH(I+1) - DAMLTH(I)
      HMAX = ELDMTP - ELEVA(I)
      HMIN = ELDMTP - ELEVA(I+1)
```

```
      HMEAN = (HMAX + HMIN)/2.
C   CUMULATIVE VOLUME SUMMING
    3 AMAX = HMAX*DMTPW + (HMAX**2)*ZM
      AMIN = HMIN*DMTPW + (HMIN**2)*ZM
      AMEAN = HMEAN*DMTPW + (HMEAN**2)*ZM
      VOLDAM = VOLDAM + SLGTH*(AMIN + AMAX+ 4.*AMEAN)/162.
      IF(I.NE.1) GO TO 1
C   BEGIN COMPUTATION OF RIPRAP VOLUME. DECREMENT TO TOP OF RIPRAP.
      I = IMAX
    6 I = I - 1
      IF(ELRPTP.LT.ELEVA(I)) GO TO 6
C   FIND PROJECTED AREA ON A VERTICAL PLANE OF RIPRAP ON FACE BETWEEN TOP
C     OF RIPRAP AND NEXT CONTOUR DOWN.
      SLGTH = DAMLTH(I)+(ELRPTP-ELEVA(I))*(DAMLTH(I+1)-DAMLTH(I))/
     1(ELEVA(I+1) - ELEVA(I))
      SLG = DAMLTH(I)
      ELG = ELEVA(I)
C   PROVIDE FOR NO CONTOURS BETWEEN TOP AND BOTTOM OF RIPRAP.
      IF(ELRPBT.LE.ELEVA(I)) GO TO 7
      ELG = ELRPBT
      SLG = DAMLTH(I)+(ELRPBT-ELEVA(I))*(DAMLTH(I+1)-DAMLTH(I))/
     1(ELEVA(I+1) - ELEVA(I))
    7 AREA = (ELRPTP-ELG)*(SLG+SLGTH)/2.0
C   CONTINUE CUMULATING PROJECTED AREAS DOWN DAM FACE UNTIL HIT BOTTOM
C   OF RIPRAP.
    8 I = I - 1
      SLG = DAMLTH(I)
      ELG = ELEVA(I)
      IF(ELRPBT.LE.ELEVA(I)) GO TO 9
      ELG = ELRPBT
      SLG = DAMLTH(I)+(ELRPBT-ELEVA(I))*(DAMLTH(I+1)-DAMLTH(I))/
     1(ELEVA(I+1) - ELEVA(I))
    9 AREA = AREA + (ELEVA(I+1) - ELG)*(DAMLTH(I+1) + SLG)/2.0
      IF(I.NE.1.AND.ELRPBT.LT.ELEVA(I)) GO TO 8
C   CONVERTING PROJECTED AREA TO RIPRAP VOLUME
   10 VOLRP = AREA*SQRT(ZUP**2 + 1.0)*DPRP/27.0
   11 IF(DMDTLS) WRITE(6,1350) VOLDAM,VOLCT,VOLRP
 1350 FORMAT(//10X,14HDAM QUANTITIES/15X,15HVOLUME OF DAM =,10X,F10.0,
     11X,11HCUBIC YARDS/15X,22HCUTOFF TRENCH VOLUME =,3X,F10.0,1X,11HCUB
     2IC YARDS/15X,15HRIPRAP VOLUME =,10X,F10.0,1X,11HCUBIC YARDS)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE DAMVOL LEFT)
      RETURN
      END


      SUBROUTINE DMCOST(AQR,BYVERT,CONID,COSTDM,CRELOC,CRFSM,CSMD,DFR,
     1DMDTLS,ELEVA,ELSPFL,ESMD,LOOPTR,MDAM,PRCON,RESACR,RESVOL,RKEX,
     2SBCONC,SBEX,SEDSTR,SPCN,SPEX,TPELEV,TRAREA,UCCLR,UCCNID,UCCT,
     3UCDAM,UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,USUBW,VALUE,VLAGST,
     4VLURST,VOLCT,VOLDAM,VOLRP)
```

```
C    UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 12, 1968
C    DETERMINES THE COST OF THE DAM AND RESERVOIR FROM UNIT COSTS AND
C    CONSTRUCTION QUANTITIES
      LOGICAL DMDTLS,LOOPTR
      DIMENSION CRELOC(25),ELEVA(25),RESACR(25),RESVOL(25)
      REAL MDAM
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE DMCOST ENTERED)
C   ESTIMATE COST OF DAM EMBANKMENT.
      CEMB = UCDAM*VOLDAM + UCCT*VOLCT + UCRP*VOLRP
      IF(DMDTLS) WRITE(6,1) CEMB
    1 FORMAT(15X,22HDAM EMBANKMENT COSTS $,F10.2)
C   ESTIMATE COST OF EMERGENCY SPILLWAY.
      CSPL = UCSPEX*SPEX + UCRKEX*RKEX + UCSPCN*SPCN
      IF(DMDTLS) WRITE(6,2) CSPL
    2 FORMAT(15X,22HEMER. SPILLWAY COSTS $,F10.2)
C   ESTIMATE COST OF EMERGENCY SPILLWAY STILLING BASIN.
      CSB = UCSPCN*SBCONC + UCSPEX*SBEX
      IF(DMDTLS) WRITE(6,3) CSB
    3 FORMAT(15X,22HSTILLING BASIN COSTS $, F10.2)
C   ESTIMATE COST OF PRINCIPAL SPILLWAY INCLUDING ENTRY STRUCTURE AND
C   ENERGY DISSIPATOR.
      CPRSP = UCPRCN*PRCON + UCCNID*CONID + UCTRK*TRAREA
      IF(DMDTLS) WRITE(6,4) CPRSP
    4 FORMAT(15X,22HPRIN. SPILLWAY COSTS $,F10.2)
C DETERMINE THE RESERVOIR AREA TO BE CLEARED OF VEGETATIVE GROWTH.
C   CLEAR FROM 5 FEET BELOW TOP OF SEDIMENT  STORAGE TO ELEVATION OF
C   EMERGENCY SPILLWAY CREST.
      DO 5 I = 2,25
      IF(RESVOL(I).GT.SEDSTR) GO TO 6
    5 CONTINUE
C   FIND ELEVATION OF BOTTOM OF CLEARED AREA.
    6 CLRBOT = ELEVA(I-1)+(SEDSTR-RESVOL(I-1))*(ELEVA(I)-ELEVA(I-1))/
     1(RESVOL(I)-RESVOL(I-1))-5.0
C   FIND ACREAGE ON RESERVOIR BOTTOM NOT NEEDING CLEARING.
      IF(CLRBOT.GT.ELEVA(1)) GO TO 7
      BOTACR = 0.0
      GO TO 10
    7 DO 8 I = 2, 25
      IF(ELEVA(I).GT.CLRBOT) GO TO 9
    8 CONTINUE
    9 BOTACR = RESACR(I-1)+(CLRBOT-ELEVA(I-1))*(RESACR(I)-RESACR(I-1))/
     1(ELEVA(I)-ELEVA(I-1))
C   FIND RESERVOIR ACREAGE UP TO TOP CLEARING LINE.
   10 DO 11 J = I,25
      IF(ELEVA(J).GT.ELSPFL) GO TO 12
   11 CONTINUE
   12 TOPACR = RESACR(J-1)+(ELSPFL-ELEVA(J-1))*(RESACR(J)-RESACR(J-1))/
     1(ELEVA(J)-ELEVA(J-1))
C   ESTIMATE CLEARING COST.
      CCLR = UCCLR*(TOPACR-BOTACR)
```

```
      IF(DMDTLS) WRITE(6,13) CCLR
   13 FORMAT(15X,22HRESR. CLEARING COSTS $,F10.2)
C  TOTAL RESERVOIR CONSTRUCTION COST
      CONCST = CEMB+CSPL+CSB+CPRSP+CCLR
      IF(DMDTLS) WRITE(6,14) CONCST
   14 FORMAT(/15X,18HCONSTRUCTION COSTS,14X,1H$,F11.2)
C  ADD ALLOWANCES FOR CONTINGENCIES, DESIGN, ENGINEERING, AND
C  CONSTRUCTION SUPERVISION.
      CENCN = (CSMD*ESMD - 1.0)*CONCST
      IF(DMDTLS) WRITE(6,15) CENCN
   15 FORMAT(15X,20HENGR + CONTINGENCIES,12X,1H$,F11.2)
C  SUBTOTAL
      CTOT1 = CONCST + CENCN
      IF(DMDTLS) WRITE(6,16) CTOT1
   16 FORMAT(20X,8HSUBTOTAL,19X,1H$,F11.2)
C DETERMINE RIGHT-OF-WAY COST
C  ESTABLISH ELEVATION TO WHICH RIGHT-OF-WAY WILL BE PURCHASED,THE ACRES
C     REQUIRED, AND THE COST OF LAND AND STRUCTURES.
      PURELV = TPELEV + BYVERT
      DO 17 K = J, 25
      IF(ELEVA(K).GT.PURELV) GO TO 18
   17 CONTINUE
   18 ROWACR = RESACR(K-1)+(PURELV-ELEVA(K-1))*(RESACR(K)-RESACR(K-1))/
     1(ELEVA(K) - ELEVA(K-1))
      UCROW = VALUE + VLURST*USUBW + VLAGST*(1.0 - USUBW)
      CROW = ROWACR*UCROW
      IF(DMDTLS) WRITE(6,19) CROW,ROWACR
   19 FORMAT(15X,18HRIGHT OF WAY COSTS,2X,1H$,F11.2/17X,F10.2,2X,
     115HACRES PURCHASED)
C  COST OF RIGHT-OF-WAY ACQUISITION
      CAQR = (AQR - 1.0)*CROW
      IF(DMDTLS) WRITE(6,20) CAQR
   20 FORMAT(15X,17HACQUISITION COSTS,3X,1H$,F11.2)
C  COST OF RELOCATING HIGHWAYS AND OTHER FACILITIES IN THE RESERVOIR
C  SITE
      DO 27 K = J, 25
      IF(ELEVA(K).GT.TPELEV) GO TO 28
   27 CONTINUE
   28 CRELO = CRELOC(K-1)+(TPELEV-ELEVA(K-1))*(CRELOC(K)-CRELOC(K-1))/
     1(ELEVA(K) - ELEVA(K-1))
      IF(DMDTLS) WRITE(6,21) CRELO
   21 FORMAT(15X,16HRELOCATION COSTS,4X,1H$,F11.2)
C  LAND AND RELOCATION COST SUBTOTAL
      CTOT2 = CROW + CAQR + CRELO
      IF(DMDTLS) WRITE(6,16) CTOT2
C  GRAND TOTAL
      CTOT = CTOT1 + CTOT2
      IF(DMDTLS) WRITE(6,22) CTOT
   22 FORMAT(/20X,23HTOTAL INSTALLATION COST,14X,1H$,F11.2)
C  ANNUAL COST OF DAM AND RESERVOIR
      ANCOST = CTOT*CRFSM
      ANMAIN = CTOT1*MDAM
```

```
      IF(DMDTLS) WRITE(6,23) ANCOST,ANMAIN
   23 FORMAT(/15X,32HANNUAL CAPITAL RECOVERY COST = $,F10.2/15X,32HANNUA
     1L RESERVOIR MAINTENANCE = $,F10.2)
      COSTDM = ANCOST + ANMAIN
      PERFR = 100.0*DFR
      WRITE(6,24) PERFR, COSTDM
   24 FORMAT(//8X,32HRESERVOIR STORAGE CONTAINING THE,1X,F6.2,1X,
     137HPERCENT FLOOD HAS AN ANNUAL COST OF $,F10.2)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE DMCOST LEFT)
      RETURN
      END


      SUBROUTINE EMSPVL(CONBOT,CONWAL,D1,DMDTLS,DPROCK,ELEVA,ELSPFL,
     1ELSPTP,EREX,GRADSP,HLSIDE,HWAL,IMAX,LGAPCH,LOOPTR,NWH,QEMSP,
     2SPCONC,SPLNG,SPRKEX,TPELEV,WDEMSP,ZCUT)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C  DETERMINES THE DIMENSIONS, CROSS-SECTIONS AND QUANTITIES FOR THE
C        OPEN-CHANNEL EMERGENCY SPILLWAY.
C VERSION OF APRIL 15, 1967
      LOGICAL DMDTLS, LOOPTR
      REAL LGAPCH
      DIMENSION CONWAL(25),ELEVA(25),F(28),HLSIDE(25),HWAL(25),
     1LGAPCH(25)
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE EMSPVL ENTERED)
C  DETERMINE THE DEPTH OF FLOW AT A POINT WHERE CHUTE BOTTOM IS TEN FEET
C   LOWER THAN THE CREST ELEVATION BY TRIAL AND ERROR SOLUTION OF CUBIC
C   ENERGY EQUATION.  CHUTE WALL VOLUME IS FIGURED IN THREE SECTIONS:
C   10-FOOT SECTION AT CREST, FROM CREST TO POINT WHERE CHUTE BOTTOM HAS
C   DROPPED 10 FEET, AND FROM THIS POINT TO THE STILLING BASIN.
      FALL = ELSPTP - ELSPFL + 10.0
C  HEAD LOSS ASSUMED AT ONE TENTH KINETIC ENERGY GAIN FOR ACCELERATING
C  FLOW.
      CK = 1.1*(QEMSP/WDEMSP)**2/64.4
C  CHECK FOR SUBCRITICAL FLOW DOWN SPILLWAY.  IF THE FLOW IS SUBCRITICAL
C  ASSUME UNIFORM FLOW DOWN CHUTE.
      IF(CK.LT.(4.0/27.0*FALL**3.0)) GO TO 100
      WRITE(6,55)
   55 FORMAT(10X,40HSUBCRITICAL FLOW OVER EMERGENCY SPILLWAY)
      D2 = ELSPTP - ELSPFL
      IF(DMDTLS) WRITE(6,1967) D2
 1967 FORMAT(10X,7HDEPTH =,F7.3)
      GO TO 6
C  IF FLOW DOWN CHUTE IS SUPERCRITICAL, SOLVE FOR DEPTH AT BOTTOM WITH A
C  TRIAL AND ERROR SOLUTION OF A CUBIC EQUATION BASED ON ENERGY.
  100 P = 0.0
      PA = 0.0
      F(1) = CK
      DO 87 K = 2, 28
```

```
      PA = P
      P = P + 0.025*FALL
      F(K) = P**3.0 - FALL*P**2 + CK
      IF((F(K-1).GT.0.0).AND.(F(K).LT.0.0))GO TO 89
   87 CONTINUE
C  SPECIAL PROVISION FOR CHUTE SLOPE SO GRADUAL THAT FLOW IS JUST BARELY
C    SUPERCRITICAL
      WRITE(6,88)
   88 FORMAT(10X,101HNO CHANGE OF SIGN UP TO D2 = 0.65(FALL). D2 WILL BE
     1 SET = 0.2(FALL) SO THAT COMPUTATIONS MAY PROCEED.)
      D2 = 0.2*FALL
      IF(DMDTLS) WRITE(6,1967) D2
      GO TO 6
   89 D2 = (P + PA)/2.0
      IF(DMDTLS) WRITE(6,1967) D2
      I = 0
    3 I = I + 1
      Y = D2**3.0 - FALL*D2**2 + CK
      YPRIME = 3.0*D2**2 - 2.0*FALL*D2
      ERROR = Y/YPRIME
C  CURRENT TRIAL AND ERROR SOLUTION OF CUBIC EQUATION.  NEW TRIALS ARE
C  MADE UP TO 20 TIMES UNTIL TERMS AGREE WITHIN 0.025 FOOT.
      D2 = D2 - ERROR
      IF(DMDTLS) WRITE(6,1967) D2
      IF(I.GT.20) GO TO 6
    4 IF(ABS(ERROR).GE.0.025) GO TO 3
C  WALL HEIGHT AND SIZE AFTER 10-FOOT DROP
    6 WLHT1 = D2 + 2.0 + 0.025*(QEMSP/(D2*WDEMSP))*D2**(1.0/3.0)
      CALL RETWAL(CONC1,CONWAL,HWAL,LOOPTR,NWH,WLHT1)
C  WALL HEIGHT AND SIZE AT CREST
      WLHT2 = TPELEV - ELSPFL + 5.0
      CALL RETWAL(CONC2,CONWAL,HWAL,LOOPTR,NWH,WLHT2)
C  MEAN WALL HEIGHT AND SIZE FOR 10-FOOT FALL SECTION
      WLHTM = (WLHT1 + WLHT2)/2.0
      CALL RETWAL(CONCM,CONWAL,HWAL,LOOPTR,NWH,WLHTM)
      CW1 = (CONC1 + CONC2 + 4.0*CONCM)/6.0
C  WALL HEIGHT AND SIZE AT CHUTE BOTTOM
      WLHTD1= D1 + 2.0 + 0.025*(QEMSP/(D1*WDEMSP))*D1**(1.0/3.0)
      CALL RETWAL(CONCD1,CONWAL,HWAL,LOOPTR,NWH,WLHTD1)
C  MEAN WALL HEIGHT AND SIZE FOR MAIN CHUTE
      WLHTCH = (WLHT1 + WLHTD1)/2.0
      CALL RETWAL(CONCCH,CONWAL,HWAL,LOOPTR,NWH,WLHTCH)
      CW2 = (CONC1 + CONCD1 + 4.0*CONCCH)/6.0
C  SUM CHUTE CONCRETE VOLUME FROM BOTTOM AND WALL QUANTITIES.
      CBOT = (43.5*WDEMSP + CONBOT*WDEMSP*(SPLNG-10.0))/27.0
      CWAL = 20.0*CONC2 + 2.0*CW1*(10.0*GRADSP - 10.0) +2.0*CW2*(SPLNG-
     110.0*GRADSP)
      SPCONC = CBOT + CWAL
C BEGIN LOCATION OF CATCH POINTS OF HILLSIDE CUT
      EL1 = TPELEV
      EL2 = ELSPFL
      EL3 = ELSPFL - 5.0
```

```
      TP = TPELEV + DPROCK
      DO 7 I = 1, IMAX
      IF(ELEVA(I).GT.TP) GO TO 8
    7 CONTINUE
    8 IH = I
C  DISTANCE TO INSIDE EDGE OF EMERGENCY SPILLWAY (LOCATED WHERE ABUTMENT
C  ROCK SURFACE IS AT TOP-OF-DAM ELEVATION).
      HLL = HLSIDE(I-1)+(TP-ELEVA(I-1))*(HLSIDE(I)-HLSIDE(I-1))/
     1(ELEVA(I)-ELEVA(I-1))
C  DISTANCE TO OUTSIDE EDGE OF EMERGENCY SPILLWAY
      HLH = HLL + WDEMSP
C  FIND INSIDE APPROACH CHANNEL CATCH POINT
      DO 9 I = 1, IMAX
      IF(ELEVA(I).GT.EL1) GO TO 10
    9 CONTINUE
   10 I = IH
      DO 11 M = 1, IH
      I = I - 1
      IF(HLSIDE(I).LE.(HLL-ZCUT*(ELEVA(I)-EL3))) GO TO 12
   11 CONTINUE
   12 I = I + 1
      I4 = I
      SL = (ELEVA(I)-ELEVA(I-1))/(HLSIDE(I)-HLSIDE(I-1))
      HL4 = (EL3-ELEVA(I-1)+HLL/ZCUT+SL*HLSIDE(I-1))/(1.0/ZCUT + SL)
      EL4 = ELEVA(I-1) + SL*(HL4-HLSIDE(I-1))
C  FIND OUTSIDE CATCH POINT FOR CUT SLOPE ABOVE SPILLWAY CHUTE.
      DO 13 I = IH, IMAX
      IF(HLSIDE(I).GE.(HLH+ZCUT*(ELEVA(I)-EL1))) GO TO 14
   13 CONTINUE
   14 SL = (ELEVA(I)-ELEVA(I-1))/(HLSIDE(I)-HLSIDE(I-1))
      HL11 = (EL1-ELEVA(I-1)+SL*HLSIDE(I-1)-HLH/ZCUT)/(SL-1.0/ZCUT)
      EL11 = ELEVA(I-1) + SL*(HL11 - HLSIDE(I-1))
C  FIND OUTSIDE CATCH POINT FOR CUT SLOPE ABOVE APPROACH CHANNEL.
      DO 15 I = IH, IMAX
      IF(HLSIDE(I).GE.(HLH+ZCUT*(ELEVA(I)-EL3))) GO TO 16
   15 CONTINUE
   16 SL = (ELEVA(I)-ELEVA(I-1))/(HLSIDE(I) - HLSIDE(I-1))
      HL13 = (EL3-ELEVA(I-1)+SL*HLSIDE(I-1)-HLH/ZCUT)/(SL-1.0/ZCUT)
      EL13 = ELEVA(I-1) + SL*(HL13 - HLSIDE(I-1))
C WIDTH OF SURFACE DIRT EXCAVATION UPSTREAM AND DOWNSTREAM FROM CREST BY
C     ADDING TRAPEZOIDAL AREAS BETWEEN SEA LEVEL AND GROUND SURFACE AND
C     SUBTRACTING TRAPEZOIDAL AREAS BETWEEN SEA LEVEL AND CHANNEL BOTTOM.
      WD=HL11-HLL-ZCUT*DPROCK
      WU=HL13-HL4-ZCUT*DPROCK
C END OF LOCATION OF CATCH POINTS
C FIND THE LENGTH OF THE APPROACH CHANNEL  (APCHLG)
      DO 1 I = 1, IMAX
      IF(ELEVA(I).GT.TPELEV) GO TO 2
    1 CONTINUE
    2 APCHLG = LGAPCH(I-1)+(TPELEV-ELEVA(I-1))*(LGAPCH(I)-LGAPCH(I-1))/
     1(ELEVA(I)-ELEVA(I-1))
C COMPUTING THE AREA OF THE APPROACH CHANNEL AT THE SPILLWAY CREST
```

```
C  SECTION.
      I = I4
      APCHAR = 0.0
      IF(HLSIDE(I).LT.HL13) GO TO 30
      APCHAR = (HL13 -HL4)*(EL13 + EL4)/2.0
      GO TO 31
   30 APCHAR = APCHAR + (HLSIDE(I4)-HL4)*(ELEVA(I4) + EL4)/2.0
   17 I = I + 1
      IF(HLSIDE(I).GT.HL13) GO TO 19
   18 APCHAR = APCHAR + (HLSIDE(I)-HLSIDE(I-1))*(ELEVA(I)+ELEVA(I-1))/2.
      GO TO 17
   19 APCHAR = APCHAR + (HL13-HLSIDE(I-1))*(EL13+ELEVA(I-1))/2.0
   31 APCHAR = APCHAR + (HLH-HL13)*(EL13+EL3)/2.0 + (HLL-HLH)*EL3 +
     1(HL4-HLL)*(EL4+EL3)/2.0
C  COMPUTING THE APPROACH CHANNEL EXCAVATION (APCHEX) BY THE
C  AVERAGE END AREA METHOD.
      APCHEX = APCHLG*APCHAR/54.0
C  COMPUTING THE AREA OF THE SPILLWAY SECTION AT THE CREST (SPCRAR) BY
C  ADDING AND SUBTRACTING TRAPEZOIDS.
      SPCRAR = 0.0
      I = IH
      IF(HLSIDE(I).LT.HL11) GO TO 32
      SPCRAR = (HL11 - HLL)*(EL11 + TP)/2.0
      GO TO 33
   32 SPCRAR = SPCRAR + (HLSIDE(IH)-HLL)*(ELEVA(IH) + TP)/2.0
   20 I = I + 1
      IF(HLSIDE(I).GT.HL11) GO TO 21
      SPCRAR = SPCRAR + (HLSIDE(I)-HLSIDE(I-1))*(ELEVA(I)+ELEVA(I-1))/2.
      GO TO 20
   21 SPCRAR = SPCRAR + (HL11-HLSIDE(I-1))*(EL11 + ELEVA(I-1))/2.0
   33 SPCRAR = SPCRAR + (HLH-HL11)*(EL11 + EL1)/2.0 +(HLL-HLH)*EL2
C  COMPUTING THE SPILLWAY CHUTE EXCAVATION (CHEX) BY THE
C  AVERAGE END AREA METHOD.
      CHEX = SPLNG*(SPCRAR + WDEMSP*(WLHTD1 + DPROCK))/54.0
C COMPUTING THE EARTH EXCAVATION (EREX)
      EREX = DPROCK*(APCHLG*(WU+WDEMSP) + SPLNG*(WD+WDEMSP))/54.0
C COMPUTING THE TOTAL SPILLWAY EXCAVATION (SPEX)
      SPEX = APCHEX + CHEX + SPCONC
C COMPUTING THE SPILLWAY ROCK EXCAVATION (SPRKEX)
      SPRKEX = SPEX - EREX
      IF(.NOT.DMDTLS) GO TO 1312
C  WRITE DESIGN DIMENSIONS AND QUANTITIES
      SLOPE = 1.0/GRADSP
      WRITE(6,501)
  501 FORMAT(/10X,29HEMERGENCY SPILLWAY QUANTITIES)
      WRITE(6,502)SPEX,SPRKEX,EREX,SPCONC,SPLNG,APCHAR,APCHLG,SPCRAR,
     1SLOPE,WLHTCH,HL4,EL4,HL13,EL13
  502 FORMAT(15X,27HTOTAL SPILLWAY EXCAVATION =,F13.2,9H  CU. YD./15X,
     126HSPILLWAY ROCK EXCAVATION =,F14.2,9H  CU. YD./15X,27HSPILLWAY EA
     2RTH EXCAVATION =,F13.2,9H  CU. YD./15X,26HSPILLWAY CONCRETE VOLUME
     3 =,F14.2,9H  CU. YD./15X,30HDISTANCE FROM CREST TO BASIN =,F10.2,
     46H  FEET,  /15X,28HAREA APP. CHANNEL AT CREST =,F12.2,9H  SQ. FT./
```

```
     515X,23HAPPROACH CHANNEL LENGTH,4X,1H=,F12.2,2X,4HFEET/15X,19HSPILL
     6WAY CREST AREA,8X,1H=,F12.2,2X,7HSQ. FT./15X,14HSPILLWAY SLOPE,
     713X,1H=,F12.2/15X,16HMEAN WALL HEIGHT,11X,1H=,F12.2,2X,4HFEET,
     8/10X,28HCATCH POINTS OF HILLSIDE CUT/23X,20HDISTANCE   ELEVATION/
     915X,5HINNER,F10.2,F12.2/15X,5HOUTER,F10.2,F12.2)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE EMSPVL LEFT)
      RETURN
      END


      SUBROUTINE FPCOST(LOOPTR)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  GIVEN FLOOD PEAKS FOR 'NDF' FREQUENCIES AND LOCAL CONDITIONS, THE
C        OPTIMUM FLOOD DAMAGE REDUCTION POLICY IS SELECTED FOR THE
C        SPECIFIED SUBWATERSHED IN THE SPECIFIED STAGE.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      LOGICAL CH9,CHANEL,HOLDNG,LINED,LL,LOOPTR,LTF,PP,PTF,RTEST,SS,STF
      REAL K1,K2,LC,MANNR,MANNT,MANNU
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE FPCOST ENTERED)
C  USE GUMBELS EQUATION TO CALCULATE THE FREQUENCY AT WHICH FLOODING
C  BEGINS BY DETERMINING WHETHER FLOODING BEGINS WITH A BIGGER OR A
C  SMALLER STORM THAN THE RESERVOIR DESIGN STORM, DETERMINING THE GUMBEL
C  PARAMETERS FOR THE APPROPRIATE STORM RANGE, AND SOLVING FOR THE
C  FREQUENCY OF A STORM PEAKING AT THE CHANNEL CAPACITY.
      J1=1
      IF(CHANEL(NW)) J1=2
      L1=1
      IF(RTEST .AND. Q0(NW) .GT. QQ(J1,KDF)) L1=KDF
      L2=NDF
      IF(RTEST .AND. Q0(NW) .LE. QQ(J1,KDF)) L2=KDF
      IF(L2 .EQ. 1) L2 = 2
      IF(L1 .EQ.NDF) L1 = NDF-1
```

```
      YDIF=YY(L1)-YY(L2)
      XF=(QQ(J1,L2)*YY(L1)/(YDIF))-(QQ(J1,L1)*YY(L2)/(YDIF))
      AG=-YDIF/(QQ(J1,L2)-QQ(J1,L1))
      YF=AG*(QO(NW)-XF)
      IF (YF .LT. FTOP) GO TO 45
      F=0.0
      GO TO 46
   45 TEMP=EXP(-YF)
      PN=EXP(-TEMP)
      F=1.-PN
C  DETERMINE THE OPTIMUM COMBINATION OF STRUCTURAL AND NONSTRUCTURAL
C  MEASURES.
   46 CALL CHOPTM(LOOPTR)
C  PROVIDE FOR MEASURES WHICH DID NOT PROVE WORTHWHILE DURING THE
C  SUBWATERSHED STAGE JUST ANALYZED BUT WHICH SHOULD BE CONSIDERED
C  DURING THE NEXT SUBWATERSHED STAGE.
      IF(PTF)  GO TO 282
      PP=.FALSE.
  282 IF(LTF)  GO TO 283
      LL=.FALSE.
C  SETS STAGE IN WHICH LAND USE RESTRICTION BEGAN.
      IF(OUTPUT(5)     .GT. 0.)  GO TO 260
      LC9(NW)=-1
      GO TO 283
  260 IF(LOC(NW) .LT. 0)  LC9(NW)=NSTAGE
  283 IF(STF)  GO TO 271
      SS=.FALSE.
C  FIX SUBWATERSHED CONDITIONS FOR NEW CHANNELS CONSTRUCTED
      LN9(NW) = LGTEMP
      ND9(NW)=NDTEMP
      FD9(NW)=FDTEMP
C  ADD CONTINUING COST OF CHANNEL IMPROVEMENTS MADE DURING A PREVIOUS
C  STAGE.
      OUTPUT(4)=OUTPUT(4)+ADDCS(NW)
      OUTPUT(13)=OUTPUT(13)+ADDCS(NW)
      ADDC9(NW)=OUTPUT(4)
      IF(STEMP .LE. 0.0)  GO TO 1203
  262 IF(QO(NW) .LT. OUTPUT(3)     .AND. .NOT. CHANEL(NW)) IMPROV=2
      IF(QO(NW) .LT. OUTPUT(3)     .AND. CHANEL(NW)) IMPROV=3
C  SETS NEW CHANNEL SIZE AND CAPACITY
      Q9(NW)=OUTPUT(3)
      T9(NW)=TTEMP
      W9(NW)=WTEMP
      A9(NW)=ATEMP
      CH9(NW)=.TRUE.
C  ACCOUNTS FOR BRIDGE CHANGES
C  CAP(9) -  NUMBER OF HIGHWAY BRIDGES BUILT AND/OR ENLARGED WITHIN
C  PROGRAM.
C  CAP(10) - NUMBER OF RAILWAY BRIDGES BUILT AND/OR ENLARGED WITHIN
C  PROGRAM.
C  CAP(11) - CAPACITY OF ALL CHANGED BRIDGES IN CFS
      CA9(NW,11)=OUTPUT(3)
```

```
      IF(CAP(NW,9) .LT. HETEMP)  GO TO 265
      CA9(NW,9)=CAP(NW,9)+HTEMP
      GO TO 266
  265 CA9(NW,9)=HETEMP+HTEMP
  266 CA9(NW,10)=CAP(NW,10)+RTEMP
  267 DO 268 I=1,6
      IF(CAP(NW,I) .LT. 0.)  GO TO 269
  268 IF((CAP(NW,I) .LT. OUTPUT(3)).AND.(.NOT.LINED)) CA9(NW,I) = -1.0
  269 DO 270 I=7,8
      IF(CAP(NW,I) .LT. 0.)  GO TO 1203
  270 IF((CAP(NW,I) .LT. OUTPUT(3)).AND.(.NOT.LINED)) CA9(NW,I) = -1.0
C  IF HOLDING OF RIGHT-OF-WAY FOR FUTURE CHANNELS IS DESIRED, THE WIDTH
C       AND COST OF HOLDING THE LAND IS CALCULATED
 1203 IF (.NOT. HOLDNG) GO TO 271
C  CASES WHERE HOLDING NOT WARRANTED
      IF     (LN9(NW).EQ.4.AND.(CH9(NW)    .OR.STEMP.GT.0.0)) ITEMP=0
      IF (OUTPUT(2)     .LE. 0.025 .AND. CH9(NW)) ITEMP=0
      IF(ITEMP.EQ.0) GO TO 1232
      IF (WT(NW).NE.0.0) GO TO 1234
      QY=QQ(2,NDF)
      IF     (LN9(NW).EQ.3) QY=QY*MANNT/MANNU
C  WIDTH OF EXTRA RIGHT-OF-WAY
      IF     (LN9(NW).NE.4)WT9(NW)=SAFC*(30.0+0.822*((QY/SQRT(S(NW)))**0.
     1415))
      IF     (LN9(NW).EQ.4)WT9(NW)=SAFC*(20.0+BDMIN*((QY*MANNR*(X+
     12.0)**0.667/(SQRT(S(NW))*1.49*BDMIN**1.667))**0.375))
 1234 IF(WT9(NW) .GE. W9(NW)) GO TO 1231
C  HAVE ENOUGH WITHOUT HOLDING EXTRA
      ITEMP=0
      GO TO 1232
C  COST OF HOLDING EXTRA RIGHT-OF-WAY
 1231 SLC = SIC(NW)
      IF(CH9(NW)) SLC =  LC(NW)
      CH=CHU*(WT9(NW)*LC(NW)-W9(NW)*SLC)*0.1212
C  NO NEED TO HOLD RIGHT-OF-WAY WHERE FLOOD DAMAGES ARE SO SMALL CHANNEL
C     IMPROVEMENT CAN PROBABLY NEVER BE JUSTIFIED.
      IF(CH      .GE. 0.333*OUTPUT(13))     ITEMP=0
 1232 IHLD9(NW)=ITEMP
      IF (IHLD9(NW) .NE. 0) GO TO 884
      WT9(NW)=0.0
      CH=0.0
  884 OUTPUT(13)=OUTPUT(13)+CH
C  WRITE SUMMARY OF MEASURES.
  271 WRITE (6,886)
  886 FORMAT(1H ,43X,29HSUMMARY OF MEASURES AND COSTS/1X,4HUNIT,1X,4H BE
     1G,13X,8HCHANNELS,16X,8HLOCATION,16X,8HPROOFING,8X,7HCOST OF,2X,7HC
     2OST OF,5X,5HTOTAL/15X,2H S,5X,2HQS,8X,2HCS,5X,2H L,5X,2HQL,8X,2HCL
     3,5X,2H P,5X,2HQP,8X,2HCP,4X,28H FLOODING UNCERTAINTY COST       )
      WRITE(6,888) NW,(OUTPUT(I),I=1,13)
  888 FORMAT(1X,I2,2PF7.2,2X,F6.3,0P2F8.0,2X,2PF6.3,0P2F8.0,2X,2PF6.3,0P
     12F8.0,3F11.0/)
C  WRITE OUT SUMMARY OF CHANNEL IMPROVEMENTS IF ANY.
```

```
      IF (.NOT. STF) CALL STROUT(LOOPTR)
C  WRITE OUT SUMMARY OF LOCATION MEASURES IF ANY.
      IF(LTF) GO TO 743
      IF(LC9(NW) .LT. 0) GO TO 743
      AREA=K1(NW)*K2(NW)*(OUTPUT(6)-OUTPUT(3))**0.375
      WRITE(6,742)     AREA
  742 FORMAT(10X,29HAREA OF RESTRICTED LAND USE =,F10.0,1X,5HACRES)
C  WRITE OUT SUMMARY OF FLOOD PROOFING IF ANY.
  743 IF(PTF) GO TO 1312
      IF(OUTPUT(9) .EQ. 0.0) GO TO 1312
      AREA=K1(NW)*K2(NW)*(OUTPUT(9)-OUTPUT(3))**0.375
      WRITE(6,746)    AREA
  746 FORMAT(10X,18HAREA FLOOD PROOFED,10X,1H=,F10.0,1X,5HACRES)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE FPCOST LEFT)
      RETURN
      END


      SUBROUTINE HYDCOM(HYDIN,HYDINT,HYDOUT,HYDTLS,HYDTM,LOOPTR,N1,NW,
     1RK24)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 10, 1968
C  CONVERTS A LOCAL SUBWATERSHED HYDROGRAPH WITH TIME INCREMENT BETWEEN
C        TABULATED FLOWS EQUALLING SUBWATERSHED TPW/N1 TO A HYDROGRAPH
C        WITH A FIXED TIME INCREMENT (READ IN INPUT DATA FOR GENERAL
C        USE) BETWEEN TABULATED FLOWS AND ADDS FLOWS AT EACH TIME TO THE
C        HYDROGRAPH COMING DOWN THE MAINSTREAM.
C DEFINITIONS OF TERMS IN CALLING ARGUMENT
C   HYDTM -- 20 TIME ELEMENTS FOR LOCAL INFLOW HYDROGRAPH
C   HYDIN -- 20 FLOW ELEMENTS FOR LOCAL INFLOW HYDROGRAPH
C   HYDOUT -- 50 FLOW ELEMENTS FOR COMBINED HYDROGRAPH
C   HYDINT -- TIME BETWEEN ELEMENTS IN COMBINED HYDROGRAPH
      DIMENSION HYDIN(20),HYDOUT(50),HYDTM(20)
      LOGICAL HYDTLS,LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE HYDCOM ENTERED)
      TIME = 0.0
C  ADD SUBWATERSHED HYDROGRAPH TO EACH OF 50 POINTS ON MAINSTREAM
C  HYDROGRAPH.
      DO 10 I = 1, 50
      TIME = TIME + HYDINT
C  FIND TIME ON SUBWATERSHED HYDROGRAPH JUST PAST CURRENT POINT ON
C  MAINSTREAM HYDROGRAPH.
      DO 8 J = 1,20
      IF(HYDTM(J).GT.TIME) GO TO 6
    8 CONTINUE
C  IF SUBWATERSHED HYDROGRAPH NOT LONG ENOUGH FOR ALL POINTS NEEDED ON
C    MAINSTREAM HYDROGRAPH, SKIP TO CALCULATION BASED ON A RECESSION
C  CONSTANT.
      GO TO 30
```

```
C   SPECIAL INTERPOLATION FOR POINTS SOONER THAN FIRST TIME IN HYDTM(20).
    6 IF(J.EQ.1) GO TO 7
C   NORMAL INTERPOLATION FOR POINTS BETWEEN TWO "HYDTM(20)" ELEMENTS.
      IF(ABS(HYDTM(N1)- TIME).GE.0.5*HYDINT) GO TO 12
C   ADD PEAK AT CLOSEST TIME POINT TO ASSURE VERY SHARP HYDROGRAPH IS NOT
C   MISSED.
      HYDOUT(I) = HYDOUT(I) + HYDIN(N1)
      GO TO 10
   12 HYDOUT(I) = HYDOUT(I)+HYDIN(J-1)+(HYDIN(J)-HYDIN(J-1))*(TIME-HYDTM
     1(J-1))/HYDTM(1)
      GO TO 10
    7 HYDOUT(I) = HYDOUT(I) + HYDIN(J)*TIME/HYDTM(1)
   10 CONTINUE
      GO TO 20
C   EACH POINT ON RECESSION IS RK24 TIMES THE PRECEDING ONE.
   30 HYDLOC = HYDIN(20)
      DO 31 K = 1,50
      HYDLOC = RK24*HYDLOC
   31 HYDOUT(K) = HYDOUT(K) + HYDLOC
   20 IF(.NOT.HYDTLS) GO TO 1312
C   WRITE COMBINED HYDROGRAPH.
      WRITE(6,50)NW
   50 FORMAT(15X,60HCOMBINED ROUTED AND LOCAL INFLOW HYDROGRAPHS AT SUBW
     1ATERSHED,I3)
      WRITE(6,52) (HYDOUT(I), I = 1,50)
   52 FORMAT(10X,10F9.2)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE HYDCOM LEFT)
      RETURN
      END


      SUBROUTINE PLACEA(CC,LOOPTR,QR,UU,X)
C   UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C           VERSION OF JULY 1, 1967
C     ARITHMETIC INTERPOLATION SUBROUTINE.  UU=TOTAL TRIBUTARY
C     URBANIZATION, CC=TOTAL TRIBUTARY CHANNELIZATION, X=TWO DIMENSIONAL
C     ARRAY WITH FLOW AS A FUNCTION OF CC AND UU, 'QR'=VALUE RETURNED TO
C     MAIN PROGRAM.  UU AND CC ARE DECIMAL VALUES.  'QR' IS IN CFS.
      LOGICAL LOOPTR
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE PLACEA ENTERED)
      U=UU
      C=CC
      DIMENSION X(11,11)
      U=U*10.+1.
      C=C*10.+1.
      I=C
      J=U
      CI=I
      UJ=J
```

```
      QA=X(I,J)+(C-CI)*(X(I+1,J)-X(I,J))
      QB=X(I,J+1)+(C-CI)*(X(I+1,J+1)-X(I,J+1))
      QR=QA+(U-UJ)*(QB-QA)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE PLACEA LEFT)
      RETURN
      END


      SUBROUTINE PRNSP(CONID,DMDTLS,DMTPW,DRQ,ELEVA,ELPRFL,ELSPFL,FPIPE,
     1LOOPTR,PRCON,TPELEV,TRAREA,TRV,TWELEV,ZDN,ZUP)
C   UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 15, 1967
C   SIZES THE PRINCIPAL SPILLWAY SO IT WILL PASS THE DESIGN FLOOD.
C        DESIGN IS A VERTICAL TOWER WITH MORNING GLORY ENTRANCE, A
C        HORIZONTAL PIPE THROUGH THE DAM, AND AN IMPACT DISSIPATOR.
      LOGICAL DMDTLS,LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE  PRNSP ENTERED)
C  DESIGN HEAD IS WITH WATER SURFACE AT EMERGENCY SPILLWAY CREST.
      HDPRSP = ELSPFL - TWELEV
C  LENGTH OF VERTICAL TOWER AND HORIZONTAL PIPE
      PLNGV = ELPRFL - ELEVA
      PLNGH = DMTPW + (ZUP+ZDN)*(TPELEV-ELEVA)
      PLNGT = PLNGV + PLNGH
C  BEGIN WITH 3.0 INCH PIPE AND INCREASE SIZE BY 3.0 INCH INCREMENTS
C  UNTIL FIND A PIPE BIG ENOUGH TO PASS THE REQUIRED DESIGN FLOW.
      PD = 0.25
    1 VHEAD = HDPRSP/((FPIPE*PLNGT/PD) + 1.25)
      VEL = SQRT(64.4*VHEAD)
      Q = (0.7854*PD**2)*VEL
      IF(Q.GE.DRQ) GO TO 2
      PD = PD + 0.25
      GO TO 1
C  FORMULA FOR ESTIMATING THICKNESS OF PIPE CONCRETE
    2 PTH = 0.025*PD*SQRT(HDPRSP)
C  CONCRETE AREA OF PIPE CROSS SECTION, CIRCULAR TOP AND SQUARE BOTTOM
C  ON OUTSIDE.
      PCAREA = (PD+2.0*PTH)*(0.5*PD+PTH) + 1.57*(0.5*PD+PTH)**2
     1-0.7854*PD**2
C  VOLUME OF CONCRETE IN PIPE
      PRCON = (PLNGT*PCAREA)/27.0
C  VOLUME OF CONCRETE IN IMPACT DISSIPATOR BASED ON APPROXIMATE FORMULA
      CONID = 0.158*DRQ + 1.7
C  AREA OF OPENING REQUIRED THROUGH ENTRY TRASHRACK AND
C  ANTI-VORTEX CONTROL.
      TRAREA = DRQ/(0.6*TRV)
      IF(DMDTLS) WRITE(6,4) HDPRSP,Q,PD,PRCON,CONID,TRAREA
    4 FORMAT(//10X,33HFOR THE DESIGN PRINCIPAL SPILLWAY/15X,6HHEAD =,
     1F5.0,1X,4HFEET,4X,10HFLOWRATE =,F5.0,1X,3HCFS,4X,15HPIPE DIAMETER
     2=,F5.2,1X,4HFEET/15X,13HPIPE CONCRETE
```

```
     3,14X,1H=,F9.2,2X,11HCUBIC YARDS/15X,28HIMPACT DISSIPATOR CONCRETE
     4=,F9.2,2X,11HCUBIC YARDS/15X,14HTRASHRACK AREA,13X,1H=,F9.2,2X,
     511HSQUARE FEET)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,21HSUBROUTINE PRNSP LEFT)
      RETURN
      END


      SUBROUTINE RDDATA
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 12, 1968
C   SUBROUTINE RDDATA READS THE DATA NEEDED FOR THE ANALYSIS
C        AND COMBINES SELECTED TERMS FOR LATER USE.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      REAL IPP,K1,K2,LC,LGAPCH,LGDAM,LGEMSP,MANNR,MANNT,MANNU,MCH,MDAM,
     1MFP,MIN,MTLCH,NIN
      LOGICAL BLDNOW,CHECK,DMDTLS,HOLDNG,HYDTLS,LOOPTR,LTF,NODAM,PTF,
     1STF,TRACE,UNC
      DIMENSION AFCTR(3,11),AFCTRT(11),AFCTRV(2,11),AK12(15),D(3,15),
     1DK12(15),QK12(15)
```

```
C  INFORMATION IS READ USING A SPECIAL READ SUBROUTINE WHICH ALLOWS
C          GREATER FORMAT FREEDOM AND ALSO ALLOWS COMMENTS TO BE
C          WRITTEN ON THE DATA CARDS.
C  PROGRAM CONTROL PARAMETERS
      CALL READ (L1,L2,L3,L4,L5,L6,L7,L8,L9,L10,L11,NSTEMX,MW)
      IF (L1 .EQ. 1) UNC=.TRUE.
      IF (L1 .NE. 1) UNC=.FALSE.
      IF (L2 .NE. 1) PTF=.TRUE.
      IF (L2 .EQ. 1) PTF=.FALSE.
      IF (L3 .NE. 1) LTF=.TRUE.
      IF (L3 .EQ. 1) LTF=.FALSE.
      IF (L4 .NE. 1) STF=.TRUE.
      IF (L4 .EQ. 1) STF=.FALSE.
      IF (L5 .EQ. 1) TRACE=.TRUE.
      IF (L5 .NE. 1) TRACE=.FALSE.
      IF (L6 .EQ. 1) CHECK=.TRUE.
      IF (L6 .NE. 1) CHECK=.FALSE.
      IF (L7 .EQ. 1) HOLDNG=.TRUE.
      IF (L7 .NE. 1) HOLDNG=.FALSE.
      IF (L8 .EQ. 1) DMDTLS=.TRUE.
      IF (L8 .NE. 1) DMDTLS=.FALSE.
      IF (L9 .EQ. 1) HYDTLS=.TRUE.
      IF (L9 .NE. 1) HYDTLS=.FALSE.
      IF (L10 .EQ. 1) LOOPTR=.TRUE.
      IF (L10 .NE. 1) LOOPTR=.FALSE.
      IF (L11 .NE. 1) NODAM=.TRUE.
      IF (L11 .EQ. 1) NODAM=.FALSE.
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE RDDATA ENTERED)
C  ADDITIONAL DRAINAGE AREA ADDED BY CHANNEL REACH
      DO 80  K=1,MW
   80 CALL READ (AW(K))
C  MAIN LINE, TRIBUTARY, AND IMPROVED CHANNEL LENGTHS
      DO 140  K=1,MW
  140 CALL READ (LC(K))
      DO 200  K=1,MW
  200 CALL READ (TCL(K))
      DO 190  K=1,MW
  190 CALL READ (SIC(K))
      DO 426  K=2,MW
      DO 426  J=1,NSTEMX
      IF(K.EQ.2) CTOTR(1,J) = 0.0
  426 CALL READ (CTOTR(K,J))
C  FLOOD PEAK HYDROLOGY
      CALL READ (QB43,QB05)
      DO 50 IC =1,11
      DO 50 JU =1,11
   50 CALL READ (Q43(IC,JU))
      DO 60 IC =1,11
      DO 60 JU =1,11
   60 CALL READ (Q05(IC,JU))
      DO 30 I=1,3
```

```
      DO 30 J=1,11
   30 CALL READ (AFCTR(I,J))
C  FLOOD VOLUME HYDROLOGY
      CALL READ (VB43,VB05)
      DO 10 IC = 1, 11
      DO 10 JU = 1, 11
   10 CALL READ(V43(IC,JU))
      DO 20 IC = 1, 11
      DO 20 JU = 1, 11
   20 CALL READ(V05(IC,JU))
      DO 31 I = 1,2
      DO 31 J = 1, 11
   31 CALL READ(AFCTRV(I,J))
C  FLOOD PEAK TIMING DATA
      CALL READ (TPB)
      DO 40 IC = 1,11
   40 CALL READ(TP(IC))
      DO 51 J = 1, 11
   51 CALL READ(AFCTRT(J))
C  FLOOD HYDROGRAPH SHAPE DATA
      CALL READ (HYDINT)
      DO 61 J = 1, 21
      DO 61 I = 1, 5
   61 CALL READ(HYDBAS(I,J))
C CALCULATE SUBWATERSHED AREA FACTORS FOR V43,V05, AND TP
      DO 70 K = 1, MW
      IF (AFCTR(1,1) .LE. AW(K)) GO TO 63
      AFW(1,K) = AFCTR(2,1)
      AFW(2,K) = AFCTR(3,1)
      AFV(1,K) = AFCTRV(1,1)
      AFV(2,K) = AFCTRV(2,1)
      AFT(K) = AFCTRT(1)
      GO TO 70
   63 DO 62 I = 1, 10
      IF(AFCTR (1,I).LE.AW(K).AND.AFCTR (1,I+1).GT.AW(K)) GO TO 64
   62 CONTINUE
   64 DO 66 L = 2,3
   66 AFW(L-1,K) = AFCTR (L,I)+(ALOG(AW(K))-ALOG(AFCTR (1,I)))/
     1(ALOG(AFCTR (1,I+1))-ALOG(AFCTR (1,I)))*(AFCTR (L,I+1)-AFCTR (L,I)
     2)
      DO 67 L = 1,2
   67 AFV(L,K) = AFCTRV(L,I)+(ALOG(AW(K))-ALOG(AFCTR (1,I)))/
     1(ALOG(AFCTR (1,I+1))-ALOG(AFCTR (1,I)))*(AFCTRV(L,I+1)-AFCTRV(L,I)
     2)
      AFT(K) = AFCTRT(I)+(ALOG(AW(K))-ALOG(AFCTR (1,I)))/(ALOG(AFCTR (1,
     1I+1))-ALOG(AFCTR (1,I)))*(AFCTRT(I+1)-AFCTRT(I))
   70 CONTINUE
C  FLOOD DAMAGES - GENERAL
      DO 160  K=2,MW
  160 CALL READ (Q0(K))
C   READ MAGNITUDE OF ANY KNOWN FLOOD PEAK AND ASSOCIATED MAXIMUM
C          DEPTH OF FLOODING AND AREA FLOODED
```

```
      DO 130 K=2,MW
  130 CALL READ (QK12(K),AK12(K),DK12(K))
C   CALCULATE SUBWATERSHED VALUES OF
C          K1 = (MAXIMUM FLOODING DEPTH)/(Q**0.375)
C          K2 = (ACRES FLOODED)/(MAXIMUM FLOODING DEPTH)
      DO 280 K = 2,MW
      K1(K) = DK12(K)/((QK12(K)- Q0(K))**0.375)
  280 K2(K) = AK12(K)/DK12(K)
C   FLOOD DAMAGES - URBAN
      CALL READ (VLURST,COEFDM)
C   FLOOD DAMAGES - AGRICULTURAL
      DO 21  K=2,MW
      DO 21  J=1,3
   21 CALL READ (D(J,K))
      CALL READ (CDA,CDB,CDC,CDAV,CDBV,CDCV)
      DO 11 I=1,11
   11 CALL READ (FRU(I))
      CALL READ (VLAGST)
C   FLOOD DAMAGES - UNCERTAINTY
      CALL READ (VA)
C   GENERAL DESIGN VARIABLES
      CALL READ (R,TIMST,TIME,MRDF,NDF)
      DO 41 I=1,NDF
   41 CALL READ (DF(I))
C   CHANNEL IMPROVEMENT - PHYSICAL FACTORS
      DO 71  K=2,MW
   71 CALL READ (AO(K))
      DO 150  K=2,MW
  150 CALL READ (LINING(K))
      CALL READ (MANNU,MANNT,MANNR,ZU,ZT)
      DO 170  K=2,MW
  170 CALL READ (S(K))
      DO 210  K=2,MW
  210 CALL READ (TF(K))
      CALL READ (BDMAX,BDMIN,HMAX,NIN)
      DO 90  K=2,MW
      DO 90  J=1,8
   90 CALL READ (CAP(K,J))
      CALL READ (BW)
C   CHANNEL IMPROVEMENT - COST FACTORS
      CALL READ (CX,FM,CIN,CLSF,CCY,CBR,CRR,AQR,SAFC,CSM,ESM,MIN,MCH,
     1MTLCH)
C   FLOOD PROOFING - COST FACTORS
      CALL READ (FP,VF,DD,MFP)
C   LOCATION ADJUSTMENT - COST FACTORS
      CALL READ (CLEN,RPI,FIA,FIB,FIC,IPP)
C   DISCOUNTING CORRECTION TO RIGHT-OF-WAY COST
      AQR = AQR + RPI/R - 1.0
C   DEGREE OF URBANIZATION
      NDFF=NSTEMX+1
      DO 230  K=1,MW
      DO 230  J=1,NDFF
```

```
  230 CALL READ (USUBW(K,J))
      DO 240  K=1,MW
      DO 240  J=1,NDFF
  240 CALL READ (UTOTR(K,J))
C  LAND VALUE
      DO 250  K=1,MW
      DO 250  J=1,NDFF
  250 CALL READ (VALUE(K,J))
C  HYDROLOGIC DATA FOR RESERVOIR DESIGN
      CALL READ (HYDMLT)
C CUMULATIVE RUNOFF CURVE
      CALL READ(AWG,IMPTY)
      DO 75 I = 1, 26
      CALL READ(CUMVOL(I))
   75 CUMVOL(I) = AW(1)*CUMVOL(I)/AWG
      RK24 = (CUMVOL(9)/CUMVOL(8))**(HYDINT/24.0)
C  WHETHER XTRSTR IS NEEDED NOW AND GATED DELAY IN HOURS
      CALL READ(IB,GDELAY)
      IF(IB .EQ. 1) BLDNOW = .TRUE.
      IF(IB .EQ. 0) BLDNOW = .FALSE.
C MUSKINGUM PARAMETERS FOR CHANNEL ROUTING
      DO 81 NW = 2, MW
   81 CALL READ(CHKN(NW),CHKY(NW),CHXN(NW),CHXY(NW))
C PROPERTIES OF THE DAM SITE BY ELEVATION CONTOUR
      CALL READ(IMAX,NHILSD)
      IF (NHILSD .GE. 2) CALL READ(HBRLM)
      IF (NHILSD .EQ. 3) CALL READ(HBRMH)
      DO 91 I = 1,IMAX
      CALL READ(ELEVA(I),RESACR(I),LGDAM(I),LGEMSP(I),LGAPCH(I),
     1 CRELOC(I),HLSIDL(I))
      IF(NHILSD .GE. 2) CALL READ(HLSIDM(I))
      IF(NHILSD .EQ. 3) CALL READ(HLSIDH(I))
   91 CONTINUE
      IF(NHILSD .NE. 1) GO TO 94
      DO 92 I=1,IMAX
   92 HLSIDE(I) = HLSIDL(I)
   94 IS = 0
C VOLUME OF WALL CONCRETE AS A FUNCTION OF WALL HEIGHT
      CALL READ(NWH)
      DO 100 I = 1, NWH
  100 CALL READ(HWAL(I), CONWAL(I))
C PHYSICAL FACTORS USED IN DAM AND RESERVOIR DESIGN
      CALL READ(BYVERT,CONBOT,CTBW,CWEIR,DMFRBD,DMTPW,DPRCKH,DPRCKV,
     1DPRP,FPIPE,QRATIO,SEDIN,STLBOT,TRV,TWELEV,WDEMSP,XTRSTR,ZCT,ZDN,
     2ZES,ZUP)
C UNIT COST FACTORS FOR ESTIMATING COST OF DAM AND RESERVOIR
      CALL READ(UCDAM,UCCT,UCRP,UCSPEX,UCRKEX,UCSPCN,UCPRCN,UCCNID,
     1UCTRK,UCCLR,CSMD,ESMD,MDAM)
C  BENEFITS ACCRUING DOWNSTREAM FROM AREA OF PRIMARY ANALYSIS
      DO 112 I = 1,2
      DO 110 J = 1, 10
  110 CALL READ(DMBN(I,J))
```

```
  112 CONTINUE
      DO 111 I = 1, NSTEMX
  111 CALL READ(DMBNF(I))
C  CALCULATE COMPOUND INTEREST FACTORS (SPECIAL FORMULAS FOR ZERO
C          DISCOUNT RATE)
      PWF=1./((1.+RPI)**TIME)
      SPWF=((1.+RPI)**TIME-1.)/(RPI*(1.+RPI)**TIME)
      IF (R .GE. 0.0001) GO TO 260
      CRF=1./TIME
      CRFSM=1./TIMST
      GSF=-0.5+TIME/2.0
      SPWFAC=TIME
      PWFR = 1.0
      GO TO 270
  260 CRF=(R*(1.+R)**TIME)/((1.+R)**TIME-1.)
      CRFSM=(R*(1.+R)**TIMST)/((1.+R)**TIMST-1.)
      GSF=1./R-(TIME*R)/(R*((1.+R)**TIME-1.))
      SPWFAC=1./CRF
      PWFR = 1.0/((1.0+R)**TIME)
C  CALCULATE FACTORS FOR COMPUTING COST OF STRUCTURAL MEASURES
  270 SK1=195.6*CSM*ESM*FM*CX*(CRFSM+MCH)
      SK2=NIN*CIN*ESM*CSM*(CRFSM+MIN)
      SK3=0.121*AQR*CRFSM
      SK4=BW*CBR*CSM*CRFSM
      SK5=CRR*CSM*CRFSM
      SK6=0.037*CSM*ESM*FM*CCY*(CRFSM+MIN)
      SK7=5280.*CLSF*CSM*ESM*(CRFSM+MTLCH)
      SK8=5280.*SK6/FM
C  CALCULATE FACTOR FOR COMPUTING COST OF FLOOD PROOFING
      CPF=0.5*DD*VF*FP*(CRF+MFP)*VLURST
C  CALCULATE FARM INCOME AND CROP DAMAGE FACTORS
      DO 434 K = 2, MW
      FIF(K) = FIA*D(1,K) + FIB*D(2,K) + FIC*D(3,K)
      CG(K) = CDAV*D(1,K) + CDBV*D(2,K) + CDCV*D(3,K)
  434 CDF(K) = CDA*D(1,K) + CDB*D(2,K) + CDC*D(3,K)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE RDDATA LEFT)
      RETURN
      END


      SUBROUTINE RESRTE(CWEIR,DRQ,ELEVA,ELFDBG,ELPEAK,ELPRFL,ELSPFL,
     1GDELAY,HYDTIM,HYDTLS,IMAX,LOOPTR,RESINF,RESVOL,TWELEV,WDEMSP,ZDN,
     2ZUP)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 15, 1967
C SUBROUTINE RESRTE TAKES A 50 ELEMENT HYDROGRAPH (RESINF) AND ROUTES IT
C        THROUGH A RESERVOIR WITH ROUTING INCREMENT (HYDTIM) IN HOURS.
C        THE ROUTED HYDROGRAPH IS RETURNED IN THE LOCATION OF THE
C        INPUT ARRAY RESINF.
      DIMENSION ELEVA(25),GOUTF(25),GSTOR(25),OUTFLO(25),RESEL(25),
```

```
     1RESINF(50),RESOUT(50),RESVOL(25),STOR(25),STOUT(50)
      LOGICAL HYDTLS,LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE RESRTE ENTERED)
C  ESTIMATED LENGTH OF WEIR CREST AROUND PRINCIPAL SPILLWAY ENTRANCE
      PRM=1.52*((1.0+  ZDN+ZUP)*DRQ**2)**0.2
      HDPRSP = ELSPFL - TWELEV
C  CALCULATE AMOUNT OF FLOW THROUGH PRINCIPAL SPILLWAY UNDER BASE FLOW
C    CONDITIONS.  IF THE PRINCIPAL SPILLWAY IS GATED, THE GATES ARE
C  ASSUMED TO BE OPERATED SO AS TO MAINTAIN CONSTANT FLOW WITH
C  INCREASING HEAD.
      IF (GDELAY .EQ. 0.0) GO TO 70
      STFLOW = DRQ*SQRT((ELFOBG-TWELEV)/HDPRSP)
      STWEIR = PRM*3.25*(ELFOBG-ELPRFL)**1.5
      IF (STWEIR .LT. STFLOW) STFLOW = STWEIR
C  ESTABLISH ARRAY OF ELEVATIONS FOR USE IN RESERVOIR ROUTING.
C  INCREMENT INCREASED WITH GREATER HEAD BECAUSE RELATIONSHIP BETWEEN
C  DISCHARGE AND HEAD BECOMES MORE LINEAR.  STOP WHEN TOP GIVEN CONTOUR
C  IS REACHED.
   70 RESEL(1) = ELPRFL
      K = ELPRFL
      ADD = K
      RESEL(2) = ADD + 0.5
      IF(RESEL(2).LT.ELPRFL) RESEL(2) = RESEL(2) + 0.5
      K = RESEL(2)
      ADD = K
      RESEL(3) = ADD + 1.0
      DO 31 K = 4,25
      IF(K.LE.11) ADD = 1.0
      IF(K.GE.12.AND.K.LE.13) ADD = 2.0
      IF(K.GE.14.AND.K.LE.17) ADD = 5.0
      IF(K.GE.18.AND.K.LE.20) ADD = 10.0
      IF(K.GE.21.AND.K.LE.23) ADD = 20.0
      IF(K.GE.24) ADD = 40.0
      RESEL(K) = RESEL(K-1) + ADD
      IF(RESEL(K).GE.ELEVA(IMAX)) GO TO 35
   31 CONTINUE
C  DEVELOP S/T+O AND OUTFLOW CURVES (VALUES FOR EACH ESTABLISHED
C  ELEVATION) FOR ROUTING. IF THE SPILLWAY IS GATED, DEVELOP A SECOND
C  PAIR OF CURVES FOR THE GATE BEING USED.
   35 DO 33 K = 1, 25
      QWEIR = 0.0
      QSPILL = 0.0
      DO 32 J = 1, IMAX
      IF(ELEVA(J).GT.RESEL(K)) GO TO 34
   32 CONTINUE
C  STORAGE VOLUME FOR GIVEN ELEVATION
   34 VOL = RESVOL(J-1)+(RESEL(K)-ELEVA(J-1))*(RESVOL(J)-RESVOL(J-1))/
     1(ELEVA(J) - ELEVA(J-1))
C  WATER SURFACE TOO LOW FOR ANY OUTFLOW
      IF (RESEL(K) .LE. ELPRFL) GO TO 100
C  EMERGENCY SPILLWAY FLOW
```

```
      IF(RESEL(K).GT.ELSPFL)QWEIR = WDEMSP*CWEIR*(RESEL(K)-ELSPFL)**1.5
C   PRINCIPAL SPILLWAY FLOW CHECKING BOTH PIPE AND WEIR CONTROL
      QSPILL = DRQ*SQRT((RESEL(K)-TWELEV)/HDPRSP)
      QSPLWR = PRM*3.25 *(RESEL(K)-ELPRFL)**1.5
      IF (QSPLWR .LT. QSPILL) QSPILL=QSPLWR
  100 OUTFLO(K) = QWEIR + QSPILL
C   PRINCIPAL SPILLWAY FLOW WITH GATE USED, LIMITED TO MAXIMUM OF STFLOW
      IF (GDELAY .EQ. 0.0) GO TO 71
      IF (STFLOW .LT. QSPILL) QSPILL = STFLOW
      GOUTF(K) = QWEIR + QSPILL
      GSTOR(K) = 12.12*VOL/HYDTIM + 0.5*GOUTF(K)
   71 STOR(K) = 12.12*VOL/HYDTIM + OUTFLO(K)/2.0
      IF(RESEL(K).GE.ELEVA(IMAX)) GO TO 36
   33 CONTINUE
C   ESTABLISH S/T+O AND OUTFLOW AT BEGINNING OF ROUTING.
   36 DO 5 I = 1, 25
      IF(RESEL(I).GT.ELFDBG) GO TO 6
    5 CONTINUE
    6 STOUT(1) = STOR(I-1) + (ELFDBG-RESEL(I-1))*(STOR(I)-STOR(I-1))/
     1(RESEL(I) - RESEL(I-1))
      RESOUT(1)=OUTFLO(I-1)+(STOUT(1)-STOR(I-1))*(OUTFLO(I)-OUTFLO(I-1))
     1/(STOR(I) - STOR(I-1))
C   INITIALIZE VALUES FOR FINDING MAGNITUDE AND TIME OF PEAK OUTFLOW.
      PEAK = RESOUT(1)
      TIM = 0.0
      PKTIME = 0.0
C   RESERVOIR ROUTING LOOP
      DO 9 I = 2,50
      TIMEP = TIM
      TIM = TIM + HYDTIM
C   TEST FOR GATE BEING USED.
      IF (GDELAY .EQ. 0.0) GO TO 172
      IF (.NOT.(TIM .GT.GDELAY .AND. TIMEP .LE. GDELAY)) GO TO 172
C   CORRECTION TO S/T+O CURVE WHEN GATE IS FIRST OPENED WIDE ONCE THE
C   PRESCRIBED HYDROGRAPH DELAY PERIOD IS COMPLETED.
      DO 200 J = 2,25
      IF (GSTOR(J) .GT. STOUT(I-1)) GO TO 201
  200 CONTINUE
  201 STOUT(I-1)=STOR(J-1)+(STOUT(I-1)-GSTOR(J-1))*(STOR(J)-STOR(J-1))/
     1 (GSTOR(J) - GSTOR(J-1))
C   BASIC ROUTING RECURSION
  172 STOUT(I) = STOUT(I-1)-RESOUT(I-1) + (RESINF(I-1) + RESINF(I))/2.0
      IF (TIM .GT. GDELAY) GO TO 72
C   ESTIMATE OUTFLOW IF GATE IS OPERATING.
      DO 73 J = 2,25
      IF (GSTOR(J) .GT. STOUT(I)) GO TO 74
   73 CONTINUE
   74 RESOUT(I)= GOUTF(J-1)+(STOUT(I)-GSTOR(J-1))*(GOUTF(J)- GOUTF(J-1))
     1/(GSTOR(J)-GSTOR(J-1))
      GO TO 75
C   ESTIMATE OUTFLOW IF GATE IS OPEN.
   72 DO 7 J = 2, 25
```

```
      IF(STOR(J).GT.STOUT(I)) GO TO 8
    7 CONTINUE
    8 RESOUT(I)=OUTFLO(J-1)+(STOUT(I)-STOR(J-1))*(OUTFLO(J)-OUTFLO(J-1))
     1/(STOR(J) - STOR(J-1))
   75 CONTINUE
C  DETERMINE WHETHER CURRENT OUTFLOW IS A NEW PEAK.
      IF(PEAK.GE.RESOUT(I)) GO TO 9
      PEAK = RESOUT(I)
      PKTIME = TIM
C  END OF RESERVOIR ROUTING LOOP
    9 CONTINUE
C  DETERMINE PEAK WATER SURFACE ELEVATION.
      DO 10 I = 1, 25
      IF(OUTFLO(I).GT.PEAK) GO TO 11
   10 CONTINUE
   11 ELPEAK=RESEL(I-1)+(PEAK-OUTFLO(I-1))*(RESEL(I)-RESEL(I-1))/
     1(OUTFLO(I) - OUTFLO(I-1))
      IF(.NOT.HYDTLS) GO TO 13
C  WRITE ROUTING TABLES.
      WRITE(6,21) PEAK,ELPEAK,PKTIME,HYDTIM
   21 FORMAT(10X,  /53X,16HPEAK DISCHARGE =,F10.0//53X,19HELEVATION OF P
     1EAK =,F7.2//53X,14HTIME TO PEAK =,F12.0//53X,16HTIME INCREMENT =,
     2F10.2// 57X,17HRESERVOIR OUTFLOW/)
      WRITE(6,22) (RESOUT(I), I = 1,50)
   22 FORMAT(20X,10F9.2)
      WRITE(6,55)
      WRITE(6,56)
   56 FORMAT(47X,40HRESERVOIR DATA USED IN ROUTING PROCEDURE/  52X,
     19HELEVATION,4X,9HS/T + O/2,4X,7HOUTFLOW)
      DO 50 I = 1,25
      WRITE(6,51) RESEL(I),STOR(I),OUTFLO(I)
   51 FORMAT(48X,3F12.2)
      IF(RESEL(I).GE.ELEVA(IMAX)) GO TO 60
   50 CONTINUE
   60 IF (GDELAY .EQ. 0.0) GO TO 77
      WRITE(6,78)
   78 FORMAT(64X,6HGATED )
      WRITE(6,56)
      DO 76  I = 1,25
      WRITE(6,51) RESEL(I),GSTOR(I),GOUTF(I)
      IF (RESEL(I) .GE. ELEVA(IMAX)) GO TO 77
   76 CONTINUE
   77 WRITE(6,55)
      WRITE(6,57)
   57 FORMAT(55X,23HRESERVOIR ROUTING TABLE//52X,9HS/T + O/2,5X,6HINFLOW
     1,5X,7HOUTFLOW//)
   55 FORMAT(1H1///)
      DO 53 I = 1,50
      WRITE(6,52) STOUT(I),RESINF(I),RESOUT(I)
   52 FORMAT(48X,3F12.2)
   53 CONTINUE
C  PLACE OUTFLOW HYDROGRAPH IN ARRAY FOR RETURN TO MAIN PROGRAM.
```

```
   13 DO 25 K = 1, 50
   25 RESINF(K) = RESOUT(K)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE RESRTE LEFT)
      RETURN
      END


      SUBROUTINE RETWAL(CONC,CONWAL,HWAL,LOOPTR,NWH,WLHT)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF MARCH 21, 1967
C SUBROUTINE RETWAL  CALCULATES FOR A RETAINING WALL OF GIVEN HEIGHT
C         (WLHT) THE VOLUME OF CONCRETE PER LINEAR FOOT OF WALL, AND
C         RETURNS THAT VOLUME AS (CONC, CY/FT).
      LOGICAL LOOPTR
      DIMENSION CONWAL(25),HWAL(25)
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE RETWAL ENTERED)
C  RETAINING WALL VOLUME (CONWAL) IS GIVEN FOR CORRESPONDING WALL HEIGH
C  (HWAL).
C  EXTRAPOLATE FOR WALLS HIGHER THAN GREATEST GIVEN HEIGHT.
      IF(WLHT.LE.HWAL(NWH)) GO TO 1
      CONC = CONWAL(NWH) + 0.232*(WLHT -HWAL(NWH))
      GO TO 1312
C  INTERPOLATE FOR WALLS WITHIN GIVEN RANGE.
    1 DO 2 I = 1, NWH
      IF(HWAL(I).GT.WLHT) GO TO 3
    2 CONTINUE
    3 CONC = CONWAL(I-1) + (WLHT-HWAL(I-1))*(CONWAL(I)-CONWAL(I-1))/
     1(HWAL(I)-HWAL(I-1))
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE RETWAL LEFT)
      RETURN
      END


      SUBROUTINE RSHYDR(AFT,AFV1,AFV2,AFW1,AFW2,AW,CHANEL,GSF,HYD05,
     1HYD05N,HYD43,HYD43N,HYDBAS,HYDDS,HYDDSN,HYDINT,HYDTLS,KDF,LC,
     2LOOPTR,NDF,NW,PCT,PUT,Q05,Q43,QB05,QB43,RBIG,RESIN,RK24,SIC,STF,
     3TCL,TIC,TIME,TP,TPB,TPW,UTOT1,UTOT2,V05,V43,VB05,VB43,VF05,VF43,
     4VFDS,YY)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 12, 1968
C   DEVELOPS FLOOD HYDROGRAPHS FOR FLOW ORIGINATING WITHIN THE
C        GIVEN SUBWATERSHED AND COMBINES WITH FLOWS ROUTED DOWN
C        FROM UPSTREAM.
      DIMENSION HYD05(50),HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),
     1HYDDS(50),HYDDSN(50),HYDTM(20),HYDTP(20),Q05(11,11),Q43(11,11),
     2TP(11),V05(11,11),V43(11,11),YY(10)
      LOGICAL CHANEL,HYDTLS,LOOPTR,RBIG,RESIN,SECOND,STF
```

```
      REAL LC
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE RSHYDR ENTERED)
C  ZERO DESIGN FLOOD FOR SUBSEQUENT PRINTOUT WHERE NOT USED.
      QFDS = 0.0
      VFDS = 0.0
C  FIND TIME OF HYDROGRAPH PEAK FROM INPUT DATA
      DO 770 N1 = 1,20
      IF (HYDBAS(1,N1) .EQ. 1.0) GO TO 771
  770 CONTINUE
  771 P1 = N1
C  DEVELOP HYDROGRAPH SET FIRST WITH SUBWATERSHED CHANNELIZATION
C  EXISTING AT STAGE BEGINNING AND THEN WITH SUBWATERSHED MAIN CHANNEL
C  IMPROVED.
      SECOND = .FALSE.
C  SELECTS BETWEEN STAGE AND PROJECT LIFE TRIBUTARY CHANNELIZATION
      TIA = TIC
      IF(RBIG) TIA = PCT
C  MOST UPSTREAM WATERSHED FLOWS INTO RESERVOIR, NO INFLOW FROM
C  MORE UPSTREAM SUBWATERSHEDS.
      IF(.NOT.RESIN) GO TO 210
      DO 208 J = 1, 50
      HYD43(J) = 0.0
      HYD43N(J) = 0.0
      HYDDS(J) = 0.0
      HYDDSN(J) = 0.0
      HYD05(J) = 0.0
  208 HYD05N(J) = 0.0
C  SELECTS BETWEEN DISCOUNTED AVERAGE ANNUAL URBANIZATION OVER STAGE AND
C  OVER PROJECT LIFE.
  210 U = UTOT1 + (GSF*(UTOT2-UTOT1))/TIME
      IF(RBIG) U = PUT
C  IF HAVE ONE, GUMBEL REDUCED VARIATE FOR DESIGN FLOOD.
      IF (KDF.NE.0) YDS = YY(KDF)
C  IF CHANNELIZATION PRESENT AT BEGINNING OF STAGE, NO NEED FOR
C  HYDROGRAPHS WITHOUT CHANNELIZATION.
      IF(CHANEL) GO TO 30
      C = (SIC + TIA)/TCL
C  FIND PEAKS OF THE MEAN ANNUAL, 200- YEAR, AND DESIGN HYDROGRAPHS.
    1 CALL PLACEA(C,LOOPTR,QT43,U,Q43)
      CALL PLACEA(C,LOOPTR,QT05,U,Q05)
      QF43 = AW*AFW1*QT43*QB43
      QF05 = AW*AFW2*QT05*QB05
      IF (KDF .GT. 1 .AND. KDF .LT. NDF)
     1QFDS = YDS*(QF05-QF43)/4.718+((QF05*0.579)-(QF43*5.296))/(-4.718)
C   FIND THE VOLUMES OF THE THREE HYDROGRAPHS
      CALL PLACEA(C,LOOPTR,VT43,U,V43)
      CALL PLACEA(C,LOOPTR,VT05,U,V05)
      VF43 = AW*AFV1*VT43*VB43
      VF05 = AW*AFV2*VT05*VB05
      IF (KDF .GT. 1 .AND. KDF .LT. NDF)
     1VFDS = YDS*(VF05-VF43)/4.718+((VF05*0.579)-(VF43*5.296))/(-4.718)
```

```
      IF(QFDS .LT. VFDS) QFDS = VFDS
C     FIND THE RELATIVE TIME TO PEAK FOR THE SUBWATERSHED
      IC = 10.0*C + 1.0
      CC = IC - 1
      CC = 0.1*CC
      JC = IC + 1
      IF(IC.EQ.11) JC = 11
      TPW = AFT*TPB*(TP(IC) +  10.0*(C-CC)*(TP(JC)-TP(IC)))
C     DEVELOP THE FIRST HYDROGRAPH, MEAN ANNUAL
C     RATIO OF AVERAGE FLOW DURING HYDROGRAPH TO PEAK FLOW
      VRAT = VF43/QF43
C   SEARCH INPUT HYDROGRAPH SHAPES TO FIND THE TWO WITH BRACKETING VALUES
C   OF VRAT.  USE FLATTEST OR SHARPEST HYDROGRAPH GIVEN IF VRAT NOT
C   BRACKETED.
C     DEVELOP A 20 POINT HYDROGRAPH.
      IF(VRAT.GE.HYDBAS(1,21)) GO TO 3
      DO 2 K1 = 1, 20
    2 HYDTP(K1) = QF43*HYDBAS(1,K1)
      GO TO 9
    3 DO 6 K2 = 2,5
      IF(VRAT.GE.HYDBAS(K2,21)) GO TO 5
      DO 4 K3 = 1, 20
    4 HYDTP(K3) = QF43*(HYDBAS(K2-1,K3)+(VRAT-HYDBAS(K2-1,21))*(HYDBAS(
     1K2,K3)-HYDBAS(K2-1,K3))/(HYDBAS(K2,21)-HYDBAS(K2-1,21)))
      GO TO 9
    5 IF(K2.EQ.5) GO TO 7
    6 CONTINUE
      GO TO 9
    7 DO 8 K4 = 1,20
    8 HYDTP(K4) = QF43*HYDBAS(5,K4)
C   COMPUTE TIME OF EACH HYDROGRAPH POINT.
    9 DO 10 K5 = 1, 20
      A5 = K5
   10 HYDTM(K5) = TPW*A5/P1
C   SELECT APPROPRIATE HEADING FOR PRINTED HYDROGRAPH AND UPSTREAM
C   HYDROGRAPH FOR COMBINATION.
      IF(SECOND) GO TO 100
      IF(HYDTLS) WRITE(6,1355) HYDINT
 1355 FORMAT(/10X,69HCOMBINED HYDROGRAPH, MEAN ANNUAL FLOOD,  NATURAL CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
C   COMBINE DEVELOPED SUBWATERSHED HYDROGRAPH WITH FLOWS ROUTED FROM
C   UPSTREAM.
      CALL HYDCOM(HYDTP,HYDINT,HYD43N,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
      GO TO 101
  100 IF(HYDTLS) WRITE(6,1315) HYDINT
 1315 FORMAT(/10X,69HCOMBINED HYDROGRAPH, MEAN ANNUAL FLOOD, IMPROVED CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
C   COMBINE DEVELOPED SUBWATERSHED HYDROGRAPH WITH FLOWS ROUTED
C   FROM UPSTREAM.
      CALL HYDCOM(HYDTP,HYDINT,HYD43,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
C     DEVELOP SECOND HYDROGRAPH, 200-YEAR
  101 VRAT = VF05/QF05
```

```
C   SEARCH INPUT HYDROGRAPH SHAPES TO FIND THE TWO WITH BRACKETING VALUES
C   OF VRAT.  USE FLATTEST OR SHARPEST HYDROGRAPH GIVEN IF VRAT
C   NOT BRACKETED.
C      DEVELOP A 20 POINT HYDROGRAPH.
       IF(VRAT.GE.HYDBAS(1,21)) GO TO 12
       DO 11 L1 = 1, 20
   11 HYDTP(L1) = QF05*HYDBAS(1,L1)
       GO TO 18
   12 DO 15 L2 = 2,5
       IF(VRAT.GE.HYDBAS(L2,21)) GO TO 14
       DO 13 L3 = 1,20
   13 HYDTP(L3) = QF05*(HYDBAS(L2-1,L3)+(VRAT-HYDBAS(L2-1,21))*(HYDBAS
     1(L2,L3)-HYDBAS(L2-1,L3))/(HYDBAS(L2,21)-HYDBAS(L2-1,21)))
       GO TO 18
   14 IF(L2.EQ.5) GO TO 16
   15 CONTINUE
       GO TO 18
   16 DO 17 L4 = 1,20
   17 HYDTP(L4) = QF05*HYDBAS(5,L4)
C   SELECT APPROPRIATE HEADING FOR PRINTED HYDROGRAPH AND UPSTREAM
C   HYDROGRAPH FOR COMBINATION.
   18 IF(SECOND) GO TO 102
       IF(HYDTLS) WRITE(6,1316) HYDINT
 1316 FORMAT(/10X,69HCOMBINED HYDROGRAPH,    200-YEAR  FLOOD,  NATURAL CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
C   COMBINE DEVELOPED SUBWATERSHED HYDROGRAPH WITH FLOWS ROUTED FROM
C   UPSTREAM.
       CALL HYDCOM(HYDTP,HYDINT,HYD05N,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
       GO TO 103
  102 IF(HYDTLS) WRITE(6,1317) HYDINT
 1317 FORMAT(/10X,69HCOMBINED HYDROGRAPH,    200-YEAR  FLOOD, IMPROVED CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
C   COMBINE DEVELOPED SUBWATERSHED HYDROGRAPH WITH FLOWS ROUTED FROM
C   UPSTREAM.
       CALL HYDCOM(HYDTP,HYDINT,HYD05,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
C    DEVELOP THE THIRD HYDROGRAPH, RESERVOIR DESIGN FLOOD
C   NO NEED FOR ADDITIONAL HYDROGRAPH IF RESERVOIR FLOOD EQUALS ONE OF
C   OTHER TWO.
  103 IF(QFDS .EQ. 0.0) GO TO 29
       VRAT = VFDS/QFDS
C   SEARCH INPUT HYDROGRAPH SHAPES TO FIND THE TWO WITH BRACKETING VALUES
C   OF VRAT.  USE FLATTEST OR SHARPEST HYDROGRAPH GIVEN IF VRAT
C   NOT BRACKETED.
C      DEVELOP A 20 POINT HYDROGRAPH.
       IF(VRAT.GE.HYDBAS(1,21)) GO TO 22
       DO 21 M1 = 1,20
   21 HYDTP(M1) = QFDS*HYDBAS(1,M1)
       GO TO 28
   22 DO 25 M2 = 2,5
       IF(VRAT.GE.HYDBAS(M2,21)) GO TO 24
       DO 23 M3 = 1, 20
   23 HYDTP(M3) = QFDS*(HYDBAS(M2-1,M3)+(VRAT-HYDBAS(M2-1,21))*(HYDBAS
```

```
     1(M2,M3)-HYDBAS(M2-1,M3))/(HYDBAS(M2,21)-HYDBAS(M2-1,21)))
      GO TO 28
   24 IF(M2.EQ.5) GO TO 26
   25 CONTINUE
      GO TO 28
   26 DO 27 M4 = 1, 20
   27 HYDTP(M4) = QFDS*HYDBAS(5,M4)
      GO TO 28
C  ZERO VESTIGIAL DESIGN HYDROGRAPH
   29 DO 37 M5=1,20
   37 HYDTP(M5) = 0.0
      GO TO 107
C  SELECT APPROPRIATE HEADING FOR PRINTED HYDROGRAPH AND UPSTREAM
C  HYDROGRAPH FOR COMBINATION.
   28 IF(SECOND) GO TO 105
      IF(HYDTLS) WRITE(6,1318) HYDINT
 1318 FORMAT(/10X,69HCOMBINED HYDROGRAPH, RES. DESIGN FLOOD,  NATURAL CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
      CALL HYDCOM(HYDTP,HYDINT,HYDDSN,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
      GO TO 107
  105 IF(HYDTLS) WRITE(6,1319) HYDINT
 1319 FORMAT(/10X,69HCOMBINED HYDROGRAPH, RES. DESIGN FLOOD, IMPROVED CH
     1ANNELS, INTERVAL =,F4.2,1X,5HHOURS)
      CALL HYDCOM(HYDTP,HYDINT,HYDDS,HYDTLS,HYDTM,LOOPTR,N1,NW,RK24)
C  WRITE HYDROGRAPH PARAMETERS AND PEAKS.
  107 IF(HYDTLS)WRITE(6,1320)QF43,QF05,QFDS,VF43,VF05,VFDS,TPW
 1320 FORMAT(15X,11HFLOOD PEAKS/15X,6HQF43 =,F8.1,10X,6HQF05 =,F8.1,10X,
     16HQFDS =,F8.1/15X,19HAVERAGE FLOOD FLOWS/15X,6HVF43 =,F8.1,10X,
     26HVF05 =,F8.1,10X,6HVFDS =,F8.1/15X,5HTPW =,F5.1,2X,5HHOURS)
      IF(HYDTLS)WRITE(6,1321)AW,U,C,AFW1,QT43,AFV1,VT43,AFW2,QT05,AFV2,
     1VT05
 1321 FORMAT(15X,27HBASIC HYDROGRAPH PARAMETERS/15X,4HAW =,F8.2,2X,3HU =
     1,F8.2,2X,3HC =,F8.2/15X,17HMEAN ANNUAL FLOOD,2X,   5HAFQ =,F8.2,
     22X,4HQT =,F8.2,2X,5HAFV =,F8.2,2X,4HVT =,F8.2/15X,14H200-YEAR FLOO
     3D,5X,5HAFQ =,F8.2,2X,4HQT =,F8.2,2X,5HAFV =,F8.2,2X,4HVT =,F8.2)
C  NO NEED FOR MORE HYDROGRAPHS IF ALREADY HAVE SIX OR IF CHANNEL
C  IMPROVEMENT IS NOT TO BE CONSIDERED BECAUSE OF INPUT DATA OR BECAUSE
C  UPSTREAM FROM RESERVOIR.
  106 IF (SECOND.OR.RESIN.OR.STF) GO TO 522
C  ADJUST FOR IMPROVED CHANNELS AND DEVELOP ANOTHER HYDROGRAPH SET.
   30 SECOND = .TRUE.
      C = (TIA + LC)/TCL
      GO TO 1
  522 IF(.NOT. RESIN) GO TO 1312
C  IF DEALING WITH RESERVOIR INFLOW, DESIGN FLOOD VOLUMES MUST BE
C  RELATED TO CUMULATIVE RUNOFF VALUES FOR U=C=0.0 FOR USE IN PRINCIPAL
C  SPILLWAY SIZING.
      IF (KDF.EQ.1) VFDS = VF43
      IF (KDF.EQ.NDF) VFDS = VF05
      CALL PLACEA(0.0,LOOPTR,VT43,0.0,V43)
      VF43 = AW*AFV1*VT43*VB43
 1312 IF (LOOPTR) WRITE(6,1314)
```

```
 1314 FORMAT (10X,22HSUBROUTINE RSHYDR LEFT)
      RETURN
      END


      SUBROUTINE SPLSIZ
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 12, 1968
C  SELECTS THE OPTIMUM EMERGENCY SPILLWAY WIDTH FROM THE ECONOMIC
C        TRADEOFF BETWEEN THE COST OF A HIGHER DAM (INCLUDING RIGHT-OF-
C        WAY) AND THE COST OF A LARGER SPILLWAY.
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      COMMON/RS1/AFT(15),AFV(2,15),CHKN(15),CHKY(15),CHXN(15),CHXY(15),
     1 CONWAL(25),CRELOC(25),CUMVOL(26),DMBN(2,10),DMBNF(5),ELEVA(25),
     2 HLSIDE(25),HLSIDH(25),HLSIDL(25),HLSIDM(25),HWAL(25),HYD05(50),
     3 HYD05N(50),HYD43(50),HYD43N(50),HYDBAS(5,21),HYDDS(50),
     4 HYDDSN(50),HYDEM(50),LGAPCH(25),LGDAM(25),LGEMSP(25),RESACR(25),
     5 RESVOL(25),TP(11),V05(11,11),V43(11,11),WFIX(5)
      COMMON/RS2/BLDNOW,BYVERT,CONBOT,COSTDM,COSTFP,CSMD,CTBW,CWEIR,
     1 DMDTLS,DMFRBD,DMTPW,DPRCKH,DPRCKV,DPRP,DRQ,ELFB05,ELFB43,ELFDBG,
     2 ELPRFL,ELSPFL,ELSPTP,ESMD,FLDSTR,FPIPE,FRES,GDELAY,HBRLM,HBRMH,
     3 HYDINT,HYDMLT,HYDTLS,IMAX,IMPTY,IS,KNBOT,LOOPTR,MDAM,
     4 MRDF,NHILSD,NODAM,NWH,QEMSP,QRATIO,RBIG,RK24,RSBLT,RSFLD,SEDIN,
     5 SEDSTR,STLBOT,TPB,TPELEV,TPW,TRV,TWELEV,UCCLR,UCCNID,UCCT,UCDAM,
     6 UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,VB05,VB43,VF05,VF43,VFDS,
     7 WDEMSP,XTRSTR,ZCT,ZDN,ZES,ZUP
      LOGICAL DMDTLS,GOBIG,LOOPTR,WFIX
      INTEGER TRIP
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE SPLSIZ ENTERED)
C  ANALYSIS OF ALTERNATIVE SPILLWAY SIZES BEGINS WITH READ VALUE OF
C  "WDEMSP", CALCULATES A COST, AND THEN TRIES A SMALLER SIZE.  THE SIZE
C  IS REDUCED IN 20 PERCENT INCREMENTS UNTIL A MINIMUM COST IS FOUND.
C  HOWEVER, IF THE FIRST REDUCTION INCREASES THE COST, THE SIZE IS
C  INSTEAD INCREASED IN 20 PERCENT INCREMENTS UNTIL A MINIMUM COST
```

```
C   IS FOUND.
        TRIP = 1
        GOBIG = .FALSE.
C   POINT OF RETURN WITH NEW WDEMSP
      4 DO 5 I=1,50
C   ROUTE THE EMERGENCY SPILLWAY FLOOD THROUGH SPILLWAY AND SET DAM CREST
C      ELEVATION FOR CURRENT SPILLWAY SIZE.
      5 HYDEM(I) = HYDMLT*HYD05N(I)
        CALL RESRTE(CWEIR,DRQ,ELEVA,ELFB05,ELSPTP,ELPRFL,ELSPFL,0.0,
       1HYDINT,HYDTLS,IMAX,LOOPTR,HYDEM,RESVOL,TWELEV,WDEMSP,ZDN,ZUP)
        TPELEV = ELSPTP + DMFRBD
C   THE RESULTING TOP OF DAM ELEVATION IS USED TO SELECT THE APPROPRIATE
C      EMERGENCY SPILLWAY SITE.  THE SITE CROSS SECTION IS PLACED IN
C   HLSIDE() FOR FIGURING DESIGN QUANTITIES.  ISG IS THE NUMBER OF THE
C   SELECTED SITE.
        ISG = 1
        IF(NHILSD .EQ. 1) GO TO 60
        IF(TPELEV .GT. HBRLM) GO TO 52
        DO 51 I=1,IMAX
     51 HLSIDE(I) = HLSIDL(I)
        GO TO 60
     52 IF(TPELEV .GT. HBRMH) GO TO 54
     53 HLSIDE(I) = HLSIDM(I)
        ISG = 2
        GO TO 60
     54 DO 55 I = 1,IMAX
     55 HLSIDE(I) = HLSIDH(I)
        ISG = 3
     60 QEMSP = CWEIR*WDEMSP*(ELSPTP-ELSPFL)**1.5
        IF(DMDTLS) WRITE(6,1301) WDEMSP,TPELEV,QEMSP,ISG
   1301 FORMAT(12X,21HFOR TRIAL OF WDEMSP =,F4.0,1X,4HFEET/
       115X,13HTOP OF DAM AT,F7.1,3X,7HQEMSP =,F8.1,1X,3HCFS
       2/12X,25HSPILLWAY SITE SELECTED IS, I2)
        DFR = 0.0
        IF(XTRSTR .EQ. 0.0) DFR=1.0/FRES
C   ASSUME FACE OF DAM RIPRAPPED AGAINST WAVE ACTION FROM 2.0 FEET BELOW
C   TOP OF SEDIMENT STORAGE TO ELEVATION OF EMERGENCY SPILLWAY DESIGN
C   FLOOD CREST.
        ELRPTP = ELSPTP
        ELRPBT = ELPRFL - 2.0
C   DESIGN AND ESTIMATE QUANTITIES FOR DAM EMBANKMENT.
        CALL DAMVOL(CTBW,LGDAM,DMDTLS,DMTPW,DPRCKV,DPRP,TPELEV,ELEVA,
       1ELRPBT,ELRPTP,IMAX,LOOPTR,VOLCT,VOLDAM,VOLRP,ZCT,ZDN,ZUP)
C   DESIGN AND ESTIMATE QUANTITIES FOR EMERGENCY SPILLWAY STILLING BASIN.
        CALL STLBAS(CONBOT,CONWAL,D1,DMDTLS,ELEVA,ELSPFL,ELSPTP,GRADSP,
       1HWAL,IMAX,KNBOT,LGEMSP,LOOPTR,NWH,QEMSP,SBCONC,SBEX,SPLNG,STLBOT,
       2TPELEV,TWELEV,WDEMSP)
C   DESIGN AND ESTIMATE QUANTITIES FOR EMERGENCY SPILLWAY CREST AND CHUTE
        CALL EMSPVL(CONBOT,CONWAL,D1,DMDTLS,DPRCKH,ELEVA,ELSPFL,ELSPTP,
       1SPEX,GRADSP,HLSIDE,HWAL,IMAX,LGAPCH,LOOPTR,NWH,QEMSP,SPCONC,
       2SPLNG,SPRKEX,TPELEV,WDEMSP,ZCT)
C   DESIGN AND ESTIMATE QUANTITIES FOR PRINCIPAL SPILLWAY (NO SPILLWAY IF
```

```
C  NO FLOOD STORAGE.)
      TRAREA = 0.0
      PRCON = 0.0
      CONID = 0.0
      IF(FLDSTR.GT.0.0)CALL PRNSP(CONID,DMDTLS,DMTPW,DRQ,ELEVA(1),ELPRFL
     1,ELSPFL,FPIPE,LOOPTR,PRCON,TPELEV,TRAREA,TRV,TWELEV,ZDN,ZUP)
C  ESTIMATE "COSTDM" FROM ABOVE QUANTITIES AND READ UNIT COSTS.
      CALL DMCOST(AQR,BYVERT,CONID,COSTDM,CRELOC,CRFSM,CSMD,DFR,DMDTLS,
     1ELEVA,ELSPFL,ESMD,LOOPTR,MDAM,PRCON,RESACR,RESVOL,SPRKEX,SBCONC,
     2SBEX,SEDSTR,SPCONC,SPEX,TPELEV,TRAREA,UCCLR,UCCNID,UCCT,UCDAM,
     3UCPRCN,UCRKEX,UCRP,UCSPCN,UCSPEX,UCTRK,USUBW(NW,NSTAGE),
     4VALUE(NW,NSTAGE),VLAGST,VLURST,VOLCT,VOLDAM,VOLRP)
C  SET "CSTLOW" AS LOWEST "COSTDM" FOUND THUS FAR IF IT IS (FIRST VALUE
C  MUST BE LOWEST.)
      IF(TRIP.EQ.1 .OR. CSTLOW .GT. COSTDM) GO TO 21
      GO TO 20
   21 CSTLOW = COSTDM
      ISD = ISG
C  "WDEMSP" WILL EITHER STAY THE SAME OR BE INCREASED AS GO TO LATER
C  STAGES.  HIGHER RIGHT-OF-WAY VALUES MAKE LONGER SPILLWAY CRESTS MORE
C  ECONOMICAL.
   20 IF(NSTAGE .NE. 1 .OR. GOBIG) GO TO 10
C  FIRST TRY A SMALLER SIZE TO SEE IF IT COSTS LESS.
      IF(TRIP .EQ. 1) GO TO 6
C  IF THE FIRST TRY AT SIZE REDUCTION INCREASES THE COST, TRY A LARGER
C  SIZE TO SEE IF IT COSTS LESS.
      IF(TRIP .EQ. 2 .AND. COSTDM .GT. CSTLOW) GO TO 7
C  IF THE FIRST TRY AT SIZE REDUCTION REDUCES THE COST, KEEP TRYING
C  SMALLER SIZES UNTIL A COST INCREASE IS ENCOUNTERED.
      IF(TRIP .GE. 2 .AND. COSTDM .LE. CSTLOW) GO TO 6
C  SET ECONOMIC SIZE.
      WDEMSP = 1.2*WDEMSP
      GO TO 6968
C  REDUCE SIZE AND TRY AGAIN.
    6 WDEMSP = WDEMSP/1.2
      TRIP = TRIP+1
      GO TO 4
C  REVERSE SIZE CHANGE FROM DECREASE TO INCREASE AND TRY AGAIN.
    7 WDEMSP =1.44*WDEMSP
      GOBIG = .TRUE.
      TRIP = TRIP+1
      GO TO 4
C  WHEN BEGIN BY INCREASING SIZE IN STAGES AFTER THE FIRST, MAKE AT
C  LEAST ONE INCREASE BEFORE QUITTING.
   10 IF(TRIP.EQ.1) GO TO 12
C  KEEP TRYING LARGER SIZES UNTIL COST REACHES A MINIMUM.
      IF(COSTDM .LE. CSTLOW) GO TO 12
C  SET ECONOMIC SIZE.
      WDEMSP = WDEMSP/1.2
      GO TO 6968
C  INCREASE SIZE AND TRY AGAIN.
   12 WDEMSP =1.2*WDEMSP
```

```
      TRIP = TRIP+1
      GO TO 4
C  SET OPTIMUM COST AND LOCATION.
 6968 WFIX(NSTAGE) = .TRUE.
      COSTDM = CSTLOW
      WRITE(6,1300) NSTAGE,WDEMSP
 1300 FORMAT(12X,12HFOR NSTAGE =,I2,3X,8HWDEMSP =,F6.1,1X,4HFEET)
      IS = ISD
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE SPLSIZ LEFT)
      RETURN
      END


      SUBROUTINE STLBAS(CONBOT,CONWAL,D1,DMDTLS,ELEVA,ELSPFL,ELSPTP,
     1GRADSP,HWAL,IMAX,KNBOT,LGEMSP,LOOPTR,NWH,QEMSP,SBCONC,SBEX,
     2SPLNG,STLBOT,TPELEV,TWELEV,WDEMSP)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF MARCH 29, 1967
C     SUBROUTINE STLBAS DESIGNS THE NECESSARY STILLING BASIN FOR THE
C     EMERGENCY SPILLWAY.
C  GIVEN THE DISCHARGE (QEMSP), WIDTH OF SPILLWAY (WDEMSP), ELEVATION OF
C        THE TOP OF THE DAM (TPELEV), ELEVATION OF THE SPILLWAY CREST
C        (ELSPFL), ELEVATION OF THE RESERVOIR SURFACE (ELSPTP), AND THE
C        ARRAY (LGEMSP) EXPRESSING THE NECESSARY SPILLWAY LENGTH AS A
C        FUNCTION OF THE ELEVATION OF THE TOP OF THE DAM, THIS
C        SUBROUTINE LOCATES AND SIZES THE EMERGENCY SPILLWAY STILLING
C        BASIN AND COMPUTES THE NECESSARY EXCAVATION (SBEX) AND CONCRETE
C        VOLUME (SBCONC).
      LOGICAL DMDTLS, KNBOT,LOOPTR
      REAL LGEMSP
      DIMENSION CONWAL(25),ELEVA(25),F(28),HWAL(25),LGEMSP(25)
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,25HSUBROUTINE STLBAS ENTERED)
C  INTERPOLATE EMERGENCY SPILLWAY LENGTH FROM READ DATA ACCORDING TO
C  ELEVATION OF DAM TOP.
      DO 51 I = 1, IMAX
      IF(ELEVA(I).GT.TPELEV) GO TO 52
   51 CONTINUE
   52 EMSPLG = LGEMSP(I-1)+(TPELEV-ELEVA(I-1))*(LGEMSP(I)-LGEMSP(I-1))/
     1(ELEVA(I) - ELEVA(I-1))
C  INITIALIZE BOTTOM OF STILLING BASIN AT BOTTOM OF CREEK ELEVATION
C  UNLESS HAVE A BETTER ELEVATION FROM A PREVIOUS TRIAL.
      IF(.NOT.KNBOT) BOTTOM = ELEVA(1)
C  ADJUST BOTTOM ELEVATION BY TRIAL AND ERROR UNTIL CONJUGATE DEPTH
C  AFTER HYDRAULIC JUMP EQUALS TAILWATER ELEVATION.
    1 FALL = ELSPTP - BOTTOM
C  HEAD LOSS ASSUMED AT ONE TENTH KINETIC ENERGY GAIN FOR ACCELERATING
C  FLOW.
      VK = (QEMSP/WDEMSP)**2/64.4
      CK = 1.1*VK
```

```
C   CHECK FOR SUBCRITICAL FLOW DOWN SPILLWAY, IF THE FLOW IS SUBCRITICAL,
C   ASSUME UNIFORM FLOW DOWN CHUTE.
       IF(CK.LT.(4.0/27.0*FALL**3.0)) GO TO 9
       WRITE(6,55)
   55 FORMAT(10X,40HSUBCRITICAL FLOW OVER EMERGENCY SPILLWAY)
       D1 = ELSPTP - ELSPFL
       IF(DMDTLS) WRITE(6,1967) D1
 1967 FORMAT(10X,7HDEPTH =,F7.3)
       D2 = D1
       GO TO 6
C   IF FLOW DOWN CHUTE IS SUPERCRITICAL, SOLVE FOR DEPTH AT BOTTOM WITH A
C   TRIAL AND ERROR SOLUTION OF CUBIC EQUATION BASED ON ENERGY.
    9 P = 0.0
       PA = 0.0
       F(1) = CK
       DO 87 K = 2, 28
       PA = P
       P = P + 0.025*FALL
       F(K) = P**3.0 - FALL*P**2 + CK
       IF((F(K-1).GT.0.0).AND.(F(K).LT.0.0)) GO TO 89
   87 CONTINUE
C   SPECIAL PROVISION FOR CASE OF VERY LOW DAM WITH FLOW JUST BARELY
C     SUPERCRITICAL
       WRITE(6,88)
   88 FORMAT(10X,101HNO CHANGE OF SIGN UP TO D1 = 0.65(FALL). D1 WILL BE
     1 SET = 0.1(FALL) SO THAT COMPUTATIONS MAY PROCEED.)
       D1 = 0.1*FALL
       IF(DMDTLS) WRITE(6,1967) D1
       FRNUM = QEMSP/WDEMSP/D1/SQRT(32.2*D1)
       D2 = D1/2.0*(SQRT(1.0 + 8.0*FRNUM**2)-1.0)
       BOTTOM = TWELEV - D2 -VK/D2**2
       GO TO 6
   89 D1 = (P + PA)/2.0
       IF(DMDTLS) WRITE(6,1967) D1
       I = 0
    2 I = I + 1
       Y = D1**3.0 - FALL*D1**2 + CK
       YPRIME = 3.0*D1**2 - 2.0*FALL*D1
       ERROR = Y/YPRIME
C   CURRENT TRIAL AND ERROR SOLUTION OF CUBIC EQUATION.  NEW TRIALS ARE
C   MADE UP TO 20 TIMES UNTIL TERMS AGREE WITHIN 0.025 FOOT.
       D1 = D1 - ERROR
       IF(DMDTLS) WRITE(6,1967) D1
       IF(I.GT.20) GO TO 5
       IF(ABS(ERROR).GE.0.025) GO TO 2
C   WATER SURFACE ELEVATION DOWNSTREAM FROM JUMP CALCULATED AND COMPARED
C   WITH KNOWN TAILWATER ELEVATION.  IF THEY DO NOT AGREE WITHIN 2.0
C   FEET, ADJUST BOTTOM ELEVATION AND REPEAT.
    5 FRNUM = QEMSP/WDEMSP/D1/SQRT(32.2*D1)
       D2     = D1/2.0*(SQRT(1.0 + 8.0*FRNUM**2) - 1.0)
       DNWS = BOTTOM + D2 + VK/D2**2
       IF(ABS(DNWS-TWELEV).LT.0.5) GO TO 6
```

```
   11 BOTTOM = BOTTOM + TWELEV - DNWS
      GO TO 1
C  STILLING BASIN BOTTOM ELEVATION HAS BEEN ESTABLISHED.
    6 KNBOT = .TRUE.
C  STILLING BASIN QUANTITIES INCLUDE STILLING BASIN PROPER PLUS PORTION
C  OF CHUTE DOWNSTREAM FROM HORIZONTAL PROJECTION OF TOP OF STILLING
C  BASIN WALL.
C  WALL HEIGHTS (INCLUDING FREEBOARD) ON BASIN AND AT CHUTE BOTTOM
      WLHTB = D2 + 0.1*(VK/D1**2 + D2)
      WLHTD1= D1 + 2.0 + 0.025*(QEMSP/(D1*WDEMSP))*D1**(1.0/3.0)
      WLHTM = (WLHTB + WLHTD1)/2.0
C  CHUTE SLOPE (HORIZONTAL/VERTICAL)
      GRADSP = EMSPLG/(ELSPFL-BOTTOM)
C  LENGTH OF STILLING BASIN AND CHUTE PORTION.  REMAINING CHUTE LENGTH
C    CALCULATED FOR TAKING INTO "EMSPVL".
      SBLNG = 4.0*D2
      CHLNG = GRADSP*(WLHTB - WLHTD1)
      SPLNG = EMSPLG - CHLNG
C  CONCRETE VOLUMES
      CALL RETWAL(CONCB,CONWAL,HWAL,LOOPTR,NWH,WLHTB)
      CALL RETWAL(CONCD1,CONWAL,HWAL,LOOPTR,NWH,WLHTD1)
      CALL RETWAL(CONCM,CONWAL,HWAL,LOOPTR,NWH,WLHTM)
      CM = (CONCB + CONCD1 + 4.0*CONCM)/6.0
      WLVOL = 2.0*SBLNG*CONCB + 2.0*CHLNG*CM
      BTVOL = (SBLNG*STLBOT + CHLNG*CONBOT)*WDEMSP/27.0
      SBCONC = WLVOL + BTVOL
C  EXCAVATION FOR STILLING BASIN
      SBEX = SBCONC+(SBLNG*WDEMSP*ABS(ELEVA(1)-BOTTOM)  + CHLNG*WDEMSP*
     1WLHTD1)/27.0
      IF(DMDTLS) WRITE(6,1350)D1,D2,BOTTOM,SBCONC,SBEX
 1350 FORMAT(/10X,24HFLOW JUMPS FROM DEPTH OF,F5.2,1X,18HFEET TO A DEPTH
     1 OF,F5.2,1X,4HFEET/10X,33HSTILLING BASIN BOTTOM ELEVATION =,F7.2,
     21X,4HFEET/10X,25HSTILLING BASIN QUANTITIES/15X,10HCONCRETE =,F7.2,
     31X,2HCY/15X,12HEXCAVATION =,F9.2,1X,2HCY)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE STLBAS LEFT)
      RETURN
      END
      SUBROUTINE STR(LOOPTR)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  SELECT THE LEAST COSTLY TYPE OF CHANNEL IMPROVEMENT AND DETERMINE THE
C           RESULTING DESIGN DIMENSIONS AND COSTS
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),T0(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 W0(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
```

```
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      REAL LC,MANNR,MANNT,MANNU,ND
      LOGICAL CHANEL,CHECK,HOLDNG,LINED,LOOPTR
      IF (LOOPTR) WRITE (6,1313)
 1313 FORMAT (10X,22HSUBROUTINE STR ENTERED)
      LINED=.FALSE.
      ND=NDT(NW)
      FD=FDA(NW)
C   CALCULATE RIGHT-OF-WAY COST IN $/ACRE IF THIS WAS NOT DONE PREVIOUSLY
      IF(RC    .GE.0.0)  GO TO 20
      LTA=NSTAGE
      LTB=NSTAGE
C   DETERMINE STAGE WHEN NEW BUILDING FIRST RESTRICTED FROM FLOOD PLAIN
      IF (LOC(NW).GT.0) LTB=LOC(NW)
C   DETERMINE STAGE WHEN LAND PURCHASED FOR HOLDING
      IF(.NOT. HOLDNG) GO TO 21
      IF(IHOLD(NW).LE.0) GO TO 21
      LTA=IHOLD(NW)
      LTB=LTA
   21 IF(CHANEL(NW)) GO TO 22
C   RIGHT-OF-WAY COST = LAND VALUE + STRUCTURES' VALUE
      RC     =VALUE(NW,LTA)+VLURST*USUBW(NW,LTB)/3.0
      GO TO 20
   22 RC     =VALUE(NW,LTA)+VLURST*USUBW(NW,LTB)
C   DETERMINE SUBWATERSHED WEIGHTED AVERAGE DESIGN FLOW
   20 Q=QS
C   CALL BRIDGE UNLESS RECTANGULAR LINED CHANNEL HAS ALREADY BEEN BUILT
      IF(LINING(NW) .NE. 4  .OR. .NOT. CHANEL(NW))  CALL BRIDGE(CAP,
     1 CHANEL,HE,HN,LC,LOOPTR,NSTAGE,NW,Q,RE,RN,USUBW)
C   GO TO SECTION ON CHANNEL TYPE DESIRED
      IF(LINING(NW) .EQ. 3)  GO TO 100
      IF(LINING(NW) .EQ. 4)  GO TO 200
C   SELECT DIMENSIONS FOR UNLINED CHANNEL
      X=BDMIN
    3 H=((Q*MANNU*(X+2.*(SQRT(1.+ZU*ZU)))**0.667)/(SQRT(S(NW))*1.49*(X+Z
     1U)**1.667))**0.375
      IF(H .LE. HMAX .OR. X .GE. BDMAX)  GO TO 4
      X=X+0.5
      GO TO 3
C   CHECK DEVELOPED AGAINST CRITICAL TRACTIVE FORCE
    4 TFF=62.4*H*S(NW)
      IF(TFF .GT. TF(NW))  GO TO 5
C   CALCULATE FINAL UNLINED CHANNEL DIMENSIONS
      B=X*H
      T=B+2.*ZU*H
```

```
      A=0.5*H*(B+T)
      AEXTRA = A - AO(NW)
      AMINM = 0.2*A
      IF (.NOT. CHANEL(NW) .AND. AEXTRA .LT. AMINM) AEXTRA = AMINM
      W=B+2.4*H*ZU+30.
C  CALCULATE UNLINED CHANNEL COST
      CS=SK1*LC(NW)* AEXTRA    +SK2*LC(NW)+SK3*RC    *(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      IF (LINING(NW).EQ.1) GO TO 50
      LINING(NW)=1
      TT=T
      AA=A
      WW=W
C  IF NOT COMMITTED TO CHANNEL TYPE, TRY OTHERS TO SEE IF THEY ARE LESS
C          EXPENSIVE
      GO TO 100
   50 IF(.NOT. CHANEL(NW)) GO TO 1312
C  IT MAY BE LESS EXPENSIVE TO INCREASE CHANNEL CAPACITY BY LINING THAN
C  BY ENLARGING.
      AZ=A
      A=AO(NW)
      SLOPE=S(NW)
      HU=(TO(NW)-SQRT(TO(NW)**2 -4.0*ZU*A))/(2.0*ZU)
      BU=TO(NW)-2.0*ZU*HU
   51 PU1=2.0*HU*SQRT(1.0+ZU*ZU)
      PU=BU+1.1*PU1
C  CAPACITY OF CHANNEL IF LINED
      QLINED=(1.49*A*((A/(BU+PU1))**0.667)*SQRT(SLOPE))/MANNT
C  LINING ALSO REDUCES RESIDUAL DAMAGES BY INCREASING CAPACITY MORE
C          THAN DOES ENLARGING
      QSS=QS
      QPP=QP
      QLL=QL
      CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,2,NW,QO,QP,QS,
     1QX,R,UN,UNC,VA,VLAGST,VLURST)
      CDZ=CD
      CUZ=CU
      QS=QLINED
      QP=QS
      QL=QS
      CALL CD1(CD,COEFDM,CRFSM,CU,FA,GA,ITOP,K1,K2,LOOPTR,2,NW,QO,QP,QS,
     1QX,R,UN,UNC,VA,VLAGST,VLURST)
C  GO BACK TO ENLARGING IF THAT IS LESS EXPENSIVE
      IF (CS.LE.SK7*PU*LC(NW)+CD+CU-CDZ-CUZ) GO TO 52
C  SET COSTS AND CONSTANTS FOR LINED CHANNEL
      CS=SK7*PU*LC(NW)
      T=TO(NW)
      W=WO(NW)
      A=AO(NW)
      LINED=.TRUE.
      GO TO 1312
C  RESTORE FLOWS ALTERED TO ESTIMATE RESIDUAL DAMAGES
```

```
   52 QS=QSS
      QL=QLL
      QP=QPP
      A=AZ
      GO TO 1312
C   DETERMINE SLOPE REDUCTION REQUIRED TO REDUCE TRACTIVE FORCE TO
C   CRITICAL.
    5 SLOPE=S(NW)
    6 IF(CHECK) WRITE(6,313) TFF
  313 FORMAT(10X,5HTFF =,F5.2)
      X=1.05*X
      SLOPE=0.95*SLOPE
      H=((Q*MANNU*(X+2.*(SQRT(1.+ZU*ZU)))**0.667)/(SQRT(SLOPE)*1.49*(X+Z
     1U)**1.667))**0.375
      TFF=62.4*H*SLOPE
      IF(TFF .GT. TF(NW)) GO TO 6
C   CALCULATE FINAL DIMENSION OF UNLINED CHANNEL WITH DROP STRUCTURES
      B=X*H
      T=B+2.*ZU*H
      A=0.5*H*(B+T)
      AEXTRA = A - AO(NW)
      AMINM = 0.2*A
      IF (.NOT. CHANEL(NW) .AND. AEXTRA .LT. AMINM) AEXTRA = AMINM
      W=B+2.4*H*ZU+30.0
C   AMOUNT OF FALL PROVIDED BY AND NUMBER OF DROP STRUCTURES
      FT=5280.*LC(NW)*(S(NW)-SLOPE)
C   FALL LIMITED TO FIVE FEET PER DROP STRUCTURE
      IF (FT .GT. 5.0) GO TO 7
      FD=FT
      ND=1.0
      GO TO 9
    7 IF (FT .GT. 10.0) GO TO 8
      FD=0.5*FT
      ND=2.0
      GO TO 9
    8 ND=AINT(0.25*FT+0.5)
      FD=FT/ND
C   COST OF BUILDING NEW OR ENLARGING OLD DROP STRUCTURES
    9 CS=SK1*LC(NW)* AEXTRA    +SK2*LC(NW)+SK3*RC     *(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
C   FORMULA FOR COST OF SCS TYPE C DROP STRUCTURE
      CS=CS+SK6*ND*(5.2*B*H+4.3*B*FD+9.5*B+5.5*ZU*H*H+2.0*ZU*H*FD+32.0*Z
     1U*H+2.0*ZU*FD+13.0*ZU+14.1*H*H+14.6*H*FD+3.3*FD*FD+14.1*H+0.056*B*
     2H*H+0.188*H*H*H+0.132*FD*H*H+9.9)
      IF(.NOT. CHANEL(NW) .OR. LINING(NW) .NE. 2) GO TO 10
      H=(TO(NW)-SQRT(TO(NW)*TO(NW)-4.0*ZU*AO(NW)))/(2.0*ZU)
      B=TO(NW)-2.0*ZU*H
      CS=CS-SK6*ND*(5.2*B*H+4.3*B*FD+9.5*B+5.5*ZU*H*H+2.0*ZU*H*FD+32.0*Z
     1U*H+2.0*ZU*FD+13.0*ZU+14.1*H*H+14.6*H*FD+3.3*FD*FD+14.1*H+0.056*B*
     2H*H+0.188*H*H*H+0.132*FD*H*H+9.9)
C   SEE IF LESS EXPENSIVE TO INCREASE CAPACITY BY LINING
      IF (.NOT. CHANEL(NW)) GO TO 10
```

```
      AZ = A
      HU=H
      BU=B
      A=AO(NW)
      GO TO 51
   10 IF(LINING(NW) .EQ. 2) GO TO 1312
      IF(LINING(NW) .EQ. 0)  GO TO 11
      LINING(NW) =2
      GO TO 1312
   11 LINING(NW)=2
      TT=T
      AA=A
      WW=W
C  TRAPEZOIDAL LINED CHANNELS
  100 IF(CHANEL(NW))  GO TO 103
C  BUILDING NEW ONES
      X=BDMIN
  101 H=((Q*MANNT*(X+2.*(SQRT(1.+ZT*ZT)))**0.667)/(SQRT(S(NW))*1.49*(X+Z
     1T)**1.667))**0.375
      IF(H.LE. HMAX .OR. X .GE. BDMAX)  GO TO 102
      X=X+0.5
      GO TO 101
  102 B=X*H
      T=B+2.*ZT*H
      A=0.5*H*(B+T)
      AEXTRA = A - AO(NW)
      AMINM = 0.2*A
      IF (.NOT. CHANEL(NW) .AND. AEXTRA .LT. AMINM) AEXTRA = AMINM
      W=B+2.4*H*ZT+25.
      PR=B+2.2*H*SQRT(1.+ZT*ZT)
      CSL=SK1*LC(NW)* AEXTRA   +SK2*LC(NW)+SK3*RC     *(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CSL=CSL+SK7*PR*LC(NW)
      IF(CSL.GT.CS .AND. LINING(NW).EQ.1 .OR. LINING(NW).EQ.2) GO TO 300
      IF (LINING(NW) .EQ. 3) GO TO 150
      LINING(NW)=3
      TT=T
      AA=A
      WW=W
      CS=CSL
      GO TO 200
  150 CS=CSL
      GO TO 1312
C  ENLARGING TRAPEZOIDAL LINED CHANNELS
  103 HO=(TO(NW)-SQRT(TO(NW)*TO(NW)-4.0*ZT*AO(NW)))/(2.0*ZT)
      BO=TO(NW)-2.0*ZT*HO
      PO=BO+2.2*HO*SQRT(1.+ZT*ZT)
      Q5=QO(NW)
      HT=HO
C  ENLARGE IN FIVE PERCENT INCREMENTS AND TEST TO SEE IF LARGE ENOUGH
      H1=1.05*HO
  104 Q6=(1.49*SQRT(S(NW))*((BO+ZT*H1)*H1)**1.667)/(MANNT*(BO+2.0*H1*SQR
```

```
     1T(1.+ZT*ZT))**0.667)
      IF (Q6 .GE. Q) GO TO 105
      Q5=Q6
      HT=H1
      H1=1.05*H1
      GO TO 104
C  INTERPOLATION FOR PROPER DEPTH ONCE IT HAS BEEN BOUNDED
  105 H=HT+((H1-HT)*(Q-Q5))/(Q6-Q5)
      B=B0
      T=B+2.*ZT*H
      A=0.5*H*(B+T)
      W=B+2.4*H*ZT+25.
      PR=B+2.2*H*SQRT(1.+ZT*ZT)
      WEXTRA=W-WO(NW)
      IF (WEXTRA .LT. 0.0) WEXTRA=0.0
      CS=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC     *WEXTRA     *LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CS=CS+SK7*(PR-PO)*LC(NW)
      GO TO 1312
C  RECTANGULAR LINED CHANNELS
  200 IF(CHANEL(NW))  GO TO 201
C  BUILDING NEW ONES
      X=BDMIN
      H=(Q*MANNR*(X+2.0)**0.667 /(SQRT(S(NW))*1.49*X**1.667))**0.375
      T=X*H
      A=H*T
      AEXTRA = A - AO(NW)
      AMINM = 0.2*A
      IF (.NOT. CHANEL(NW) .AND. AEXTRA .LT. AMINM) AEXTRA = AMINM
      W=T+20.0
      PR=T+2.1*H
      CSR=SK1*LC(NW)* AEXTRA   +SK2*LC(NW)+SK3*RC     *(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CSR=CSR+SK8*(PR+2.0)*LC(NW)
      IF (CSR .GT. CS .AND. LINING(NW) .NE. 4) GO TO 300
      LINING(NW)=4
      CS=CSR
      GO TO 1312
C  ENLARGING RECTANGULAR LINED CHANNELS
  201 H0=AO(NW)/TO(NW)
      B0=TO(NW)
      Q5=QO(NW)
      HT=H0
      H1=1.05*H0
  202 Q6=(1.49*SQRT(S(NW))*(B0*H1)**1.667)/(MANNR*(B0+2.0*H1)**0.667)
      IF (Q6 .GE. Q) GO TO 203
      Q5=Q6
      HT=H1
      H1=1.05*H1
      GO TO 202
  203 H=HT+((H1-HT)*(Q-Q5))/(Q6-Q5)
      CS=SK8*2.0*(H-H0)*LC(NW)
```

```
      T=TO(NW)
      W=WO(NW)
      A=H*T
      GO TO 1312
  300 T=TT
      A=AA
      W=WW
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,19HSUBROUTINE STR LEFT)
      RETURN
      END


      SUBROUTINE STROUT(LOOPTR)
C  UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF JANUARY 8, 1968
C  PRINTS OUT SUMMARY OF CHANNEL IMPROVEMENTS
      COMMON/FLPL1/A0(15),A8(15),A9(15),ADDC8(15),ADDC9(15),ADDCS(15),
     1 AFW(2,15),AW(15),CA8(15,11),CA9(15,11),CAP(15,11),CDF(15),CG(15),
     2 CH8(15),CH9(15),CHANEL(15),CLOC(15,5),CTOTR(15,5),DF(10),FD8(15),
     3 FD9(15),FDA(15),FIF(15),FRU(11),IHLD8(15),IHLD9(15),IHOLD(15),
     4 K1(15),K2(15),LC(15),LC8(15),LC9(15),LINING(15),LN8(15),LN9(15),
     5 LOC(15),ND8(15),ND9(15),NDT(15),OUTPUT(13),Q0(15),Q05(11,11),
     6 Q43(11,11),Q8(15),Q9(15),QQ(2,15),QX(2,16),S(15),SIC(15),TO(15),
     7 T8(15),T9(15),TCL(15),TF(15),USUBW(15,6),UTOTR(15,6),VALUE(15,6),
     8 WO(15),W8(15),W9(15),WT(15),WT8(15),WT9(15),Y(16),YY(10)
      COMMON/FLPL2/A,AF,AG,AQR,ATEMP,BDMAX,BDMIN,CD,CH,CHECK,CHU,CLEN,
     1 COEFDM,CPF,CRF,CRFSM,CS,CU,F,FA,FD,FDTEMP,FTOP,GA,GSF,HE,HETEMP,
     2 HMAX,HN,HOLDNG,HTEMP,IHE,IHN,IMPROV,IPP,IRE,IRN,ITEMP,ITOP,KDF,
     3 LA,LGTEMP,LINED,LL,LTF,MANNR,MANNT,MANNU,MW,ND,NDF,NDTEMP,NSTAGE,
     4 NSTEMX,NW,PA,PB,PC,PP,PTF,PWF,PWFR,QB05,QB43,QL,QLINED,QP,QS,R,
     5 RC,RE,RETEMP,RN,RTEMP,RTEST,SAFC,SK1,SK2,SK3,SK4,SK5,SK6,SK7,SK8,
     6 SPWF,SPWFAC,SS,STEMP,STF,T,TIME,TIMST,TRACE,TTEMP,UN,UNC,UZ,VA,
     7 VLAGST,VLURST,W,WTEMP,XF,ZT,ZU
      REAL LC
      LOGICAL CH9,HOLDNG,LOOPTR
      DIMENSION CA7(11)
      IF (LOOPTR) WRITE(6,1313)
 1313 FORMAT (10X,25HSUBROUTINE STROUT ENTERED)
      A7=A9(NW)
      WT7=WT9(NW)
      W7=W9(NW)
      IHLD7=IHLD9(NW)
      SI7=SIC(NW)
      IF ( .NOT. CH9(NW)) GO TO 703
      IHN=HTEMP
      IHE=HETEMP
      IRE=RETEMP
      IRN=RTEMP
      DO 400  J=1,11
  400 CA7(J)=CA9(NW,J)
```

```
      LN7=LN9(NW)
      Q7=Q9(NW)
      T7=T9(NW)
      WRITE(6,700)
  700 FORMAT(////40X,31HSUMMARY OF CHANNEL IMPROVEMENTS//128H UNIT      T
     1YPE OF          STAGE      CAPACITY  X-SECTION    TOP     ROW  DEPTH  D
     2ROP STRUCTURES  HIGHWAY BRIDGES   RAILROAD BRIDGES        )
      WRITE(6,701)
  701 FORMAT(10X,7HCHANNEL,7X,7H ACTION,16X,4HAREA,5X,12HWIDTH   WIDTH,9X
     1,55HNUMBER HEIGHT  SAME BUILT EXTEND  SAME BUILT EXTEND         )
      WRITE(6,702)
  702 FORMAT(37X,4HCFS.,5X,7HSQ. FT.,4X,3HFT.,4X,3HFT.,4X,3HFT.,12X,3HFT
     1./)
      ND=ND9(NW)
      FD=FD9(NW)
      IF(LN7 .LE. 2) HO=(T7-SQRT(T7**2-4.0*ZU*A7))/(2.0*ZU)
      IF(LN7 .EQ. 3) HO=(T7-SQRT(T7**2-4.0*ZT*A7))/(2.0*ZT)
      IF(LN7 .EQ. 4) HO=A7/T7
      ICAP9=CA7(9)
      ICDIF=IHN+IHE
      IUH = IABS(ICAP9 - ICDIF)
      DO 704 I=1,6
      IF(CA7(I) .LT. 0.0) GO TO 7055
  704 IUH=IUH+1
 7055 IF (NSTAGE .EQ. 1 .OR. USUBW(NW,NSTAGE) .LT. 0.25) GO TO 705
      IF (USUBW(NW,NSTAGE) .LT. 0.50) GO TO 7056
      NBR=3.0*LC(NW)+0.5
      GO TO 7057
 7056 NBR=2.0*LC(NW)+0.5
 7057 IF (IUH+ICDIF .LT. NBR) IUH=NBR-ICDIF
  705 IUR=0
      IF(IMPROV .EQ. 1) IUR=CA7(10)
      DO 706 I=7,8
      IF(CA7(I) .LT. 0.0) GO TO 707
  706 IUR=IUR+1
  707 III=LN7
      GO TO (711,712,713,714),III
  711 IF(IMPROV    -2) 715,716,717
  712 IF(IMPROV    -2) 718,719,720
  713 IF(IMPROV    -2) 721,722,723
  714 IF(IMPROV    -2) 724,725,726
  715 WRITE(6,727) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  727 FORMAT(1X,I2,2X,17HUNLINED W/O DROPS,2X,9HUNCHANGED,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  716 WRITE(6,728) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  728 FORMAT(1X,I2,2X,17HUNLINED W/O DROPS,2X,9HBUILT     ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  717 WRITE(6,729) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  729 FORMAT(1X,I2,2X,17HUNLINED W/O DROPS,2X,9HENLARGED ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
```

```
      GO TO 703
  718 WRITE(6,730) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  730 FORMAT(1X,I2,2X,17HUNLINED W DROPS   ,2X,9HUNCHANGED,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  719 WRITE(6,731) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  731 FORMAT(1X,I2,2X,17HUNLINED W DROPS   ,2X,9HBUILT    ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  720 WRITE(6,732) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  732 FORMAT(1X,I2,2X,17HUNLINED W DROPS   ,2X,9HENLARGED ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  721 WRITE(6,733) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  733 FORMAT(1X,I2,2X,17HTRAPEZOIDAL LINED,2X,9HUNCHANGED,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  722 WRITE(6,734) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  734 FORMAT(1X,I2,2X,17HTRAPEZOIDAL LINED,2X,9HBUILT    ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
C    TRAPEZOIDAL LINING ADDED - DISCOVERED BY A DESIGN FREQUENCY
C           NOT IN ARRAY DF
  723 DO 536 LDF=1,NDF
      IF(OUTPUT(2) .EQ. DF(LDF)) GO TO 327
  536 CONTINUE
      WRITE(6,537) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  537 FORMAT(1X,I2,2X,28HTRAPEZOIDAL LINING ADDED        ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  327 WRITE(6,735) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  735 FORMAT(1X,I2,2X,17HTRAPEZOIDAL LINED,2X,9HENLARGED ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  724 WRITE(6,736) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  736 FORMAT(1X,I2,2X,17HRECTANGULAR LINED,2X,9HUNCHANGED,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  725 WRITE(6,737) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  737 FORMAT(1X,I2,2X,17HRECTANGULAR LINED,2X,9HBUILT    ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
      GO TO 703
  726 WRITE(6,738) NW,Q7,A7,T7,W7,HO,ND,FD,IUH,IHN,IHE,IUR,IRN,IRE
  738 FORMAT(1X,I2,2X,17HRECTANGULAR LINED,2X,9HENLARGED ,F8.0,F11.1,F9.
     11,F7.1,F6.1,5X,I2,F8.1,4X,I2,3X,I2,5X,I2,5X,I2,3X,I2,5X,I2)
  703 CONTINUE
C   WRITE OUT SUMMARY TABLE OF HOLDING COST
      IF(.NOT.HOLDNG) GO TO 1312
      IF(IHLD7 .EQ. 0) GO TO 1312
      ACH=(WT7*LC(NW)-W7*SI7)*0.1212
      IF (ACH .EQ. 0.0) GO TO 1312
      CHU=CH/ACH
```

```
      WRITE(6,698)
  698 FORMAT(1H////,
     1        15X,76H             RIGHT-OF-WAY PRESERVED FOR FUTURE CHANNE
     2L CONSTRUCTION              //2X,4HUNIT,3X,14H HOLDING WIDTH,2X,14H
     3CHANNEL WIDTH,6X,10H AREA HELD,2X,17HUNIT HOLDING COST,2X,18HTOTAL
     4 HOLDING COST/16X,4HFEET,12X,4HFEET,12X,5HACRES,5X,16HDOLLARS PER
     5ACRE,7X,7HDOLLARS)
      WRITE (6,699) NW,WT7,W7,ACH,CHU,CH
  699 FORMAT (4X,I2,10X,F4.0,12X,F4.0,11X,F6.2,10X,F6.0,13X,F6.0)
 1312 IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,22HSUBROUTINE STROUT LEFT)
      RETURN
      END


      SUBROUTINE UCFIX(CRFSM,CTOTR,GSF,HYDTLS,LOOPTR,NSTAGE,NSTEMX,NW,
     1PCT,PUT,PWFR,SPWFAC,TIME,TIMST,UTOTR)
C UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III
C VERSION OF APRIL 15, 1967
C FIXES AVERAGE ANNUAL VALUES OF URBANIZATION AND CHANNELIZATION FOR THE
C        SUBWATERSHED OVER THE LIFE OF THE DAM AND RESERVOIR.  THESE
C        VALUES ARE USED IN THE HYDROLOGY FOR SIZING THE RESERVOIR FOR
C        THE AVERAGE FLOOD THREAT OVER THE PROJECT LIFE ONCE THE
C        RESERVOIR HAS PROVEN JUSTIFIED TO PROTECT AGAINST THE FLOOD
C        THREAT WITHIN THE STAGE.
      DIMENSION CTOTR(15,5), UTOTR(15,6)
      LOGICAL HYDTLS,LOOPTR
      IF(LOOPTR) WRITE(6,1313)
 1313 FORMAT(10X,24HSUBROUTINE UCFIX ENTERED)
C  STAGE COUNTER BEGINNING WITH CURRENT STAGE.
      NSTG = NSTAGE
C  FIND PRESENT WORTH OF PUT AND PCT IN FIRST STAGE.  PRESENT WORTH HAS
C  NO PHYSICAL SIGNIFICANCE AND IS ONLY AN INTERMEDIATE STEP IN
C  CALCULATING A DISCOUNTED ANNUAL AVERAGE.
      PUT = UTOTR(NW,NSTAGE)+GSF*(UTOTR(NW,NSTAGE+1)-UTOTR(NW,NSTAGE))/
     1 TIME
      PUT = PUT*SPWFAC
      PCT = CTOTR(NW,NSTAGE)*SPWFAC
C  EXIT FOR ONE STAGE ANALYSIS
      IF(TIME.EQ.TIMST) GO TO 10
C  PROCEED THROUGH UP TO FOUR SUBSEQUENT STAGES.
      DO 8 I = 1,4
      A = I
      NSTG = NSTG + 1
C  IF PROJECT LIFE EXTENDS PAST END OF INPUT DATA, ASSUME WATERSHED
C    DEVELOPMENT REMAINS AT LAST VALUE.
      IF(NSTG.GT.NSTEMX) GO TO 2
C  DISCOUNTED AVERAGE ANNUAL VALUES WITHIN STAGE FOR WHICH DATA GIVEN
      UT2 = UTOTR(NW,NSTG)+ GSF*(UTOTR(NW,NSTG+1)-UTOTR(NW,NSTG))/TIME
      CT2 = CTOTR(NW,NSTG)
      GO TO 4
```

```
C   DISCOUNTED AVERAGE ANNUAL VALUES WITHIN STAGE PAST END OF DATA
    2 UT2 = UTOTR(NW,NSTEMX+1)
      CT2 = CTOTR(NW,NSTEMX)
C   FIND CUMULATIVE PRESENT WORTH OF STAGES STUDIED THUS FAR.
    4 PUT = PUT + UT2*SPWFAC*PWFR**A
      PCT = PCT + CT2*SPWFAC*PWFR**A
C   TEST FOR NUMBER OF STAGES TO BE ANALYZED.
      IF(TIMST.LE.(A+1.0)*TIME) GO TO 10
    8 CONTINUE
C   CONVERT PRESENT WORTH TO DISCOUNTED AVERAGE ANNUAL VALUES.
   10 PUT = PUT*CRFSM
      PCT = PCT*CRFSM
   20 IF(HYDTLS) WRITE(6,1315)PUT,PCT
 1315 FORMAT(15X,5HPUT =,F5.2,2X,5HPCT =,F5.2)
      IF (LOOPTR) WRITE(6,1314)
 1314 FORMAT (10X,21HSUBROUTINE UCFIX LEFT)
      RETURN
      END
```

```
CDSKIP   CSECT
         SAVE  (14,12),,*          ENTRY ROUTINE
         BALR  12,0                *
         USING *,12                *
         LR    11,13               *
         LA    13,SAVE             *
         ST    13,8(11)            *
         ST    11,4(13)            *
         L     6,=V(CARDSW)        LOAD GR6 WITH ENTRY POINT IN READ
         MVI   0(6),X'0'           SET THE SWITCH TO FORCE READING OF
*                                  NEW CARD
         L     13,SAVE+4           RETURN
         L     14,12(13)           *
         MVI   12(13),X'FF'        *
         RETURN (15,12)            *
SAVE     DS      18F
         END
READ     CSECT
         ENTRY CARDSW
         SAVE  (14,12),,*           *
         BALR  12,0                 *
         USING *,12                 * ENTRY-  LINKAGE SETUP
         MVI   TRANSTAB+92,X'FF'   REMOVE THIS CARD TO READ PAST '*'
         LR    11,13                *
         LA    13,AREA              *
         ST    13,8(11)
         ST    11,4(13)             *
         B     PROBLEM              *
AREA     DS    18F                  *  THIS PROGRAM'S SAVE AREA
DSRN     DC    AL4(5)
PROBLEM  LR    4,1                  SAVE CONTENTS OF ARG. PTR.
```

```
         LA     5,INAREA               SET UP ORIG. CARD PTR.
         LA     6,BUFFER               SET UP TRANS. CARD PTR.
         L      7,COLPTR
         CLI    CARDSW,X'1'            *
         BE     NONEWC                 * LINKAGE
GETACARD LA     2,DSRN                 LOAD ADDRESS OF DATA SET REF NO
         LA     7,1
         L      1,=V(FIOCS#)           LINK TO
         BALR   0,1                    FORTRAN IOCS
         DC     AL2(240)               ROUTINE
         SR     3,7
         STC    3,MOVE+1
         MVI    INAREA,C' '            CLEAN OUT THE
         MVC    INAREA+1(255),INAREA        INPUT AREA
X        EQU    1
MOVE     MVC    INAREA(X),0(2)
         MVC    BUFFER(256),INAREA  DUPLICATE THE CARD IN BUFFER
         TR     BUFFER(256),TRANSTAB  TRANSLATE THE DUPLICATED CARD
         AR     3,7
         LA     2,0(3,6)
         MVI    0(2),X'FF'  PUT END OF RECORD CHARACTER AFTER THE CARD
         MVI    CARDSW,X'1'    TURN ON THE GOT-A-CARX SWITCH
NONEWC   LA     8,0(7,6)               PUT INDEXED COLUMN PTR. IN 8
         CLI    0(8),X'0'              CHECK CURRENT COL FOR SIGNIF.
         BNE    FOUND                  BRANCH IF SIGNIFICANT
         LA     7,1(0,7)               INCREMENT COL PTR.
         B      NONEWC                 GO TRY AGAIN
FOUND    CLI    0(8),X'FF'             HAVE WE FINISHED THE CARD
         BE     GETACARD               YES, GO GET ONE
         CLC    0(1,8),TRY1            START OF A LEGAL NO(DIGIT)
         BE     YESITIS                YES, ELSE
         CLC    0(2,8),TRY2            START OF A LEGAL NO(SIGN,DIGIT)
         BE     YESITIS                YES, ELSE
         CLC    0(3,8),TRY3            STRT OF A LEGAL NO(SIGN,PTR,DIG)
         BE     YESITIS                YES, ELSE
         CLC    0(2,8),TRY4            START OF A LEGAL NUMBER(DPT,DIG)
         BE     SETFT                  YES, ELSE
         B      NONEWC+12              GO BACK AND LOOK AGAIN
SETFT    MVI    FLTSW,X'1'
YESITIS  MVI    DATA,X'1'              WE HAVE FOUND LEGAL DATA
         ST     8,START
         MVC    OLD(1),0(8)
         LA     7,1(7)
         SR     9,9                    CLEAR GR9 AND
         IC     9,OLD                  STICK THE OLD TRANS CHAR IN 18
         LA     8,0(6,7)               STORE THE NEW INDEXED COL PTR IN 8
         CLI    0(8),X'FF'
         BE     NOTVALID
         CLI    ESW,X'1'               HAVE WE FOUND AN 'E'
         BNE    *+12                   NO ELSE
         LA     10,OLDTABED            PUT 'ED' TABLE ADD IN 10
         B      OUT                    AND GO ON
```

```
         CLI   DSW,X'1'            HAVE WE FOUND AN 'D'
         BNE   *+12                NO ELSE
         LA    10,OLDTABED         PUT  'FT' TABLE ADD IN 10
         B     OUT                 AND GO ON
         CLI   FLTSW,X'1'          ELSE LOAD 'NO' TABLE ADD
         BNE   *+12                NO. ELSE
         LA    10,OLDTABFT         PUT 'FT' TABLE ADD IN 10
         B     OUT                 AND GO ON
         LA    10,OLDTABNO         ELSE LOAD 'NO' TABLE ADD
OUT      MVC   HOLDER(5),0(10)     MOVE PROPER TABLE TO HOLDER
         SR    10,10               CLEAR GR10
         IC    10,0(0,8)           AND PUT THE NEW CHAR IN TI
         LA    11,NEWTAB-1         PUT ADDRESS OF NEW CHAR IN 11
         LA    11,0(10,11)         PUT INDEXED NEWTAB ADDR IN 11
         MVC   INST+1(1),0(11)          PUT PROP. MASK IN TM INST
         LA    9,HOLDER-1(9)       PUT INDEXED HOLDER ADDR IN GR9
INST     TM    0(9),X'0'           TM INSTRUCTION
         BZ    NOTVALID            BRANCH IF NTO A VALID CHAR
         CLI   0(8),X'3'           IS THIS AN 'E'
         BNE   T2                  BRANCH IF NOT
         MVI   ESW,X'1'            TURN ON 'E' SWITCH
         B     YESITIS+8           GO GET NEXT CHAR
T2       CLI   0(8),X'4'           IS THIS A 'D'
         BNE   T3                  BRANCH IF NOT
         MVI   DSW,X'1'            TURN ON 'D' SWITCH
         B     YESITIS+8           GO GET NEXT CHAR
T3       CLI   0(8),X'2'           IS THIS A '.'
         BNE   YESITIS+8           GET NEXT CHAR IF NOT
         MVI   FLTSW,X'1'          TURN ON FLTSW
         B     YESITIS+8           GET NEXT CHAR
NOTVALID CLI   0(8),X'FF'          IS THIS END-OF-CARD?
         BNE   STATRAN             NO, GO CONVERT DATA
         CLI   DATA,X'1'           HAVE WE OFUND DATA
         BNE   GETACARD            NO, THEN GET A CARD
         MVI   CARDSW,X'0'         WE NEED A CARD
STATRAN  ST    8,STOP              STORE STOPPING ADDRESS
         S     8,START             COMPUTE LENGTH
         STC   8,LENGTH            PUT LENGTH IN 'LENGTH'
         L     2,0(0,4)            SET PTR TO CORR ARG IN GR2
         L     3,START             PUT START ADDR IN 3
         S     3,=F'256'
         L     1,=V(ADCON#)        MOVE LINK ADDR IN GR1
         CLI   ESW,X'1'            'E' SWITCH ON?
         BE    PERFEC              BRANCH IF YES
         CLI   DSW,X'1'
         BE    PERFDC              BRANCH IF YES
         CLI   FLTSW,X'1'          '.' SWITCH ON
         BE    PERFFC              BRANCH IF YES
PERFIC   MVC   CON1+1(1),LENGTH    PERFORM I CONVERSION
         L     1,40(1)             PUT LENGTH IN CONSTANT
         BALR  0,1
CON1     DC    XL2'0400'
```

```
         B        DONECONV               LEAVE
PERFEC   MVC      CON2+1(1),LENGTH       PERFORM E CONVERSION
         L        1,8(1)                 PUT LENGTH IN CONSTANT
         BALR     0,1
CON2     DC       XL4'04000000'
         B        DONECONV               LEAVE
PERFDC   MVC      CON3+1(1),LENGTH       PERFORM D CONVERSION
         L        1,8(1)                 PUT LENGTH IN CONSTANT
         BALR     0,1
CON3     DC       XL4'08000000'
         B        DONECONV               LEAVE
PERFFC   MVC      CON4+1(1),LENGTH       PERFORM F CONVERSION
         L        1,0(1)                 PUT LENGTH IN CONSTANT
         BALR     0,1
CON4     DC       XL4'04000000'
DONECONV MVI      FLTSW,X'0'             TUNR OFF '.'
         MVI      ESW,X'0'               TURN OFF 'E'
         MVI      DATA,X'0'
         MVI      DSW,X'0'               TRUN OFF 'D' SWITCH
         LA       4,4(4)                 INCREMENT POINTER TO ARG LIST
         LTR      2,2                    CURRENY ARG LAST ARG
         BP       GETACARD-8
         B        TURNOFF+4
TURNOFF  MVI      CARDSW,X'0'            TURN ON NEW CARD SWITCH
         ST       7,COLPTR
         L        13,AREA+4              LOAD RETURN AREA
         L        14,12(13)
         MVI      12(13),X'FF'
         RETURN (15,12)
FORMAT   DC       CL8'(20A4)   '
         DS       0F
INAREA   DS       CL256
BUFFER   DS       CL256
         DC       X'FF'
         DS       3X
TRANSTAB DC       75X'0'
         DC       X'2'
         DC       2X'0'
         DC       X'1'
         DC       17X'0'
         DC       X'1'
         DC       99X'0'
         DC       X'0403'
         DC       42X'0'
         DC       10X'5'
         DC       6X'0'
TRY1     DC       X'5'
TRY2     DC       X'0105'
TRY3     DC       X'010205'
TRY4     DC       XL2'0205'
CARDSW   DC       X'0'
DATA     DC       X'0'
```

```
START     DS    1F
OLD       DS    CL1
COLPTR    DS    1F
STOP      DS    1F
OLDTABFT  DC    X'0838888838'
OLDTABNO  DC    X'4838888878'
OLDTABED  DC    X'0808888808'
FLTSW     DC    X'0'
ESW       DC    X'0'
DSW       DC    X'0'
NEWTAB    DC    X'8040201008'
HOLDER    DS    XL5
LENGTH    DS    CL1
          END   READ
```

# APPENDIX B

DATA INPUT TO UNIV. OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM III

SOUTH FORK OF LICKING RIVER STUDY - HINKSTON CREEK RESERVOIR SITE

```
* PROGRAM CONTROL PARAMETERS

   1        *  L1 - "0" EXCLUDES UNCERTAINTY FROM DAMAGES
   1        *  L2 - "0" EXCLUDES CONSIDERATION OF FLOOD PROOFING
   0        *  L3 - "0" EXCLUDES CONSIDERATION OF LAND USE MEASURES
   1        *  L4 - "0" EXCLUDES CONSIDERATION OF CHANNEL IMPROVEMENT
   1        *  L5 - "0" EXCLUDES PRINTING OF ALL COMBINATIONS TRIED
   1        *  L6 - "0" EXCLUDES PRINTING OF EACH NEW OPTIMUM
            *          COMBINATION
   0        *  L7 - "0" EXCLUDES CONSIDERATION OF HOLDING EXTRA
            *          RIGHT-OF-WAY
   1        *  L8 - "0" EXCLUDES PRINTING OF DAM DETAILS
   1        *  L9 - "0" EXCLUDES PRINTING OF HYDROLOGIC DETAILS
   1        * L10 - "0" EXCLUDES PRINTING OF SUBROUTINE ENTRY AND EXIT
   1        * L11 - "0" EXCLUDES CONSIDERATION OF DAM
   5        * NSTEMX - NUMBER OF PLANNING STAGES
  12        * MW - NUMBER OF SUBWATERSHEDS

   * AW() - ADDITIONAL DRAINAGE AREA ADDED BY CHANNEL REACH IN SQ.MI.
174.21 85.86 328.56 16.85 2.76 17.70 28.30 8.13 81.75 49.00 130.30 3.65

* MAIN LINE, TRIBUTARY, AND IMPROVED CHANNEL LENGTHS
   * LC() - LENGTH OF MAIN LINE CHANNEL WITHIN SUBWATERSHED, IN MILES
   168.50 22.30 6.29 7.01 1.99 2.04 8.10 4.66 7.81 1.42 23.13 2.70
   * TCL() - TOTAL LENGTH OF CHANNEL IN TRIBUTARY AREA ADDED, IN MILES
 168.5  88.8  320.1  14.9  2.8  13.6  29.1  6.8  76.3  43.9  122.6  3.6
   * SIC() - INITIAL IMPROVED CHANNEL LENGTH IN SUBWATERSHED, IN MILES
        0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0

   * CTOTR() - IMPROVED CHANNEL LENGTH WITHIN TRIBUTARY AREA ADDED BUT
   *            NOT ON MAIN LINE STREAM, IN MILES
   *        STAGE 1   STAGE 2   STAGE 3   STAGE 4   STAGE 5 SUBWATERSHED
              0.0       0.0       0.0       0.0       0.0       * 2
              0.0       0.0       0.0       0.0       0.0       * 3
              0.0       0.0       0.0       0.0       0.0       * 4
              0.0       0.0       0.0       0.0       0.0       * 5
              0.0       0.0       0.0       0.0       0.0       * 6
              0.0       0.0       0.0       0.0       0.0       * 7
```

| | | | | | |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | * 8 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | * 9 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | * 10 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | * 11 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | * 12 |

* FLOOD PEAK HYDROLOGY

199.2 * QB43 - MEAN ANNUAL FLOOD PEAK FROM ONE SQUARE MILE
448.6 * QB05 - 200-YEAR FLOOD PEAK FROM ONE SQUARE MILE

* Q43() - RELATIONSHIP AMONG URBANIZATION, CHANNELIZATION, AND MEAN
* ANNUAL FLOOD PEAK FROM ONE SQUARE MILE, EXPRESSED AS
* MULTIPLES OF THE PEAK WITH U=0.0 AND C=0.0

| *0.00 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 = U |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 1.12 | 1.26 | 1.36 | 1.49 | 1.61 | 1.74 | 1.87 | 1.98 | 2.13 | 2.29 *C=.0 |
| 1.04 | 1.17 | 1.30 | 1.43 | 1.56 | 1.68 | 1.82 | 1.95 | 2.08 | 2.22 | 2.38 *C=.1 |
| 1.12 | 1.24 | 1.37 | 1.50 | 1.64 | 1.77 | 1.90 | 2.03 | 2.17 | 2.31 | 2.49 *C=.2 |
| 1.17 | 1.30 | 1.44 | 1.57 | 1.72 | 1.84 | 1.98 | 2.13 | 2.27 | 2.44 | 2.60 *C=.3 |
| 1.21 | 1.36 | 1.50 | 1.65 | 1.79 | 1.93 | 2.09 | 2.24 | 2.40 | 2.57 | 2.73 *C=.4 |
| 1.25 | 1.42 | 1.58 | 1.74 | 1.88 | 2.02 | 2.20 | 2.37 | 2.54 | 2.71 | 2.86 *C=.5 |
| 1.34 | 1.49 | 1.66 | 1.82 | 1.98 | 2.16 | 2.33 | 2.53 | 2.69 | 2.88 | 3.02 *C=.6 |
| 1.40 | 1.57 | 1.75 | 1.92 | 2.12 | 2.29 | 2.50 | 2.69 | 2.88 | 3.06 | 3.24 *C=.7 |
| 1.47 | 1.65 | 1.86 | 2.03 | 2.26 | 2.46 | 2.65 | 2.88 | 3.06 | 3.26 | 3.44 *C=.8 |
| 1.55 | 1.77 | 1.96 | 2.19 | 2.43 | 2.63 | 2.86 | 3.10 | 3.31 | 3.54 | 3.79 *C=.9 |
| 1.65 | 1.88 | 2.13 | 2.38 | 2.63 | 2.83 | 3.11 | 3.39 | 3.68 | 4.05 | 4.54 *C=1. |

* Q05() - RELATIONSHIP AMONG URBANIZATION, CHANNELIZATION, AND 200-
* YEAR FLOOD PEAK FROM ONE SQUARE MILE, EXPRESSED AS
* MULTIPLES OF THE PEAK WITH U=0.0 AND C=0.0

| *0.00 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 = U |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 1.06 | 1.10 | 1.16 | 1.21 | 1.27 | 1.33 | 1.37 | 1.44 | 1.51 | 1.59 *C=.0 |
| 1.02 | 1.07 | 1.12 | 1.17 | 1.22 | 1.27 | 1.33 | 1.38 | 1.44 | 1.52 | 1.63 *C=.1 |
| 1.05 | 1.09 | 1.13 | 1.19 | 1.23 | 1.29 | 1.34 | 1.40 | 1.46 | 1.56 | 1.67 *C=.2 |
| 1.08 | 1.11 | 1.16 | 1.21 | 1.26 | 1.31 | 1.36 | 1.41 | 1.49 | 1.61 | 1.71 *C=.3 |
| 1.11 | 1.15 | 1.19 | 1.24 | 1.29 | 1.33 | 1.39 | 1.45 | 1.54 | 1.66 | 1.75 *C=.4 |
| 1.16 | 1.20 | 1.23 | 1.29 | 1.33 | 1.37 | 1.44 | 1.51 | 1.62 | 1.72 | 1.80 *C=.5 |
| 1.21 | 1.24 | 1.29 | 1.33 | 1.37 | 1.43 | 1.49 | 1.58 | 1.71 | 1.80 | 1.86 *C=.6 |
| 1.26 | 1.31 | 1.35 | 1.39 | 1.44 | 1.49 | 1.57 | 1.69 | 1.81 | 1.89 | 1.94 *C=.7 |
| 1.35 | 1.39 | 1.43 | 1.49 | 1.53 | 1.60 | 1.72 | 1.79 | 1.94 | 2.00 | 2.12 *C=.8 |
| 1.46 | 1.51 | 1.59 | 1.68 | 1.79 | 1.89 | 1.97 | 2.06 | 2.12 | 2.19 | 2.29 *C=.9 |
| 1.83 | 1.89 | 1.98 | 2.09 | 2.17 | 2.26 | 2.34 | 2.43 | 2.51 | 2.65 | 2.77 *C=1. |

* AFCTR() - RATIOS OF CSM FOR FLOOD PEAKS FROM STATED DRAINAGE AREA
* TO CSM FOR FLOOD PEAKS FROM ONE SQ.MI. FOR TWO FLOOD
* FREQUENCIES
* DRAINAGE AREA IN SQ.MI.

| 1.0 | 3.0 | 5.0 | 7.0 | 27.0 | 40.0 | 70.0 | 100.0 | 200.0 | 500.0 | 1000.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| * MEAN ANNUAL FLOOD | | | | | | | | | | |
| 1.000 | 0.772 | 0.705 | 0.685 | 0.649 | 0.540 | 0.416 | 0.350 | 0.254 | 0.165 | 0.120 |
| * 200-YEAR FLOOD | | | | | | | | | | |

1.000 0.796 0.721 0.687 0.568 0.473 0.364 0.306 0.222 0.144 0.105

* FLOOD VOLUME HYDROLOGY

141.6 * VB43 - SFD IN MEAN ANNUAL HYDROGRAPH FROM ONE SQ. MILE
292.4 * VB05 - SFD IN 200-YEAR HYDROGRAPH FROM ONE SQ. MILE

* V43() - RELATIONSHIP AMONG URBANIZATION, CHANNELIZATION, AND MEAN
* ANNUAL FLOOD VOLUME FROM ONE SQUARE MILE, EXPRESSED AS
* MULTIPLES OF THE VOLUME WITH U=0.0 AND C=0.0

| *0.00 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | = U |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 1.12 | 1.24 | 1.35 | 1.47 | 1.59 | 1.70 | 1.81 | 1.93 | 2.05 | 2.16 | *C=.0 |
| 1.12 | 1.27 | 1.40 | 1.53 | 1.66 | 1.79 | 1.91 | 2.04 | 2.15 | 2.28 | 2.34 | *C=.1 |
| 1.22 | 1.40 | 1.52 | 1.66 | 1.78 | 1.90 | 2.03 | 2.15 | 2.28 | 2.40 | 2.52 | *C=.2 |
| 1.28 | 1.48 | 1.62 | 1.76 | 1.90 | 2.03 | 2.17 | 2.30 | 2.44 | 2.57 | 2.70 | *C=.3 |
| 1.34 | 1.54 | 1.70 | 1.86 | 2.02 | 2.16 | 2.32 | 2.48 | 2.64 | 2.78 | 2.89 | *C=.4 |
| 1.42 | 1.63 | 1.80 | 1.96 | 2.13 | 2.29 | 2.46 | 2.63 | 2.78 | 2.94 | 3.07 | *C=.5 |
| 1.50 | 1.71 | 1.90 | 2.07 | 2.25 | 2.42 | 2.58 | 2.75 | 2.92 | 3.08 | 3.25 | *C=.6 |
| 1.59 | 1.81 | 2.00 | 2.18 | 2.36 | 2.54 | 2.71 | 2.89 | 3.07 | 3.25 | 3.43 | *C=.7 |
| 1.67 | 1.89 | 2.09 | 2.28 | 2.47 | 2.66 | 2.85 | 3.04 | 3.24 | 3.43 | 3.62 | *C=.8 |
| 1.74 | 1.98 | 2.18 | 2.38 | 2.60 | 2.80 | 3.00 | 3.18 | 3.40 | 3.60 | 3.80 | *C=.9 |
| 1.82 | 2.04 | 2.27 | 2.49 | 2.70 | 2.91 | 3.13 | 3.34 | 3.55 | 3.77 | 3.98 | *C=1. |

* V05() - RELATIONSHIP AMONG URBANIZATION, CHANNELIZATION, AND 200-
* YEAR FLOOD VOLUME FROM ONE SQUARE MILE, EXPRESSED AS
* MULTIPLES OF THE VOLUME WITH U=0.0 AND C=0.0

| *0.00 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | = U |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 1.03 | 1.08 | 1.14 | 1.20 | 1.28 | 1.33 | 1.39 | 1.45 | 1.52 | 1.59 | *C=.0 |
| 1.10 | 1.15 | 1.20 | 1.26 | 1.33 | 1.39 | 1.46 | 1.53 | 1.59 | 1.65 | 1.70 | *C=.1 |
| 1.17 | 1.21 | 1.27 | 1.34 | 1.40 | 1.48 | 1.55 | 1.62 | 1.69 | 1.78 | 1.83 | *C=.2 |
| 1.23 | 1.28 | 1.33 | 1.40 | 1.48 | 1.55 | 1.63 | 1.71 | 1.80 | 1.87 | 1.94 | *C=.3 |
| 1.28 | 1.34 | 1.40 | 1.47 | 1.55 | 1.62 | 1.71 | 1.81 | 1.89 | 1.98 | 2.07 | *C=.4 |
| 1.34 | 1.39 | 1.47 | 1.53 | 1.62 | 1.71 | 1.81 | 1.90 | 2.00 | 2.10 | 2.19 | *C=.5 |
| 1.39 | 1.46 | 1.53 | 1.61 | 1.70 | 1.79 | 1.89 | 2.00 | 2.11 | 2.22 | 2.32 | *C=.6 |
| 1.44 | 1.52 | 1.60 | 1.69 | 1.80 | 1.89 | 1.99 | 2.11 | 2.22 | 2.33 | 2.43 | *C=.7 |
| 1.50 | 1.58 | 1.67 | 1.76 | 1.87 | 1.98 | 2.09 | 2.22 | 2.33 | 2.43 | 2.56 | *C=.8 |
| 1.55 | 1.63 | 1.73 | 1.84 | 1.96 | 2.08 | 2.20 | 2.32 | 2.43 | 2.56 | 2.68 | *C=.9 |
| 1.61 | 1.67 | 1.79 | 1.91 | 2.04 | 2.17 | 2.30 | 2.42 | 2.56 | 2.68 | 2.81 | *C=1. |

* AFCTRV() - RATIOS OF CSM FOR FLOOD VOLUMES FROM STATED DRAINAGE
* AREA TO CSM FOR FLOOD VOLUMES FROM ONE SQ.MI. FOR TWO
* FLOOD FREQUENCIES
* DRAINAGE AREA IN SQUARE MILES

*1.0 3.0 5.0 7.0 27.0 40.0 70.0 100.0 200.0 500.0 1000.0
* MEAN ANNUAL FLOOD
1.000 0.870 0.806 0.767 0.593 0.493 0.380 0.320 0.232 0.151 0.110
* 200-YEAR FLOOD
1.000 0.886 0.832 0.799 0.609 0.507 0.390 0.328 0.238 0.155 0.113

* FLOOD PEAK TIMING DATA

```
  3.5      * TPB - HOURS TO PEAK FOR HYDROGRAPH FROM ONE SQUARE MILE
 * TP() - RELATIONSHIP BETWEEN TIME TO PEAK AND CHANNELIZATION
 *        EXPRESSED AS MULTIPLES OF TIME TO PEAK WITHOUT
 *        CHANNELIZATION
* C = 0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
      1.000 0.840 0.745 0.670 0.605 0.550 0.500 0.460 0.425 0.390 0.364
 * AFCTRT() - RELATIONSHIP BETWEEN DRAINAGE AREA AND TIME TO PEAK
 *   DRAINAGE AREA IN SQUARE MILES
* A = 1.00 3.00 5.00 7.00 27.00 40.00 70.00 100.00 239.00 500.00 1000.0
 *   TIME TO PEAK RATIO
     1.00 1.39 1.62 1.79  2.58  3.02  3.57   3.98   5.17   6.45   7.93


* FLOOD HYDROGRAPH SHAPE DATA

  1.0      * HYDINT - HOURS BETWEEN POINTS ON COMBINED HYDROGRAPHS

 * HYDBAS() - FIVE BASIC HYDROGRAPH SHAPES - ALL FLOWS EXPRESSED AS
 *              FRACTIONS OF FLOW AT PEAK
 *  SHARPER  SHARP  AVERAGE   FLAT  FLATTER
     0.041   0.107   0.082   0.094   0.488      * 1TPW/7
     0.065   0.119   0.155   0.416   0.563      * 2TPW/7
     0.084   0.159   0.369   0.447   0.620      * 3TPW/7
     0.110   0.216   0.635   0.630   0.689      * 4TPW/7
     0.376   0.374   0.669   0.853   0.820      * 5TPW/7
     0.787   0.770   0.858   0.963   0.953      * 6TPW/7
     1.000   1.000   1.000   1.000   1.000      * PEAK
     0.815   0.785   0.885   0.986   0.963      * 8TPW/7
     0.530   0.539   0.687   0.920   0.913      * 9TPW/7
     0.330   0.364   0.518   0.794   0.860      *10TPW/7
     0.206   0.253   0.381   0.665   0.806      *11TPW/7
     0.130   0.182   0.243   0.547   0.751      *12TPW/7
     0.083   0.138   0.162   0.431   0.700      *13TPW/7
     0.054   0.108   0.140   0.314   0.650      *14TPW/7
     0.035   0.089   0.116   0.219   0.600      *15TPW/7
     0.024   0.075   0.105   0.161   0.555      *16TPW/7
     0.017   0.066   0.101   0.120   0.515      *17TPW/7
     0.013   0.059   0.098   0.093   0.477      *18TPW/7
     0.010   0.054   0.085   0.075   0.440      *19TPW/7
     0.008   0.049   0.064   0.059   0.408      *20TPW/7
     0.236   0.275   0.367   0.489   0.689      *AVG/PEAK


* FLOOD DAMAGES - GENERAL

  * QO() - EXISTING SUBWATERSHED CHANNEL CAPACITY IN CFS
        4000.   18000.   23000.   23000.   15000.   20000.    * 2 -  7
        7000.   18000.   20000.   19000.   30000.             * 8 - 12
  * QK(),AK(),DK() - MAGNITUDE OF ANY KNOWN FLOOD PEAK AND ASSOCIATED
  *                  MAXIMUM DEPTH OF FLOODING AND AREA FLOODED
     * FLOOD PEAK    AREA FLOODED   MAXIMUM DEPTH   SUBWATERSHED
```

```
*     CFS              ACRES              FEET
    15750.             765.               15.            * 2
    24500.             420.                7.            * 3
    24750.             455.                6.            * 4
    24800.             140.                2.            * 5
    25100.             240.                3.            * 6
    25800.             515.                8.            * 7
    26000.             270.               14.            * 8
    27700.             770.               10.            * 9
    28600.             190.                9.            * 10
    31000.            2285.               11.            * 11
    31600.             340.               10.            * 12

* FLOOD DAMAGES - URBAN

   20000.   * VLURST - MEAN VALUE OF URBAN STRUCTURES, IN $/ACRE
   0.052    * COEFDM - FLOOD DAMAGE PER FOOT OF FLOOD DEPTH PER DOLLAR
            *          OF BUILDING MARKET VALUE

* FLOOD DAMAGES - AGRICULTURAL

  * D() - FRACTION OF SUBWATERSHED FLOOD PLAIN LAND WITHIN EACH OF
  *       THREE SOIL CLASSES
      *    BEST SOIL        MEDIUM SOIL       WORST SOIL SUBWATERSHED
              0.0               1.0              0.0         * 2
              1.0               0.0              0.0         * 3
              1.0               0.0              0.0         * 4
              1.0               0.0              0.0         * 5
              1.0               0.0              0.0         * 6
              1.0               0.0              0.0         * 7
              1.0               0.0              0.0         * 8
              1.0               0.0              0.0         * 9
              1.0               0.0              0.0         * 10
              1.0               0.0              0.0         * 11
              1.0               0.0              0.0         * 12

   10.00    * CDA - CROP DAMAGE PER ACRE OF MOST PRODUCTIVE SOIL WHEN
            *       FLOODED TO A MINIMAL DEPTH
    8.00    * CDB - CROP DAMAGE PER ACRE OF INTERMEDIATE SOIL WHEN
            *       FLOODED TO A MINIMAL DEPTH
    6.00    * CDC - CROP DAMAGE PER ACRE OF LEAST PRODUCTIVE SOIL WHEN
            *       FLOODED TO A MINIMAL DEPTH
    0.00    * CDAV - INCREMENTAL DAMAGE PER ACRE OF MOST PRODUCTIVE
            *        SOIL PER ADDITIONAL FOOT OF FLOOD DEPTH
    0.00    * CDBV - INCREMENTAL DAMAGE PER ACRE OF INTERMEDIATE
            *        SOIL PER ADDITIONAL FOOT OF FLOOD DEPTH
    0.00    * CDCV - INCREMENTAL DAMAGE PER ACRE OF LEAST PRODUCTIVE
            *        SOIL PER ADDITIONAL FOOT OF FLOOD DEPTH

  * FRU() - RELATIONSHIP BETWEEN AGRICULTURAL PRODUCTIVITY AND
```

```
*         URBANIZATION EXPRESSED AS A MULTIPLE OF FULL RURAL VALUE
* U=0.00  0.10  0.20  0.30  0.40  0.50  0.60  0.70  0.80  0.90  1.00
    1.00  0.97  0.91  0.82  0.71  0.58  0.44  0.37  0.30  0.23  0.16
105.00    * VLAGST - MEAN VALUE OF AGRICULTURAL STRUCTURES,
          *          IN $/ACRE


* FLOOD DAMAGES - UNCERTAINTY

   2.575   * VA - NORMAL DEVIATE USED IN EVALUATING UNCERTAINTY


* GENERAL DESIGN VARIABLES

   0.03125 * R - DISCOUNT RATE USED IN PLANNING
   50.0    * TIMST - DESIGN LIFE OF CHANNEL IMPROVEMENTS IN YEARS
   10.0    * TIME - DURATION OF ONE PLANNING STAGE
   1       * MRDF - LOCATION IN ARRAY DF OF MINIMUM RESERVOIR
           *        DESIGN FLOOD
   10      * NDF - NUMBER OF DESIGN FLOOD FREQUENCIES CONSIDERED
  * DF() - DESIGN FLOOD FREQUENCIES TO BE CONSIDERED IN ANALYSIS
 0.43  0.20  0.15  0.10  0.06  0.04  0.03  0.02  0.01  0.005


* CHANNEL IMPROVEMENT - PHYSICAL FACTORS

  * A0() - INITIAL SUBWATERSHED CHANNEL CROSS SECTIONAL AREA IN SQ.FT.
  2160. 2800. 3800. 4800. 4050. 5250. 2750. 5100. 3600. 4550. 5250.
  * LINING() - DESIGNATION OF CHANNEL TYPES TO BE CONSIDERED IN
  *               SUBWATERSHED
  *            '0' ALL TYPES OF CHANNEL IMPROVEMENT TO BE CONSIDERED
  *            '1' CONSIDERS ONLY UNLINED CHANNELS, NO EXISTING DROP
  *                STRUCTURES
  *            '2' CONSIDERS ONLY UNLINED CHANNELS, EXISTING DROP
  *                STRUCTURES
  *            '3' CONSIDERS ONLY TRAPEZOIDAL LINED CHANNELS
  *            '4' CONSIDERS ONLY RECTANGULAR LINED CHANNELS
     0  0  0  0  0  0  0  0  0  0  0     *  LINING(MW-1)

   0.030   * MANNU - MANNINGS 'N' FOR UNLINED PRISMATIC CHANNELS
   0.016   * MANNT - MANNINGS 'N' FOR LINED TRAPEZOIDAL CHANNELS
   0.012   * MANNR - MANNINGS 'N' FOR LINED RECTANGULAR CHANNELS
   1.5     * ZU - SIDE SLOPE OF UNLINED PRISMATIC CHANNELS
   1.0     * ZT - SIDE SLOPE OF LINED TRAPEZOIDAL CHANNELS

  * S() - AVERAGE LONGITUDINAL SUBWATERSHED CHANNEL SLOPE
 0.000234   0.000680   0.000432   0.000228   0.000214   0.000549 *2- 7
 0.000378   0.000546   0.000400   0.000792   0.001298            *8-12

  * TF() - MAXIMUM ALLOWABLE TRACTIVE FORCE FOR SUBWATERSHED CHANNELS
  *        IN POUNDS PER SQ.FT.
      1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  2.5
```

```
10.0      * BDMAX - MAXIMUM ALLOWABLE RATIO OF CHANNEL BOTTOM
          *         WIDTH TO DEPTH
4.0       * BDMIN - MINIMUM ALLOWABLE RATIO OF CHANNEL BOTTOM
          *         WIDTH TO DEPTH
25.       * HMAX - MAXIMUM CHANNEL DESIGN DEPTH, IN FEET
6.0       * NIN - NO. DRAINAGE INLETS REQUIRED PER MILE OF CHANNEL

   * CAP() - NUMBER AND CAPACITY IN CFS OF EXISTING BRIDGES
   *              HIGHWAY BRIDGES                          RAILWAY BRIDGES
*  1        2        3        4        5        6        1        1       SUBW
210000. 140400.  59625.   55620.   46350.   -1.      105750.  -1.     *   2
  -1.     -1.      -1.      -1.      -1.     -1.        -1.    -1.     *   3
118125.   -1.      -1.      -1.      -1.     -1.        -1.    -1.     *   4
132300.   -1.      -1.      -1.      -1.     -1.      256500.  -1.     *   5
148500. 118800.    -1.      -1.      -1.     -1.        -1.    -1.     *   6
  -1.     -1.      -1.      -1.      -1.     -1.      238500.  -1.     *   7
198900.   -1.      -1.      -1.      -1.     -1.        -1.    -1.     *   8
211500.   -1.      -1.      -1.      -1.     -1.      266400.  -1.     *   9
126900.   -1.      -1.      -1.      -1.     -1.        -1.    -1.     *  10
211500. 126900.  86060.     -1.      -1.     -1.        -1.    -1.     *  11
342090.   -1.      -1.      -1.      -1.     -1.      256500.  -1.     *  12

30.0      * BW - REQUIRED WIDTH OF HIGHWAY BRIDGES IN FEET


* CHANNEL IMPROVEMENT - COST FACTORS

0.45      * CX - UNIT COST OF CHANNEL EXCAVATION IN $/C.Y.
1.10      * FM - MULTIPLIER FOR CHANNEL EXCAVATION COST TO ACCOUNT
          *      FOR RIPRAP AND SEEDING
900.0     * CIN - COST PER DRAINAGE INLET IN DOLLARS
0.70      * CLSF - UNIT COST OF TRAPEZOIDAL LINING IN $/SQ.FT.
60.0      * CCY - COST OF IN PLACE STRUCTURAL CONCRETE FOR
          *       RECTANGULAR CHANNELS IN $/SQ.FT.
15.0      * CBR - UNIT COST OF HIGHWAY BRIDGES IN $/SQ.FT.
300.0     * CRR - UNIT COST OF RAILROAD BRIDGES IN $/LINEAR FT.
1.24      * AQR - MULTIPLE OF RIGHT-OF-WAY COST USED TO INCLUDE
          *       COSTS OTHER THAN FOR LAND AND IMPROVEMENTS
1.00      * SAFC - RATIO OF RIGHT-OF-WAY WIDTH TO BE HELD TO
          *        RIGHT-OF-WAY WIDTH EXPECTED TO BE REQUIRED
1.15      * CSM - MULTIPLE OF CHANNEL CONSTRUCTION COST TO ACCOUNT
          *       FOR CONTINGENCIES
1.25      * ESM - MULTIPLE OF CHANNEL CONSTRUCTION COST TO ACCOUNT
          *       FOR DESIGN, ADMINISTRATION, AND SUPERVISION OF
          *       CONSTRUCTION
0.005     * MIN - ANNUAL MAINTENANCE COST OF CONCRETE STRUCTURES AS
          *       FRACTION OF FIRST COST
0.015     * MCH - ANNUAL MAINTENANCE COST OF EARTH CHANNELS AS A
          *       FRACTION OF FIRST COST
0.01      * MTLCH - ANNUAL MAINTENANCE COST OF TRAPEZOIDAL LINED
          *         CHANNELS AS A FRACTION OF FIRST COST
```

* FLOOD PROOFING - COST FACTORS

```
0.035     * FP - COST OF FLOOD PROOFING PER FOOT OF DESIGN FLOOD
          *        DEPTH PER DOLLAR OF BUILDING MARKET VALUE
1.00      * VF - RATIO OF AREA REQUIRING FLOOD PROOFING TO THAT
          *        INUNDATED BY THE DESIGN FLOOD
1.30      * DD - MULTIPLIER FOR FLOOD PROOFING INSTALLATION COST TO
          *        ACCOUNT FOR DESIGN AND CONTINGENCIES
0.05      * MFP - ANNUAL MAINTENANCE COST OF FLOOD PROOFING MEASURES
          *        AS A FRACTION OF FIRST COST
```

* LOCATION ADJUSTMENT - COST FACTORS

```
1.00      * CLEN - ANNUAL COST OF ENFORCING LAND USE RESTRICTIONS IN
          *        DOLLARS PER ACRE
0.08      * RPI - RETURN RATE REQUIRED BY PRIVATE INVESTORS IN LAND
45.90     * FIA - EXPECTED ANNUAL FARM INCOME FROM MOST PRODUCTIVE
          *        SOIL IF FLOODING DOES NOT OCCUR
25.00     * FIB - EXPECTED ANNUAL FARM INCOME FROM INTERMEDIATE
          *        SOIL IF FLOODING DOES NOT OCCUR
10.00     * FIC - EXPECTED ANNUAL FARM INCOME FROM LEAST PRODUCTIVE
          *        SOIL IF FLOODING DOES NOT OCCUR
0.00      * IPP - ANNUAL OPEN SPACE AMENITIES AS A MULTIPLE OF THE
          *        FRACTION OF SURROUNDING LAND BEING URBAN
```

* DEGREE OF URBANIZATION

* USUBW() - FRACTION OF SUBWATERSHED FLOOD PLAIN IN URBAN USE

| * NOW (1970) | AFTER TIME YEARS (1980) | AFTER 2TIME YEARS (1990) | AFTER 3TIME YEARS (2000) | AFTER 4TIME YEARS (2010) | AFTER 5TIME YEARS (2020) | SUBW |
|---|---|---|---|---|---|---|
| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | * 1 |
| 0.0090 | 0.0101 | 0.0113 | 0.0125 | 0.0138 | 0.0152 | * 2 |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | * 3 |
| 0.0051 | 0.0057 | 0.0064 | 0.0071 | 0.0078 | 0.0086 | * 4 |
| 0.0168 | 0.0195 | 0.0226 | 0.0259 | 0.0296 | 0.0337 | * 5 |
| 0.3333 | 0.3472 | 0.3605 | 0.3707 | 0.3797 | 0.3876 | * 6 |
| 0.0007 | 0.0008 | 0.0009 | 0.0010 | 0.0011 | 0.0013 | * 7 |
| 0.0012 | 0.0013 | 0.0015 | 0.0017 | 0.0019 | 0.0021 | * 8 |
| 0.0012 | 0.0013 | 0.0015 | 0.0017 | 0.0019 | 0.0021 | * 9 |
| 0.0023 | 0.0026 | 0.0029 | 0.0032 | 0.0035 | 0.0038 | * 10 |
| 0.0009 | 0.0010 | 0.0011 | 0.0012 | 0.0013 | 0.0014 | * 11 |
| 0.1083 | 0.1214 | 0.1358 | 0.1505 | 0.1662 | 0.1828 | * 12 |

* UTOTR() - FRACTION OF TRIBUTARY AREA ADDED IN URBAN DEVELOPMENT

| * NOW | AFTER TIME | AFTER 2TIME | AFTER 3TIME | AFTER 4TIME | AFTER 5TIME | SUBW |
|---|---|---|---|---|---|---|

```
*        YEARS     YEARS      YEARS     YEARS     YEARS
*(1970) (1980) (1990)      (2000)    (2010)    (2020)
 0.0063 0.0071 0.0079      0.0088    0.0097    0.0107          * 1
 0.0069 0.0077 0.0086      0.0095    0.0105    0.0116          * 2
 0.0012 0.0013 0.0015      0.0017    0.0019    0.0021          * 3
 0.0006 0.0007 0.0008      0.0009    0.0010    0.0011          * 4
 0.0257 0.0288 0.0322      0.0357    0.0394    0.0433          * 5
 0.0592 0.0664 0.0743      0.0823    0.0909    0.1000          * 6
 0.0006 0.0007 0.0008      0.0009    0.0010    0.0011          * 7
 0.0000 0.0000 0.0000      0.0000    0.0000    0.0000          * 8
 0.0000 0.0000 0.0000      0.0000    0.0000    0.0000          * 9
 0.0019 0.0022 0.0025      0.0028    0.0031    0.0034          * 10
 0.0002 0.0002 0.0003      0.0003    0.0004    0.0004          * 11
 0.0991 0.1111 0.1243      0.1377    0.1520    0.1672          * 12

* LAND VALUE

   * VALUE() - VALUE OF LAND IN SUBWATERSHED FLOOD PLAIN, IN $/ACRE
        *        AFTER     AFTER      AFTER     AFTER     AFTER
        * NOW    TIME      2TIME      3TIME     4TIME     5TIME           SUBW
        *        YEARS     YEARS      YEARS     YEARS     YEARS
        *(1970) (1980) (1990)      (2000)    (2010)    (2020)
          275.0   344.0   430.0      537.0     671.0     839.0          * 1
          300.0   375.0   469.0      586.0     732.0     916.0          * 2
          300.0   375.0   469.0      586.0     732.0     916.0          * 3
          300.0   375.0   469.0      586.0     732.0     916.0          * 4
          350.0   438.0   547.0      684.0     854.0    1068.0          * 5
          500.0   625.0   781.0      977.0    1221.0    1526.0          * 6
          275.0   344.0   430.0      537.0     671.0     839.0          * 7
          275.0   344.0   430.0      537.0     671.0     839.0          * 8
          275.0   344.0   430.0      537.0     671.0     839.0          * 9
          275.0   344.0   430.0      537.0     671.0     839.0          * 10
          275.0   344.0   430.0      537.0     671.0     839.0          * 11
          500.0   625.0   781.0      977.0    1221.0    1526.0          * 12

* HYDROLOGIC DATA FOR RESERVOIR DESIGN

     2.80     * HYDMLT - RATIO OF EMERGENCY SPILLWAY DESIGN FLOOD PEAK
              *              TO THE 200-YEAR FLOOD PEAK
     621.24   * AWG - DRAINAGE AREA IN SQ. MI. USED TO DEVELOP
              *           CUMULATIVE RUNOFF CURVE
     20       * IMPTY - NUMBER OF DAYS THE DESIGN FLOOD IS DETAINED IN
              *             THE RESERVOIR
   * CUMVOL() - CUMULATIVE RUNOFF CURVE - AVERAGE FLOW IN CFS BY
   *            DURATION IN DAYS
* 0.25   0.50   0.75   1.00   1.25   1.50   1.75   2.00   3.00   4.00
 24000. 20500. 18500. 17311. 17000. 16400. 15800. 15324. 12963. 10861.
* 5.00   6.00   7.00   8.00   9.00  10.00  11.00  12.00  13.00  14.00
  9523.  8714.  8257.  7667.  7134.  6652.  6136.  5740.  5423.  5169.
*15.00  16.00  17.00  18.00  19.00  20.00
```

5047. 4939. 4799. 4622. 4456. 4315.

```
  1       * IB - WHETHER XTRSTR IS NEEDED NOW - "0" INDICATES NO DAM
          *      TO BE BUILT UNLESS JUSTIFIED BY FLOOD CONTROL
 12.0     * GDELAY - NUMBER OF HOURS HYDROGRAPH DELAYED BY
          *         CLOSING GATES
```

* MUSKINGUM ROUTING PARAMETERS

| * | K(NAT) | K(IMP) | X(NAT) | X(IMP) | SUBWATERSHED |
|---|---|---|---|---|---|
| | 11.95 | 7.97 | 0.240 | 0.360 | * 2 |
| | 1.63 | 1.08 | 0.240 | 0.360 | * 3 |
| | 1.82 | 1.22 | 0.240 | 0.360 | * 4 |
| | 0.53 | 0.36 | 0.240 | 0.360 | * 5 |
| | 0.53 | 0.36 | 0.240 | 0.360 | * 6 |
| | 2.18 | 1.63 | 0.240 | 0.360 | * 7 |
| | 1.25 | 0.94 | 0.240 | 0.360 | * 8 |
| | 2.11 | 1.58 | 0.240 | 0.360 | * 9 |
| | 0.38 | 0.28 | 0.240 | 0.360 | * 10 |
| | 6.29 | 4.73 | 0.240 | 0.360 | * 11 |
| | 0.72 | 0.55 | 0.240 | 0.360 | * 12 |

* PROPERTIES OF THE DAM SITE BY ELEVATION CONTOURS

```
  25      * IMAX - NUMBER OF ELEVATIONS USED IN INPUT DATA
  3       * NHILSD - NUMBER OF ALTERNATIVE SPILLWAY LOCATIONS
* BREAKPOINT ELEVATIONS GOVERNING CHOICE OF EMERGENCY SPILLWAY SITES
  840. * HBRLM - LOWER  BREAKPOINT ELEVATION
  870. * HBRMH - HIGHER BREAKPOINT ELEVATION
```

| * | ELEVA | RESACR | LGDAM | LGEMSP | LGAPCH | CRELOC | HLSIDE(L) | (M) | (H) |
|---|---|---|---|---|---|---|---|---|---|
| | 758. | 0. | 0. | 1000. | 500. | 0. | 0. | 0. | 0. |
| | 760. | 8. | 60. | 1000. | 500. | 0. | 10. | 0. | 0. |
| | 765. | 43. | 80. | 1000. | 500. | 0. | 30. | 0. | 0. |
| | 770. | 83. | 110. | 1000. | 500. | 0. | 60. | 0. | 0. |
| | 775. | 131. | 150. | 1000. | 500. | 0. | 100. | 0. | 0. |
| | 780. | 234. | 210. | 1000. | 500. | 0. | 130. | 0. | 0. |
| | 785. | 394. | 290. | 1000. | 500. | 0. | 220. | 0. | 0. |
| | 790. | 622. | 350. | 1000. | 500. | 0. | 280. | 0. | 0. |
| | 795. | 965. | 415. | 1000. | 500. | 3000. | 330. | 0. | 0. |
| | 800. | 1374. | 480. | 1000. | 500. | 10000. | 380. | 0. | 0. |
| | 805. | 1787. | 500. | 1000. | 475. | 204000. | 400. | 0. | 0. |
| | 810. | 2285. | 530. | 1000. | 450. | 437000. | 420. | 0. | 0. |
| | 815. | 2863. | 930. | 1000. | 425. | 709000. | 800. | 0. | 0. |
| | 820. | 3548. | 1000. | 1000. | 400. | 1031000. | 850. | 0. | 0. |
| | 825. | 4310. | 1075. | 1000. | 400. | 1388000. | 925. | 0. | 0. |
| | 830. | 5189. | 1150. | 1000. | 400. | 1801000. | 1000. | 0. | 0. |
| | 835. | 6170. | 1200. | 1000. | 400. | 2261000. | 1050. | 0. | 0. |
| | 840. | 7195. | 1230. | 1000. | 300. | 2743000. | 1100. | 0. | 0. |
| | 845. | 8514. | 1300. | 1000. | 250. | 3362000. | 1150. | 0. | 0. |
| | 850. | 10094. | 1470. | 1000. | 200. | 4103000. | 1200. | 120. | 0. |
| | 855. | 11450. | 1860. | 1000. | 150. | 4740000. | 1325. | 330. | 0. |

```
860.  13205.   2170.  1000.  100.   5564000.  1450.   500.     0.
870.  15000.   3400.  1000.  100.   6406000.  1700.  1180.     0.
880.  25000.   3650.  1800.  200.  11101000.  1800.  1500.     0.
900.  50000.  10000.  1800.  100.  22837000.  2150.  2200.  1000.

* VOLUME OF RETAINING WALL CONCRETE AS A FUNCTION OF WALL HEIGHT
*    IN CUBIC YARDS PER FOOT OF WALL LENGTH

 8        * NWH - NUMBER OF WALL HEIGHTS USED
  *  WALL HEIGHT     CONCRETE
  *      FEET          CY/FT
         0.0           0.25
         2.5           0.30
         5.0           0.40
         7.5           0.55
        10.0           0.75
        15.0           1.275
        20.0           1.95
        25.0           2.90

* PHYSICAL FACTORS USED IN DAM AND RESERVOIR DESIGN

 1.0      * BYVERT - VERTICAL DISTANCE IN FEET FROM DAM TOP TO
          *          RIGHT-OF-WAY PURCHASE LINE
 1.0      * CONBOT - THICKNESS IN FEET OF CONCRETE CHUTE BOTTOM
 50.0     * CTBW - WIDTH IN FEET OF CUTOFF TRENCH BOTTOM
 3.5      * CWEIR - EMERGENCY SPILLWAY WEIR COEFFICIENT
 5.0      * DMFRBD - DAM FREEBOARD IN FEET ABOVE PEAK OF EMERGENCY
          *          SPILLWAY FLOOD
 30.0     * DMTPW - WIDTH IN FEET OF TOP OF DAM
 5.0      * DPRCKH - DEPTH IN FEET TO BEDROCK ON EMERGENCY SPILLWAY
          *          HILLSIDE
 10.0     * DPRCKV - DEPTH IN FEET TO BEDROCK UNDER DAM
 2.0      * DPRP - DEPTH IN FEET OF RIPRAP ON DAM FACE
 0.02     * FPIPE - DARCY FRICTION FACTOR FOR PRINCIPAL SPILLWAY
          *         PIPE
 1.3      * QRATIO - RATIO OF PEAK TO AVERAGE PRINCIPAL SPILLWAY
          *          DISCHARGE
 0.5      * SEDIN - ANNUAL SEDIMENT INFLOW IN ACRE-FEET/SQUARE MILE
 2.0      * STLBOT - THICKNESS IN FEET OF STILLING BASIN BOTTOM
 3.0      * TRV - DESIGN FLOW VELOCITY THROUGH TRASHRACK IN FEET/SEC
 770.5    * TWELEV - DESIGN TAILWATER ELEVATION
 210.0    * WDEMSP - INITIAL VALUE OF EMERGENCY SPILLWAY DESIGN
          *         WIDTH IN FEET
 21000.   * XTRSTR - CONSERVATION STORAGE IN ACRE-FEET
 1.5      * ZCT - CUTOFF TRENCH SIDE SLOPE
 3.25     * ZDN - SLOPE OF DOWNSTREAM FACE OF DAM
 2.0      * ZES - CUT SLOPE IN HILLSIDE ABOVE EMERGENCY SPILLWAY
 3.0      * ZUP - SLOPE OF UPSTREAM FACE OF DAM
```

```
* UNIT COST FACTORS FOR ESTIMATING COST OF DAM AND RESERVOIR

  2.05      * UCDAM - COST OF DAM EMBANKMENT IN $/CY
  0.75      * UCCT - COST OF CUTOFF TRENCH EXCAVATION AND BACKFILL
            *          IN $/CY
  10.00     * UCRP - COST OF RIPRAP IN $/CY
  0.30      * UCSPEX - COST OF SPILLWAY EARTH EXCAVATION IN $/CY
  1.50      * UCRKEX - COST OF SPILLWAY ROCK EXCAVATION IN $/CY
  45.00     * UCSPCN - COST OF EMERGENCY SPILLWAY CONCRETE IN $/CY
  125.00    * UCPRCN - COST OF PRINCIPAL SPILLWAY CONCRETE IN $/CY
  110.00    * UCCNID - COST OF IMPACT DISSIPATOR CONCRETE IN $/CY
  100.00    * UCTRK - COST OF TRASH RACK AND INLET STRUCTURE IN
            *          $/SQ.FT. OF OPENING
  60.00     * UCCLR - COST OF RESERVOIR SITE CLEARING IN $/ACRE
  1.20      * CSMD - COST MULTIPLIER TO INCLUDE CONTINGENCIES
  1.25      * ESMD - COST MULTIPLIER TO INCLUDE ENGINEERING
  0.005     * MDAM - ANNUAL MAINTENANCE COST AS A FRACTION OF
            *          CONSTRUCTION COST

 * DMBN() - BENEFITS ACCRUING DOWNSTREAM FROM AREA OF PRIMARY
 *          ANALYSIS AS A FUNCTION OF RESERVOIR FLOOD CONTROL STORAGE
    * FLOOD STORAGE IN ACRE-FEET
0.0 5000. 10000. 15000. 20000. 30000. 40000. 50000. 98600. 986000.
    * BENEFITS IN DOLLARS
0.0 3500.  7000. 10500. 14000. 20900. 27900. 34900. 68800. 688000.
 * DMBNF() - STAGE MULTIPLIERS FOR DOWNSTREAM BENEFITS
    * STAGE       1        2        3        4        5
               0.8617   0.9522   1.0513   1.1616   1.2831
```

LIST OF REFERENCES

1. Arthur D. Little, Inc. "Projective Economic Study," Ohio River Basin, Comprehensive Survey. Vol. III, Appendix B. Cincinnati, Ohio: U. S. Army Engineer Division. 1964.

2. Bhavnagri, Viraf S., and Bugliarello, George. "Mathematical Representation of an Urban Flood Plain," Proceedings of the American Society of Civil Engineers, 91, HY2, (March, 1965)., 149-173.

3. Cline, James N. Planning Flood Control Measures by Digital Computer. Lexington, Kentucky: University of Kentucky, Water Resources Institute, Research Report No. 11, 1968.

4. Dempsey, Clyde R. The Effect of Geographical and Climatic Setting on the Economic Advantages of Alternative Flood Control Measures. Lexington, Kentucky: University of Kentucky, Water Resources Institute, Research Report No. 10, 1968.

5. Dorfman, Robert. "Basic Economic and Technologic Concepts," Maass, et.al., Design of Water-Resource Systems. Cambridge: Harvard University Press, 1962.

6. Dunham, Clarence W. Foundations of Structures. New York: McGraw-Hill Book Co., Inc., 1950.

7. Eckstein, Otto. Water Resources Development - The Economics of Project Evaluation. Cambridge, Massachusetts: Harvard University Press, 1961.

8. Grant, Eugene L., and Ireson, W. Grant. Principles of Engineering Economy. Ronald Press Company, New York, 1964.

9. Gumbel, E. J. Statistical Theory of Extreme Values and Some Practical Applications. National Bur. Standards (U. S.) Appl. Math. Ser. 33, February, 1954.

LIST OF REFERENCES
(Continued)

10. James, L. D. A Time-Dependent Planning Process for Combining Structural Measures, Land Use, and Flood Proofing to Minimize the Economic Cost of Floods. Stanford, California: Stanford University, Project on Engineering-Economic Planning, Report EEP-12, August, 1964.

11. James, L. D. "Economic Analysis of Alternative Flood Control Measures," Water Resources Research, Vol. 3 (Second Quarter, 1967), 333-343.

12. James, L. D. "Nonstructural Measures for Flood Control," Water Resources Research, Vol. 1 (First Quarter, 1965), 9-24.

13. James, L. D. "Preservation of Right-of-Way for Public Facilities," Proceedings of the American Society of Civil Engineers, Vol. 93, No. UP4 (December, 1967), 243-255.

14. Linsley, R. K., and Franzini, Joseph B. Water Resources Engineering. New York: McGraw-Hill Book Co., Inc., 1964.

15. Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H. Hydrology for Engineers. New York: McGraw-Hill Book Co., Inc., 1958.

16. McCabe, John A. Floods in Kentucky - Magnitude and Frequency. Lexington, Kentucky: University of Kentucky, Kentucky Geological Survey, 1962.

17. Rachford, Thomas M. Economic Analysis of Alternative Flood Control Measures by Digital Computer. Lexington, Kentucky: University of Kentucky, Water Resources Institute, Research Report No. 1, 1966.

18. Sheaffer, John R. Flood Proofing: An Element in a Flood Damage Reduction Program. Chicago, Illinois: University of Chicago, Department of Geography, Research Paper 65, 1960.

LIST OF REFERENCES
(Continued)

19. U. S. Department of Agriculture, Soil Conservation Service, Engineering Handbook, Section 11, Drop Spillways. Washington, D. C.

20. U. S. Department of the Interior, Bureau of Reclamation. Design of Small Dams. Washington, D. C.: U. S. Government Printing Office, 1960.

21. U. S. Department of the Interior, Geological Survey. Surface Water Records of Kentucky. Louisville, Kentucky, 1961-1965.

22. U. S. Department of the Interior, Geological Survey. Surface Water Supply of the Ohio River Basin. Washington, D. C.: U. S. Government Printing Office, 1945-1960.

23. Water Resources Council: Hydrology Committee. A Uniform Technique for Determining Flood Flow Frequencies. Washington, D. C.: Water Resources Council, Bulletin No. 15, 1967.