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RESEARCH REPORT NO. 1

# ECONOMIC ANALYSIS OF ALTERNATIVE FLOOD CONTROL MEASURES BY DIGITAL COMPUTER

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1966

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WATER RESOURCES INSTITUTE
LEXINGTON, KENTUCKY

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Research Report No. 1

# ECONOMIC ANALYSIS
# OF
# ALTERNATIVE FLOOD CONTROL MEASURES
# BY
# DIGITAL COMPUTER

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University of Kentucky Water Resources Institute
Lexington, Kentucky

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

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# ABSTRACT

The purpose of this project was to develop a digital computer program for selecting the optimum combination of flood proofing, flood-plain land use, channel improvement, and residual flood damage for a given flood-plain. Based on economic efficiency, the optimum policy is selected for each planning unit of the total flood-plain for each period of time called a planning stage. The program was written in Fortran IV for the IBM 7040 and the University of Kentucky Computing Center compiler. The program requires about 23,000 words of core storage and about 30 seconds of execution time per planning-unit-stage for typical conditions. The program is not intended to furnish a finished design but is intended to select the optimum combination of flood control measures and residual flooding with regard to both time and space.

The program was used to test the sensitivity of the optimum combination of measures to variation in discount rate, right-of-way value, population projections, value of open space amenities, adversion to large annual variation in flood damage, costs of restricting flood-plain land use, costs of flood proofing, and costs of channel improvements. It was also used to analyze the effectiveness of land use, flood proofing, and channel improvement used individually and in various combinations. Program development and sensitivity studies were based on data previously collected for the Morrison Creek Watershed near Sacramento, California.

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## Chapter I

# INTRODUCTION

Since the passage of the Flood Control Act of 1936, considerable time and effort has been expended by numerous researchers in a continuing attempt to define, quantify, and suggest the best possible means of alleviating damages caused by floods. Available figures indicate that since 1936, the Corps of Engineers alone has spent over $3,500,000,000 for flood control (1, p.1) and that total expenditures during this period by federal, state, and local agencies has been in excess of $6,000,000,000 (2, p.184). Despite this enormous expenditure, average annual flood damage in the United States exceeds $200,000,000. (3, p.9).

The magnitude of these figures, together with the fact that annual flood damages are increasing, should suggest that something better can be done to combat flood losses. In actuality it is impossible, at least for all practical purposes, to eliminate the damages caused by floods. In recognition of this fact, it would perhaps be more accurate to substitute the term "flood mitigation" (4, p.577) for the currently popular term "flood control" as the latter term represents a misnomer. The goal of those responsible for planning flood mitigation projects should be to minimize the total cost of flooding; in effect, the cost of mitigating flood damage plus the cost of damages due to residual flooding should be minimized. This can be illustrated graphically by Figure 1 (5). Curve A shows the cost of flood control measures to be an increasing function of the level of protection while curve B shows the cost of residual flooding to be a decreasing function of the level of protection. If these curves are added vertically to get curve C, there will be a minimum point D on the curve representing the least cost combination of flood control measures and residual flooding.

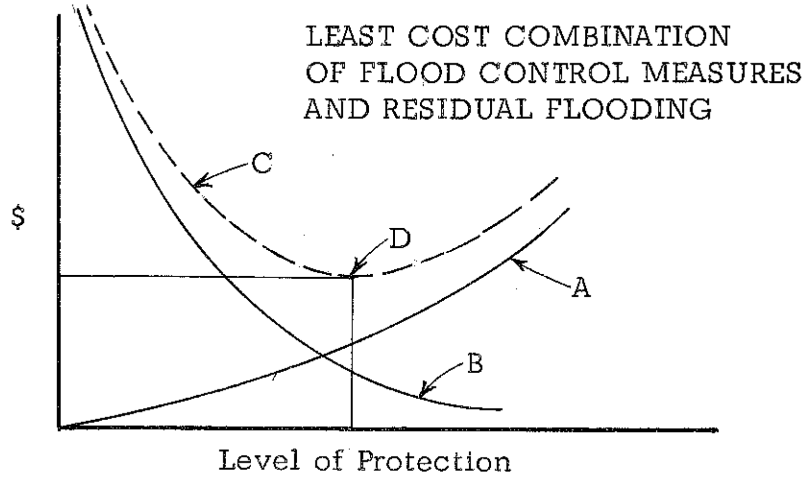

Figure 1

Despite the simplicity and the appeal of the approach illustrated by Figure 1, the practical application of the theory is another matter. It is quite difficult to quantify for project evaluation the actual damage caused by flooding. The reasons for this are many; past damages may not be indicative of expected future damages; estimates of past damages may be inaccurate; expected damages depend on future flood-plain use, which may not be accurately predicted, and much of the damage is intangible, and as such, is not easily reduced to money terms. However, it is anticipated that research into improved methodology (6) for estimating flood damages will lessen this problem.

Disagreement exists today among the agencies responsible for evaluating flood control projects concerning the classification of flood damages. However, for the purpose of evaluating alternative flood control measures, it is more important that a consistent method of evaluating damages be established and followed than it is to worry about always arbitrary classification. If a consistent method of evaluating damages could be adopted, regardless of the classification, relative advantages and disadvantages of alternative flood control measures could be viewed with increased confidence. Damages caused by flooding may be classed into four major groups: (A) direct damages accruing to inundated property, (B) indirect damages accruing to property not itself inundated, (C) secondary damages stemming from economic linkages, and (D) intangible damages for which a monetary value cannot be readily assigned. For a more detailed discussion of flood damages and flood control benefits, the reader is referred to the literature (7). The damage classification mentioned above is adhered to by the U. S. Department of Agriculture and is discussed more fully by James (8, p. 16).

Flood control measures may be classified, more distinctly than flood damages, into two principal groupings: (A) structural measures, and (B) nonstructural measures. Structural measures may be defined as improvements designated to decrease the frequency with which flows leave the channels within the flood-plain. Nonstructural measures may be defined as improvements designated to decrease the damage caused by water leaving the channels. Increasing channel capacity is the only structural measure considered in this study while nonstructural measures include flood proofing and land use measures. Flood proofing consists of measures taken to reduce the amount of damage individual structures suffer as a result of flooding. Examples of flood proofing include using building materials that are not highly susceptible to damage by water, constructing removable water-tight bulkheads at entrances to buildings, elevating floor levels within buildings, and storage of damageable contents at higher levels. Land use measures include restricting the location of damageable property from the flood-plain through the use of zoning laws or other regulatory action.

Well established procedures may be used to estimate the cost of structural measures. In general this cost is the sum of design, construction, maintenance, and right-of-way cost. Some difference of opinion does exist concerning the cost of right-of-way. This is discussed in James (8,p.26). The other items may be estimated by reference to Civil Engineering handbooks and design standards. Flood proofing costs may be estimated in much the same manner as structural costs. Although not as much information is available for designing flood proofing measures, recent efforts have done much to improve the situation (9). The problems associated with estimating land use cost are certainly more difficult than those associated with either structural cost or flood proofing costs. The cost of land use is the extra cost that is borne by those who may have to locate businesses or residences in an area that is to them less desirable than the area within the restricted zone of development. To reduce this cost to a dollar value is extremely difficult although efforts have been made to do so (8,pp.44-51).

Large scale flood control projects in the United States are planned and designed for the most part by one of several U. S. Government agencies[1]. Each of these agencies has its own manuals specifying guidelines for project formulation and

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[1] In general, the Corps of Engineers, the Soil Conservation Service, the Bureau of Reclamation, and the Tennessee Valley Authority.

design. While these manuals vary on specific details, a more or less conventional method of project analysis is followed by all of these agencies. According to Reedy (10,pp.299-306) this analysis includes (A) collecting information, (B) preparing a tentative plan, and (C) modification of the tentative plan through incremental analysis.

Until very recently, the flood damage reduction program of these agencies has almost totally been based on structural measures while nonstructural measures have been nearly excluded from their projects. The Soil Conservation Service was the only federal agency that placed significant emphasis on nonstructural measures, in their case land treatment. There are several reasons responsible for the emphasis on structural measures. First of all, it is much easier to evaluate the benefits and costs of structural than of nonstructural measures. Further, nonstructural measures are much more difficult to implement than structural measures. Flood proofing must be undertaken by individual property owners, and land use measures depend on local zoning comissions which are sometimes subjected to influences not in the interests of economic efficiency. Nevertheless, in many flood-plains, nonstructural measures, either alone or in combination with structural measures, may reduce design. While these manuals vary on specific details, a more or less conventional method of project analysis is followed by all of these agencies. According to Reedy (10, pp. 299-306) this analysis includes (A) collecting information, (B) preparing a tentative plan, and (C) modification of the tentative plan through incremental analysis.

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Additionally, the conventional practice of selecting a tentative plan and improving it by trial and adjustment may not yield an optimum design from the standpoint of minimizing the economic cost of flooding. There is not sufficient time when using this method of analysis for alternative designs to be examined sufficiently to insure that the optimum project has been selected. It is somewhat doubtful that even the best technical judgment could consistently overcome this deficiency. Further, it may be noted that the optimum project may not be found if the level of protection is specified in the initial stages of design, and all further effort is devoted to optimizing the means of achieving this level of protection. Theoretically, the level of protection provided should minimize the economic cost of flooding, and it is quite possible that a level of protection arbitrarily selected for a given project could render this goal unattainable.

The dynamic aspects of project planning are also often overlooked by the methods of project formulation used in conventional analysis. Flood control structural measures are evaluated on the basis of a rather long design life, usually fifty years or more, and are generally built initially with full design capacity. Considering that flood control benefits depend to a considerable extent on such hard to predict factors as population projections, land value estimates, and changing costs of construction causes one to wonder that it might not be better to build a project in stages, providing only the level of protection economically optimum during each stage. In addition to reducing initial investment, stage construction increases project flexibility by making it possible to adjust the plan if planning factors don't materialize as projected.

A final point that is not dealt with adequately by conventional analysis is the influence of deficiencies in hydrologic data on optimum project selection. In essence, a short period of streamflow record leaves one with great uncertainty about the frequency of occurrence of extreme flow events. An agency responsible for formulating a flood control project is, of course, concerned with the magnitude of the more rare events which do not occur often enough in a short-term record for a reliable frequency prediction. The use of the digital computer to synthesize long-term streamflow records from short-term streamflow and long-term rainfall records has met with success (11) and is certain of becoming a valuable tool in the near future.

One can readily see that aside from the difficulties of measuring such variables as the cost of restricted land use and the magnitude of indirect damages, the major drawback to more comprehensive planning by flood control agencies is the tremendous number of calculations that must be performed on large amounts of data. Even if necessary data were readily available, a proper analysis of a flood control project by desk calculator and slide rule is extremely time consuming.

The obvious solution to this problem is the use of the high speed digital computer as a major planning tool. Therefore, it has been the purpose of this study, based on the theoretical and computational framework developed by James (8), to program a dynamic flood control planning process for analysis by a digital computer and to make the program applicable to a wide variety of small watersheds. Based on the economic efficiency criterion of choosing the least cost combination of flood proofing, floodplain land use, channel improvement, and residual flooding; a computer program has been written which optimizes floodplain development with respect to both time and space. It is hoped that this flood control planning program which makes use of the speed and capacity of the digital computer will serve to overcome, or at least, to minimize some of the shortcomings of the conventional project analysis.

This computer program was developed, using the Fortran IV symbolic coding language, for use with the IBM 7040 computer. The program, at its current stage of development, is intended for use as a planning tool in the early stages of project optimization and in no way attempts to furnish a fully designed project.

In an effort to circumvent one of the failings of conventional analysis, the program has been developed to consider a wide range of alternative levels of protection from combinations of structural and nonstructural measures. The program analyzes channel improvements, flood proofing, and land use measures in combination or individually for a maximum of ten design frequencies. Levels of protection corresponding to none and the 43, 20, 15, 10, 6, 4, 3, 2, 1, and 1/2% floods were considered for each possible combination of structural and nonstructural measures. This amounts to consideration of 1331 alternative schemes of development covering a wide range in possible levels of protection; far more alternatives than can be investigated by conventional analytic procedures.

Further, the program includes a provision for incorporating adversion to a flood damage pattern which may be practically zero in most years but occasionally rises to very high values. Because of financial difficulty in coping with occasional high damages, most people would prefer to pay an equal annual flood damage bill than pay large amounts at irregular intervals. The excess of the annual amount that people would be willing to pay over the average annual damage is called the uncertainty cost. H. A. Thomas (12,pp.150-152) has advanced a procedure for quantifying this adversion and Bhavnagri and Bugliarello (13,pp.149-173) have demonstrated how it can be used in flood control project formulation. The crux of this procedure is to include as a cost of flooding an additional cost (i.e. an uncertainty cost) expressed as a function of the standard deviation of the annual flood damage time series. Conceptually the uncertainty cost is the amount in excess of the average annual damages which would have to be paid into a fund used to reimburse those suffering damages and having a specified probability of being exhausted by a series of large floods. Mathematically the cost is described by the equation:

$$CU=(V_{\alpha})\ (\sigma)\ /\ \sqrt{2r} \qquad (1)$$

where CU is the present value of the cost of uncertainty, $V_{\alpha}$ is the normal deviate with a probability $\alpha$ of being exceeded, $\alpha$ is the probability that the fund will be exhausted, $\sigma$ is the standard deviation of the flood damage time series, and r is the project discount rate. The goal of project formulation thus is to minimize the total cost of channel improvements, flood proofing, land use measures, residual flood damage, and "uncertainty". The flood control planning program allows one to optimize a given situation with or without the inclusion of uncertainty costs so that the effect on project optimization of various levels of uncertainty may be properly evaluated.

The flood control planning program also allows for consideration to be given to the dynamic aspects of flood control planning. Provisions have been made to optimize flood control planning over a series of five consecutive time periods. The length of the periods is also variable, so that one may examine five 10 year periods or five 5 year periods, etc. It is also possible to examine one 50 year period. Thus, one may systematically investigate the effects of longer or shorter planning stages to determine the relative economic advantages of stage construction as compared to building initially for full design life of the structures.

This brief introduction has been intended to review the current problems associated with the subject of planning for flood control. The remaining chapters of this paper are devoted to a detailed discussion of the development of the flood control planning program and presentation of the results of preliminary sensitivity studies performed with the computer program. The computerized flood control planning program has been based on the methodology and data previously used in the economic analysis of the Morrison Creek Watershed near Sacramento, California. Since this study uses data collected for this watershed by James (8) and because this thesis is concerned with mechanical details of the computer program rather than the theoretical aspects of the analysis, it is suggested that the reader secure a copy of his work for reference purposes while reading the remainder of this thesis.

# Chapter II

# DISCUSSION OF INPUT AND OUTPUT

The purpose of this chapter is to present the data that must be assembled for use with the flood control planning program, the procedure for reading it into the computer, and the meaning of the output produced by the computer. It is assumed that the reader has a basic knowledge of Fortran IV coding procedures.

## INPUT

The required input data for the flood control planning program consists of values which describe the physical, economic, and hydrologic characteristics of the watershed to be analyzed. The input is read from standard data processing cards and is listed on Table 1 in the order that it is read into the program. The numerical values shown on this table are those collected for the Morrison Creek Watershed and correspond to "Standard Project Conditions" as described in the chapter entitled Sensitivity Studies. Each single valued variable or array is punched onto cards according to the FORMAT presented on Table 1 and as a matter of consistency as well as necessity all floating point (non integer) values must be punched with decimals while all fixed point (integer) values must be punched without decimals. Logical variables must be punched with the single letter T to represent TRUE or the single letter F to represent FALSE.

The program has been developed to optimize flood control planning by individually optimizing watershed segments. A watershed to be analyzed by this program should be divided into a number of small, more or less homogeneous units, each preferably containing one main channel. The Morrison Creek Flood-Plain has been divided into twenty units ranging in size from 0.7 sq. mi. to 6.09 sq. mi. Because of a limitation in available internal magnetic core storage within the IBM 7040, the program has been set to sub-optimize a maximum of 25 subwatershed units.

Certain conventions have been established for arranging and assembling the necessary input data for the program; and as these must be followed, it will do well to discuss them now. First of all, each subwatershed is identified by a number; the most upstream subwatershed being designated 1, and downstream subwatersheds being numbered consecutively up to a maximum of 25. At the junctions of tributary watersheds, one must be careful to number the downstream subwatershed so that all subwatersheds upstream from it have smaller numbers. A single symbol, "NW", is used to refer to the subwatershed under consideration by the program. This numbering convention is also followed when reading values for each subwatershed into an array. For example, the subwatershed area for the fourth subwatershed must be the fourth element of the appropriate array; similarly, the channel length for the thirteenth subwatershed must be the thirteenth element of its corresponding array; and so on for each array.

Further, it may be seen that the FORMAT statements on Table 1 limit the maximum number of values that may be punched into a single card. In the event that the required number of elements to be read into an array exceeds this maximum number of values for the particular FORMAT pertaining to the array, then each card punched for this array except the last must contain the maximum number of values permissible. For example, if one wishes to read the channel lengths for 23 subwatersheds into array LC, one must punch 10 numbers into a first card, 10 numbers into a second card, and 3 numbers into a third card, as 10 numbers are the maximum allowed per card by the FORMAT pertaining to array LC.

The following discussion is devoted to a more detailed presentation of the input data as it appears on Table 1.

## BASIC DESIGN PARAMETERS

The basic design parameters for the program consist of a group of single valued variables, each listed by name on Table 1 and shown with its corresponding numerical value. A definition for each of the basic design parameters is given on Table 2. The definition for each of these variables should, for the most part,

## TABLE 1

## TABULATION OF INPUT DATA FOR FLOOD CONTROL PLANNING PROGRAM

BASIC DESIGN PARAMETERS (FORMAT 10F7.0)

| AQR | BDMAX | BDMIN | BW | COEFDM | CCY | CSM | CX | CIN | CBR |
|---|---|---|---|---|---|---|---|---|---|
| 1.15 | 10.0 | 4.0 | 64.0 | 0.052 | 60.0 | 1.15 | 0.45 | 900.0 | 15.0 |

| CRR | CLSF | CLMIN | DD | ESM | FM | FP | HMAX | IPP | MFP |
|---|---|---|---|---|---|---|---|---|---|
| 300.0 | 0.70 | 0.01 | 1.30 | 1.25 | 1.10 | 0.035 | 12.0 | 0.0 | 0.05 |

| MANNU | MANNT | MANNR | MIN | MCH | MTLCH | NIN | RPI | R | RWF |
|---|---|---|---|---|---|---|---|---|---|
| 0.030 | 0.016 | 0.012 | 0.005 | 0.015 | 0.01 | 6.0 | 0.08 | 0.03 | 1.0 |

| TIMST | TIME | TAW | VF | VLURST | VLAGST | VA | ZU | ZT | PF |
|---|---|---|---|---|---|---|---|---|---|
| 50.0 | 10.0 | 43.8 | 1.50 | 30000. | 180. | 1.645 | 1.5 | 1.0 | 1.0 |

| LF | SF |
|---|---|
| 1.0 | 1.0 |

| NID | NSTEMX | NDF | MW |
|---|---|---|---|
| 63 | 5 | 10 | 20 |

(These four values are to be punched on a separate card without decimals according to FORMAT 4I5)

LOGICAL CONTROL OPTIONS (FORMAT L5)

| UNC | PTF | LTF | STF | TRACE | CHECK |
|---|---|---|---|---|---|
| F | F | F | F | F | F |

ARRAY AFCTR (FORMAT 11F6.0)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 3.0 | 5.0 | 7.0 | 27.0 | 30.0 | 35.0 | 40.0 | 50.0 | 60.0 | 75.0 | (Area-sq. mi.) |
| 1.795 | 1.385 | 1.265 | 1.230 | 1.165 | 1.130 | 1.065 | 1.020 | 0.985 | 0.975 | 0.970 | (43% flood ratio) |
| 2.060 | 1.640 | 1.485 | 1.415 | 1.170 | 1.130 | 1.065 | 1.020 | 0.985 | 0.975 | 0.970 | (0.05% flood ratio) |

ARRAY D1 (FORMAT 7F8.0)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.00 | 0.01 | 0.05 | 0.10 | 0.25 | 0.50 | 0.75 | (Lower urban limit) |
| 0.01 | 0.05 | 0.10 | 0.25 | 0.50 | 0.75 | 1.00 | (Upper urban limit) |
| 45.40 | 45.20 | 45.00 | 42.50 | 33.20 | 18.80 | 12.00 | (Annual farm income-best soil) |
| 21.20 | 21.10 | 21.00 | 19.80 | 15.50 | 8.80 | 5.60 | (Annual farm income-medium soil) |
| 13.80 | 13.80 | 13.70 | 12.90 | 10.10 | 5.70 | 3.70 | (Annual farm income-worst soil) |
| 9.30 | 9.30 | 9.30 | 8.50 | 8.00 | 5.00 | 2.60 | (Damage by annual flood-best soil) |
| 10.70 | 10.70 | 10.70 | 9.90 | 9.30 | 4.80 | 2.90 | (Damage by annual flood-medium soil) |
| 8.80 | 8.80 | 8.80 | 8.20 | 7.10 | 3.80 | 2.40 | (Damage by annual flood-worst soil) |

ARRAY DF (FORMAT 10F7.0)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.43 | 0.20 | 0.15 | 0.10 | 0.06 | 0.04 | 0.03 | 0.02 | 0.01 | 0.005 |

ARRAY Q43 (FORMAT 10F7.0)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 605. | 675. | 760. | 825. | 900. | 975. | 1055. | 1130. | 1200. | 1290. | 1390. |
| 630. | 710. | 790. | 870. | 945. | 1020. | 1105. | 1180. | 1260. | 1345. | 1440. |
| 675. | 750. | 830. | 910. | 990. | 1070. | 1150. | 1230. | 1315. | 1400. | 1510. |
| 710. | 785. | 870. | 950. | 1040. | 1115. | 1200. | 1290. | 1375. | 1475. | 1575. |
| 735. | 825. | 910. | 1000. | 1085. | 1165. | 1265. | 1355. | 1450. | 1555. | 1650. |
| 760. | 860. | 955. | 1050. | 1140. | 1225. | 1330. | 1435. | 1535. | 1640. | 1730. |
| 810. | 900. | 1005. | 1100. | 1200. | 1305. | 1410. | 1530. | 1630. | 1740. | 1830. |
| 850. | 950. | 1060. | 1160. | 1280. | 1385. | 1515. | 1625. | 1740. | 1850. | 1960. |

```
  890.  1000.  1125.  1230.  1365.  1490.  1605.  1740.  1850.  1975.  2080.
  940.  1070.  1185.  1325.  1470.  1590.  1730.  1875.  2000.  2140.  2290.
 1000.  1140.  1200.  1440.  1590.  1710.  1880.  2050.  2225.  2450.  2750.
```

ARRAY Q05 (FORMAT 11F6.0)

```
 2350.  2480.  2590.  2720.  2850.  2975.  3120.  3230.  3380.  3540.  3740.
 2400.  2520.  2625.  2745.  2875.  2990.  3125.  3250.  3390.  3575.  3830.
 2740.  2560.  2660.  2785.  2900.  3025.  3160.  3280.  3425.  3660.  3925.
 2540.  2615.  2725.  2840.  2960.  3070.  3190.  3325.  3500.  3775.  4120.
 2610.  2700.  2800.  2925.  3025.  3130.  3260.  3410.  3630.  3910.  4120.
 2720.  2810.  2900.  3025.  3120.  3210.  3375.  3540.  3800.  4050.  4220.
 2840.  2925.  3030.  3130.  3225.  3350.  3500.  3710.  4010.  4220.  4375.
 2975.  3070.  3170.  3275.  3390.  3510.  3690.  3975.  4250.  4440.  4550.
 3180.  3270.  3370.  3490.  3600.  3760.  4050.  4200.  4560.  4690.  4980.
 3450.  3575.  3725.  3950.  4200.  4440.  4640.  4840.  4980.  5150.  5390.
 4300.  4450.  4650.  4900.  5100.  5300.  5500.  5700.  5900.  6220.  6500.
```

ARRAY A0 (FORMAT 10F7.0)

```
   0.0    0.0   20.0  280.0   80.0   20.0   27.0  300.0    0.0    0.0
   0.0   20.0    0.0   20.0    0.0  210.0   20.0  200.0  475.0 1000.0
```

ARRAY AW (FORMAT 10F7.0)

```
 33.16   1.76  37.23  38.91  39.82   1.50   6.09  50.08   6.04   6.90
 13.64  14.58   1.77   2.53   1.21   5.00   5.60   6.09  21.65  72.70
```

ARRAY CAP (FORMAT 8F8.0)

```
  6500.   5000.     10.     -1.     -1.     -1.     -1.     -1. (Subwatershed 1)
```

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 80. | 50. | 50. | 30. | 20. | 20. | -1. | -1. | (Subwatershed 2) |
| 3300. | 2800. | -1. | -1. | -1. | -1. | 12200. | -1. | (Subwatershed 3) |
| 4000. | -1. | -1. | -1. | -1. | -1. | 15000. | 2000. | (Subwatershed 4) |
| 8000. | 5000. | 5000. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 5) |
| 300. | -1. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 6) |
| 0. | 0. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 7) |
| 8600. | 8500. | 8400. | 8000. | 7100. | -1. | -1. | -1. | (Subwatershed 8) |
| 1400. | 1000. | 700. | 600. | 500. | 60. | 2500. | -1. | (Subwatershed 9) |
| 2000. | 1400. | 750. | 40. | -1. | -1. | 6000. | -1. | (Subwatershed 10) |
| 2600. | 10. | -1. | -1. | -1. | -1. | 7000. | -1. | (Subwatershed 11) |
| 5000. | 2800. | 2000. | 1800. | 30. | -1. | -1. | -1. | (Subwatershed 12) |
| 700. | 100. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 13) |
| 1100. | 500. | 450. | -1. | -1. | -1. | 2500. | -1. | (Subwatershed 14) |
| 0. | -1. | -1. | -1. | -1. | -1. | 0. | -1. | (Subwatershed 15) |
| 400. | -1. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 16) |
| 2000. | 1000. | 600. | 90. | -1. | -1. | -1. | -1. | (Subwatershed 17) |
| 3700. | 2000. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 18) |
| 7000. | -1. | -1. | -1. | -1. | -1. | -1. | -1. | (Subwatershed 19) |
| 8500. | -1. | -1. | -1. | -1. | -1. | 34000. | -1. | (Subwatershed 20) |

ARRAY D (FORMAT 6F8.0)

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 0.00 | 0.20 | 0.80 | (Subwatershed 1) | 0.00 | 0.40 | 0.60 | (Subwatershed 2) |
| 0.00 | 0.15 | 0.85 | (Subwatershed 3) | 0.00 | 1.00 | 0.00 | (Subwatershed 4) |
| 0.00 | 0.90 | 0.10 | (Subwatershed 5) | 0.00 | 1.00 | 0.00 | (Subwatershed 6) |
| 0.05 | 0.90 | 0.05 | (Subwatershed 7) | 0.00 | 0.75 | 0.25 | (Subwatershed 8) |
| 0.00 | 0.60 | 0.40 | (Subwatershed 9) | 0.00 | 0.80 | 0.20 | (Subwatershed 10) |
| 0.00 | 1.00 | 0.00 | (Subwatershed 11) | 0.00 | 0.90 | 0.10 | (Subwatershed 12) |
| 0.00 | 1.00 | 0.00 | (Subwatershed 13) | 0.00 | 1.00 | 0.00 | (Subwatershed 14) |
| 0.00 | 1.00 | 0.00 | (Subwatershed 15) | 0.00 | 1.00 | 0.00 | (Subwatershed 16) |
| 0.00 | 0.70 | 0.30 | (Subwatershed 17) | 0.00 | 0.20 | 0.80 | (Subwatershed 18) |
| 0.00 | 0.50 | 0.50 | (Subwatershed 19) | 0.00 | 0.50 | 0.00 | (Subwatershed 20) |

ARRAY FQ (FORMAT 10F7.0)

```
  1.0    1.0    1.0    1.0    1.0    1.0  0.687  0.955  0.7275   1.0
  1.0    1.0    1.0    1.0    1,0    1.0    1.0    1.0  0.8125   0.90
```

ARRAY INDEX (FORMAT 20I3)

```
(1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20-Subwatershed No.)
 1  6 11 15 18 20 22 24 25 29 33 36 38 44 49 54 58 61 63  0 (First Subscript)
 5 10 14 17 19 21 23 24 28 32 35 37 43 48 53 57 60 62 63  0 (Last Subscript)
```

ARRAY ID (FORMAT 20I3)

```
 3  4  5  8 20  3  4  5  8 20  4  5  8 20  5  8 20  8 20  8
20  8 20 20 11 12 19 20 11 12 19 20 12 19 20 19 20 14 16 17
18 19 20 16 17 18 19 20 16 17 18 19 20 17 18 19 20 18 19 20
19 20 20
```

ARRAY K1 (FORMAT 10F7.0)

```
 0.22   0.22   0.21   0.13   0.17   0.23   0.14   0.20   0.15   0.22
 0.11   0.19   0.22   0.21   0.23   0.19   0.19   0.31   0.22   0.21
```

ARRAY K2 (FORMAT 10F7.0)

```
 144.    54.   126.   242.   197.    15.   145.   177.   165.   128.
 112.   137.    37.    76.    25.    23.    26.    17.   104.   115.
```

ARRAY LC (FORMAT 10F7.0)

```
  2.5    1.7    1.6    1.3    2.3    1.3    3.0    1,7    3.9    4.4
  1.5    2.0    1.2    1.4    0.8    0.8    0.9    1.0    2.0    2.1
```

ARRAY LINING (FORMAT 20I3)

```
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
```

ARRAY Q0 (FORMAT 10F7.0)

```
   200.    25.   100.   920.   300.   100.   150.  1360.    40.    40.
    50.   100.    30.   100.     0.   940.   100.   940.  2280.    45.
```

ARRAY S (FORMAT 10F7.0)

```
 0.0012 0.0017 0.0009 0.0006 0.0009 0.0010 0.0008 0.0008 0.0012 0.0016
 0.0009 0.0015 0.0013 0.0014 0.0017 0.0006 0.0013 0.0005 0.0005 0.0004
```

ARRAY SUBA (FORMAT 10F7.0)

```
   3.38   1.76   2.31   1.68   0.91   1.50   6.09   2.67   3.87   3.13
   0.70   0.94   1.77   0.76   1.21   1.26   0.60   0.49   0.98   0.97
```

ARRAY SIC (FORMAT 10F7.0)

```
    0.0    0.0    0.0    1.3    0.9    0.7    0.0    1.2    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.8    0.0    1.0    2.0    2.1
```

ARRAY TCL (FORMAT 10F7.0)

```
   28.5    1.7   31.8   33.1   35.4    1.3    3.0   41.4    3.9    6.3
   11.7   13.7    1.2    2.6    0.8    4.2    5.1    6.1   21.8   65.3
```

ARRAY TF (FORMAT 10F7.0)

```
    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
```

```
  1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
```

<u>ARRAY TIC</u> (FORMAT 10F7.0)

```
  3.2    0.0    3.2    4.5    5.4    0.7    0.0    7.3    0.0    0.0
  0.0    0.0    0.0    0.0    0.0    0.8    0.8    1.8    3.9   13.2
```

<u>ARRAY USUBW</u> (FORMAT 6F8.0)

```
  0.00    0.01    0.04    0.15    0.45    0.75   (Subwatershed 1)
  0.02    0.04    0.15    0.55    0.80    0.90   (Subwatershed 2)
  0.08    0.20    0.55    0.80    0.90    1.00   (Subwatershed 3)
  0.59    0.80    0.90    0.95    1.00    1.00   (Subwatershed 4)
  0.36    0.80    0.95    1.00    1.00    1.00   (Subwatershed 5)
  0.24    0.65    0.90    1.00    1.00    1.00   (Subwatershed 6)
  0.78    0.91    1.00    1.00    1.00    1.00   (Subwatershed 7)
  0.56    0.70    0.90    1.00    1.00    1.00   (Subwatershed 8)
  0.01    0.03    0.07    0.12    0.30    0.45   (Subwatershed 9)
  0.01    0.04    0.09    0.15    0.35    0.55   (Subwatershed 10)
  0.02    0.35    0.65    0.80    0.85    1.00   (Subwatershed 11)
  0.07    0.40    0.75    0.85    1.00    1.00   (Subwatershed 12)
  0.04    0.20    0.50    0.75    0.85    0.95   (Subwatershed 13)
  0.27    0.55    0.80    0.95    1.00    1.00   (Subwatershed 14)
  0.20    0.45    0.70    0.85    0.95    1.00   (Subwatershed 15)
  0.30    0.50    0.75    0.95    1.00    1.00   (Subwatershed 16)
  0.24    0.60    0.80    0.95    1.00    1.00   (Subwatershed 17)
  0.50    0.60    0.70    0.85    1.00    1.00   (Subwatershed 18)
  0.00    0.30    0.60    0.80    1.00    1.00   (Subwatershed 19)
  0.14    0.30    0.50    0.75    1.00    1.00   (Subwatershed 20)
```

ARRAY UTOTR (FORMAT 6F8.0)

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.08 | 0.08 | 0.09 | 0.15 | 0.27 | 0.43 | (Subwatershed 1) |
| 0.02 | 0.04 | 0.15 | 0.55 | 0.80 | 0.90 | (Subwatershed 2) |
| 0.07 | 0.08 | 0.12 | 0.21 | 0.33 | 0.49 | (Subwatershed 3) |
| 0.10 | 0.12 | 0.16 | 0.24 | 0.36 | 0.52 | (Subwatershed 4) |
| 0.10 | 0.13 | 0.18 | 0.26 | 0.38 | 0.53 | (Subwatershed 5) |
| 0.24 | 0.65 | 0.90 | 1.00 | 1.00 | 1.00 | (Subwatershed 6) |
| 0.78 | 0.91 | 1.00 | 1.00 | 1.00 | 1.00 | (Subwatershed 7) |
| 0.21 | 0.27 | 0.34 | 0.41 | 0.51 | 0.62 | (Subwatershed 8) |
| 0.01 | 0.03 | 0.07 | 0.12 | 0.30 | 0.45 | (Subwatershed 9) |
| 0.00 | 0.02 | 0.05 | 0.08 | 0.18 | 1.35 | (Subwatershed 10) |
| 0.01 | 0.04 | 0.09 | 0.13 | 0.27 | 0.42 | (Subwatershed 11) |
| 0.01 | 0.06 | 0.14 | 0.18 | 0.30 | 0.46 | (Subwatershed 12) |
| 0.04 | 0.20 | 0.50 | 0.75 | 0.85 | 0.95 | (Subwatershed 13) |
| 0.11 | 0.31 | 0.59 | 0.81 | 0.90 | 0.97 | (Subwatershed 14) |
| 0.20 | 0.45 | 0.70 | 0.85 | 0.95 | 1.00 | (Subwatershed 15) |
| 0.18 | 0.39 | 0.66 | 0.86 | 0.94 | 0.98 | (Subwatershed 16) |
| 0.19 | 0.41 | 0.67 | 0.87 | 0.94 | 0.98 | (Subwatershed 17) |
| 0.21 | 0.43 | 0.68 | 0.86 | 0.95 | 0.99 | (Subwatershed 18) |
| 0.07 | 0.18 | 0.31 | 0.40 | 0.52 | 0.63 | (Subwatershed 19) |
| 0.17 | 0.24 | 0.33 | 0.41 | 0.52 | 0.63 | (Subwatershed 20) |

ARRAY VALUE (FORMAT 6F8.0)

| | | | | | | |
|---|---|---|---|---|---|---|
| 840. | 990. | 1600. | 3740. | 6350. | 10425. | (Subwatershed 1) |
| 1040. | 1790. | 3670. | 8490. | 12080. | 15200. | (Subwatershed 2) |
| 2030. | 5140. | 7340. | 11380. | 14570. | 17030. | (Subwatershed 3) |
| 6000. | 10850. | 14100. | 16800. | 17700. | 18500. | (Subwatershed 4) |
| 7810. | 12350. | 15850. | 17350. | 18200. | 18500. | (Subwatershed 5) |
| 6450. | 10400. | 15500. | 17200. | 18300. | 18500. | (Subwatershed 6) |

```
 11830.   14900.    17050.    17950.    18480.     18500.   (Subwatershed 7)
  6690.    9430.    12800.    14850.    17650.     18300.   (Subwatershed 8)
   830.     950.     1180.     1980.     3560.      6670.   (Subwatershed 9)
   810.    1020.     1650.     3030.     5150.      8730.   (Subwatershed 10)
  1800.    5120.     7950.    11600.    14400.     17000.   (Subwatershed 11)
  2640.    6080.    10680.    13650.    16700.     17900.   (Subwatershed 12)
  1680.    4360.     6810.    10890.    13930.     16130.   (Subwatershed 13)
  2900.    7760.    12250.    15150.    17000.     18100.   (Subwatershed 14)
  2310.    6190.     9780.    13100.    15700.     17550.   (Subwatershed 15)
  4580.    7460.    12900.    15500.    17700.     18300.   (Subwatershed 16)
  4910.    7670.    12000.    14400.    17200.     18100.   (Subwatershed 17)
  5310.    7570.    11350.    13750.    17200.     18100.   (Subwatershed 18)
  2420.    4910.     7850.    11400.    15300.     17200.   (Subwatershed 19)
  4120.    5800.     8980.    11430.     1605.     17650.   (Subwatershed 20)
```

<u>ARRAY WO</u> (FORMAT 10F7.0)

```
  0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
  0.0    0.0    0.0    0.0    0.0   84.0    0.0   90.0  106.0  118.0
```

## TABLE 2

## DEFINITION OF BASIC DESIGN PARAMETERS USED IN FLOOD CONTROL PLANNING PROGRAM

| Name | Description |
|---|---|
| AQR | Factor multiplied by right-of-way cost to include cost of acquisition. |
| BDMAX | Maximum ratio of bottom width to depth allowed in channel design. |
| BDMIN | Minimum ratio of bottom width to depth allowed in channel design. |
| BW | Required highway bridge width in feet. |
| COEFDM | Urban flood damage per foot of flood depth per dollar of building market value. |
| CCY | Cost of in place structural concrete used for channel lining in dollars per cubic yard. |
| CSM | Factor multiplied by channel construction cost to account for contingencies. |
| CX | Unit cost of channel excavation in dollars per cubic yard. |
| CIN | Cost per drainage inlet in dollars. |
| CBR | Unit cost for highway bridges in dollars per square foot. |
| CRR | Unit cost for railroad bridges in dollars per linear foot. |
| CLSF | Unit cost of trapezoidal lining in dollars per square foot. |

TABLE 2--Continued

| Name | Description |
|---|---|
| CLMIN | Minimum annual cost per acre of location alternative in dollars. |
| ESM | Factor multiplied by channel construction cost to account for design, administration, and supervision of construction. |
| FM | Factor multiplied by channel excavation cost to account for riprap and seeding. |
| FP | Cost of flood proofing per foot of design flood depth per dollar of building market value. |
| HMAX | Maximum channel design depth in feet. |
| IPP | Annual value received from the ammenities of open space expressed as a multiple of the fraction of adjacent land being urban. |
| MFP | Annual maintenance cost of flood proofing measures as a function of first cost. |
| MANNU | Value of Manning's n for prismatic unlined channels. |
| MANNT | Value of Manning's n for trapeziodal lined channels. |
| MANNR | Value of Manning's n for rectangular lined channels. |
| MIN | Annual maintenance cost of concrete structures as a fraction of first cost. |
| MCH | Annual maintenance cost of earth channels as a fraction of first cost. |
| MTLCH | Annual maintenance cost of trapezoidal lined channels as a fraction of first cost. |

TABLE 2--Continued

| Name | Description |
|---|---|
| NIN | Number of inlets required per mile of channel. |
| RPI | Rate of return required by private investors in land. |
| R | Discount rate used in project planning. |
| RWF | Multiple of right-of-way cost to be used in planning. |
| TIMST | Design life of improved channels in years. |
| TIME | Duration of planning stage in years. |
| TAW | Area in square miles of watershed studied to relate urbanization, channelization, and flood peak. |
| VF | Ratio of area requiring flood proofing to that innundated by the design flood. |
| VLURST | Value of buildings in dollars per urbanized acre. |
| VLAGST | Value of buildings in dollars per rural acre. |
| VA | The normal deviate to be used in calculating uncertainty costs. |
| ZU | Slide slope of unlined prismatic channels. |
| ZT | Slide slope of trapezoidal lined channels. |
| PF | Multiple of flood proofing cost to be used in planning. |
| LF | Multiple of land use cost to be used in planning. |
| SF | Multiple of channelization cost to be used in planning. |

TABLE 2--Continued

| Name | Description |
|---|---|
| NID | Number of items in array ID. |
| NSTEMX | Number of stages to be analyzed. |
| NDF | Number of design flood frequencies to be considered in analysis. |
| MW | Number of subwatersheds to be analyzed. |

serve to explain their use in the program. In general, the basic design parameters describe unit cost values, interest rates, design time periods, parameters associated with channel dimensions, statistical parameters, and multipliers used to test the sensitivity of the optimum "mix" of flood control measures to changes in various factors of input.

## LOGICAL CONTROL OPTIONS

The control options are logical type variables which may be read into the program as being either TRUE or FALSE as desired. The function of each option is described on Table 3.

TABLE 3

LOGICAL CONTROL PARAMETERS
USED IN FLOOD CONTROL PLANNING PROGRAM

| Name | Description of Use |
|---|---|
| UNC | Set TRUE to calculate flood damage as including damage based on Thomas uncertainty fund (12). |
| PTF | Set TRUE to eliminate flood proofing from consideration in planning. |
| STF | Set TRUE to eliminate channel improvement from consideration in planning. |
| LTF | Set TRUE to eliminate land use measures from consideration in planning. |
| TRACE | Set TRUE for printout tracing computation loops entered in comparing alternatives. |
| CHECK | Set TRUE to have intermediate output printed each time a new alternative is found to be less costly than any considered previously. |

## ARRAY AFCTR

The values in this array are multipliers used to relate to drainage area the magnitude of the 43% flood peak (mean annual flood) and the 0.05% flood peak (200-year flood). A multiplier of 1.00 applies to a drainage area of TAW sq. mi. Refering to Table 1, the first row of values for AFCTR is the area of the subwatershed in sq. mi. corresponding to the multipliers in rows two and three of the array. The program interpolates intermediate values. Values to be used in the array may be estimated by use of the Stanford Watershed Model, (8, pp. 176-198). Because agricultural income varies with soil productivity and because open land in urban areas tends to be less extensively farmed than equivelent land in the open country, it is necessary to include both factors in evaluating agricultural flood damages.

## ARRAY DI

This array relates crop income and flood damage by up to 3 soil types and up to 7 intervals expressing the amount of urbanization in a subwatershed. The program locates the proper position in the array from which values of income and damage are selected by determining which urban interval matches that in the subwatershed under consideration. The array is filled by analysis of soils maps, land use maps, and farm income and farm flood damage statistics.

### ARRAY DF

This array contains, in decimal form, the flood frequencies corresponding to the levels of protection that one wishes to consider for both structural and nonstructural flood control measures. The program will consider every combination of channel improvements, flood proofing, and land use measures for the frequencies listed. The values begin with the smallest potential design flood with the following floods being progressively larger. This array may contain a maximum of ten selected design frequencies.

### ARRAY Q43

This array contains the magnitude of the mean annual flood TAW sq. mi. as a function of tributary channelization and tributary urbanization. The information contained in this array is combined by the computer with the information in array AFCTR to develop the magnitude of the mean annual flood for each subwatershed. The program will interpolate arithmetically intermediate values of urbanization and channelization. For more specific information describing how these relationships were developed refer to the work by James (8, pp. 69-80).

### ARRAY Q05

This array is identical to array Q43 except that the values contained in Q05 pertain to the 200-year flood rather than the mean annual flood.

## ARRAY A0

This array contains the average cross-sectional area in sq. ft. for the channel in each subwatershed, taken perpendicularly to the direction of flow.

## ARRAY AW

This array contains the total area that is tributary to the downstream end of each subwatershed, in sq. mi.

## ARRAY CAP

This array contains information relating the number and capacity of highway and railroad bridges in each subwatershed. The data is arranged on cards in such a manner that each card contains the information for one subwatershed. The array dimension and the input FORMAT for this array allows for a maximum of six highway bridges and two railroad bridges per subwatershed. The first six columns of each card contain the capacity of each existing highway bridge in cfs., arranged in descending order with regard to capacity. The last two columns of each card contain the capacity of each existing railroad bridge in cfs., also arranged in descending order. All unused columns must be punched to contain a minus one (-1.) as shown on Table 1. It should be noted that CAP is dimensioned to have 11 rows, however, only the first 8 rows are to be used for input; the rows from 9 through 11 are used during program operation and may not be used for input data storage.

## ARRAY D

This array contains information dividing the area within each subwatershed flood plain into three soil classifications, namely (A) best, (B) medium, and (C) worst soil, according to agricultural productivity as determined from soils maps. The data is punched with the information for two subwatersheds per card. For example, the first card in the array as shown on Table 1 indicates that subwatershed one contains 0% of the best soil type, 20% of the medium soil type, and 80% of the worst soil type, and that subwatershed two contains 0% of the best soil type, 40% of the medium soil type, and 60% of the worst soil type. For a more complete description of the soil classification used for the Morrison Creek area refer to James (8, p. 90 and Table 8).

## ARRAY FQ

This array contains a factor for each subwatershed describing the average design flow for channel improvements as a function of the flow at the mouth of the channel. If the entire subwatershed channel has the same design flow, the value of the factor is 1. If some of the channels in the subwatershed may be designed for less than the design flow required at the subwatershed mouth, this factor has a value less than 1.

## ARRAYS INDEX AND ID

Array INDEX serves as an index to the values stored in array ID. Array ID contains for every subwatershed the identifying numbers of all downstream subwatersheds. This information is used in the program as an aid to calculating the effects of upstream channel improvements on downstream flood peaks. Array INDEX lists the subscript values which locate the information stored in ID. For example, (Fig. 1) it can be seen that the first value of INDEX is a 1 while the second value is a 5. This means that the first through the fifth numbers stored in ID, namely 3, 4, 5, 8, and 20 are the identifying numbers of the subwatersheds downstream to subwatershed 1. Further, since the second set of numbers in INDEX are 6 and 10, the sixth through the tenth numbers stored in ID, namely 3, 4, 5, 8, and 20, are the identifying numbers of the subwatersheds downstream from subwatershed 2. This procedure continues until the last subwatershed has been reached, for which zeros must be stored in INDEX since the last subwatershed has no downstream subwatersheds, as far as the program is concerned.

## ARRAY K1

This array contains for each subwatershed the ratio of the maximum depth of flooding anywhere in the flood-plain to the corresponding flood flow in excess of the channel capacity to the 0.375 power. This ratio was developed for the Morrison Creek area from subwatershed data on maximum depth of flooding during specific historical floods.

## ARRAY K2

This array contains for each subwatershed the ratio of acres flooded to the corresponding maximum flooding depth, and was also estimated from historical flood data.

## ARRAY LC

This array contains the channel length within each subwatershed in miles.

## ARRAY LINING

One value must be punched for each subwatershed. This value may be 0, 1, 2, 3, or 4 as explained below.

If one wishes to consider all types of channel improvement within the scope of the program, LINING should be punched as 0. In this case the program will select in evaluating channelization whatever type of channel is least expensive. Once the program determines that a specific type of channel improvement should be constructed during one stage it will set LINING equal to the appropriate number for subsequent stages. The type selected will be indicated in the output produced by the program.

If LINING is punched as 1, the program will not evaluate channel lining. In this case, the program will consider building or enlarging unlined channels. If the program determines that drop structures are needed to control erosion, it will automatically set LINING equal to 2.

If LINING is punched as 2 the program assumes that there is an existing unlined prismatic channel with drop structures. In this case the program will consider enlarging both the channel and drop structures.

If the subwatershed channel is currently trapezoidal and lined with unreinforced concrete, or if the channel is currently unimproved and one wishes to consider only building trapezoidal lined channels, LINING should be punched as 3.

If LINING is punched as 4, the program will consider only reinforced concrete lined rectangular channels and will either construct or enlarge only lined rectangular channels.

### ARRAY Q0

This array contains the existing channel capacity in cfs for each subwatershed.

### ARRAY S

This array contains a value describing the average longitudinal channel slope for each subwatershed, punched as a decimal.

### ARRAY SUBA

This array contains the drainage area within each subwatershed in square miles.

### ARRAY SIC

This array contains the channel length within each subwatershed in miles which was improved prior to the beginning of optimization calculations by the flood control planning program.

### ARRAY TCL

This array contains the total length of channel tributary to the downstream end of each subwatershed, in miles.

### ARRAY TF

This array contains the maximum allowable tractive force for each subwatershed, in pounds per square feet as determined from analysis of local soils.

### ARRAY TIC

This array contains the total initial length of improved channel tributary to the downstream end of each subwatershed, in miles.

### ARRAY USUBW

This array contains the percentage of each subwatershed in urban land use. Figures are given for the beginning and end of each stage. (i.e. NSTAGE + 1 values for each subwatershed) Values are punched as decimals.

### ARRAY UTOTR

This array contains the percentage of the total area tributary to each subwatershed in urban land use. (Otherwise analogus to USUBW)

### ARRAY VALUE

This array contains the current and projected market value of land, in dollars per acre, for each subwatershed. Figures are given for the beginning and end of each stage.

ARRAY WO

This array contains the initial channel right-of-way width for each subwatershed, in feet.

## OUTPUT

The information printed by the program is arranged into a group of tables which provide concise listings describing the most relevant features of the optimum "mix" of measures and residual flooding. With very slight alterations to the planning program, considerable more detailed output could be provided. However for the purposes of this study sufficient output was produced by the program at its current stage of development.

The basic output produced by the program is as shown on Table 4 and is printed at the end of each design stage. This table summarizes for each subwatershed, the frequency at which flooding begins; the design frequency, the design flow, and the cost of applying the optimum level of each of the three measures; the cost of residual flooding; the cost of uncertainty (zero if UNC is read as FALSE); and the total cost of measures and residual flooding. All costs are discounted annual values.

Also, at the end of each stage, a summary of each type of flood control measure implemented during the stage is provided. Typical examples of this summary for channel improvement, land use measures, and flood proofing measures are shown on

## TABLE 4

## BASIC OUTPUT FROM FLOOD CONTROL PLANNING PROGRAM

SUMMARY FOR STAGE 1

SUMMARY OF MEASURES AND COSTS

| UNIT | FREQ | CHANNELS | | | LAND USE | | | PROOFING | | | FLOOD | UNCERTAINTY | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | QS | CS | % | QL | CL. | % | QP | CP | COST | COST | COST |
| 1 | 84.26 | 0.0 | 200. | 0. | 0.0 | 0. | 0. | 6.0 | 1269. | 949. | 5333. | 0. | 6282. |
| 2 | 60.62 | 0.0 | 25. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 814. | 0. | 814. |
| 3 | 92.13 | 4.0 | 1519. | 6367. | 0.5 | 2230. | 3. | 3.0 | 1618. | 2394. | 1046. | 0. | 9811. |
| 4 | 25.02 | 0.5 | 2342. | 21084. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 21084. |
| 5 | 82.52 | 0.5 | 2408. | 21428. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 21428. |
| 6 | 17.03 | 0.0 | 100. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 549. | 0. | 549. |
| 7 | 65.05 | 2.0 | 970. | 31509. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 1476. | 0. | 32985. |
| 8 | 23.15 | 0.5 | 3143. | 16066. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 16066. |
| 9 | 73.03 | 0.0 | 40. | 0. | 0.0 | 0. | 0. | 6.0 | 278. | 712. | 1646. | 0. | 2358. |
| 10 | 75.01 | 0.0 | 40. | 0. | 0.0 | 0. | 0. | 6.0 | 309. | 1606. | 2663. | 0. | 4269. |
| 11 | 83.80 | 0.0 | 50. | 0. | 0.5 | 959. | 2. | 6.0 | 571. | 506. | 1252. | 0. | 1769. |
| 12 | 75.27 | 6.0 | 634. | 6448. | 0.5 | 1052. | 3. | 0.0 | 0. | 0. | 816. | 0. | 7267. |
| 13 | 59.07 | 0.0 | 30. | 0. | 0.5 | 185. | 1. | 0.0 | 0. | 0. | 684. | 0. | 684. |
| 14 | 20.07 | 0.0 | 100. | 0. | 0.5 | 255. | 1. | 0.0 | 0. | 0. | 2298. | 0. | 2299. |
| 15 | 95.45 | 0.0 | 0. | 0. | 0.5 | 150. | 1. | 4.0 | 101. | 1441. | 844. | 0. | 2285. |
| 16 | 0.00 | 0.0 | 940. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 0. |
| 17 | 60.89 | 4.0 | 364. | 4287. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 281. | 0. | 4567. |
| 18 | 0.00 | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 0. |
| 19 | 0.00 | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 0. |
| 20 | 0.00 | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0.0 | 0. | 0. | 0. | 0. | 0. |
| TOTAL COST | | | | 107189. | | | 10. | | | 7609. | 19700. | 0. | 134508. |

Tables 5, 6, and 7, respectively.

At the end of the final planning stage the program computes discounted average annual costs for each type of flood control measure, uncertainty costs, cost of residual flooding, and total cost of flooding and prints the results of these calculations in the form shown on Table 8.

In addition to the above output which is always printed by the program, it is possible through the logical control variables described on Table 3 to obtain additional supplementary information. The variable TRACE can be used to follow the movement of the optimization calculations through the main portion of the computer program. The output printed through the use of this variable lists the number of the subwatershed being considered, and each time the program control passes through a major computational loop, indicates the combination of flood proofing, location measures, and channel improvements being considered in that loop. This output makes it possible to follow the progress of program computations. The variable CHECK can be used to print out measures which at some time during the computational loop, were found to be less costly than any measure considered theretofore but did not end up as the optimum selection for the stage under consideration. The program prints this information in the order that the measures are considered in a form similar to that shown on Table 4. This option

## TABLE 5

## SUPPLEMENTARY OUTPUT PERTAINING TO CHANNEL IMPROVEMENTS

### SUMMARY OF CHANNEL IMPROVEMENTS

| UNIT | TYPE OF CHANNEL | CURRENT MEASURE | CAPACITY CFS. | X-SECTION AREA SQ. FT. | TOP WIDTH FT. | ROW WIDTH FT. | DEPTH FT. |
|---|---|---|---|---|---|---|---|
| 3 | UNLINED W/O DROPS | BUILT | 1519. | 324.9 | 53.8 | 88.4 | 7.7 |
| 4 | UNLINED W/O DROPS | ENLARGED | 2342. | 535.5 | 68.3 | 104.1 | 9.8 |
| 5 | UNLINED W/O DROPS | BUILT | 2408. | 459.1 | 64.0 | 99.5 | 9.1 |
| 7 | UNLINED W/O DROPS | BUILT | 970. | 183.1 | 40.4 | 73.9 | 5.8 |
| 8 | UNLINED W/O DROPS | BUILT | 3143. | 566.1 | 71.0 | 107.1 | 10.1 |
| 12 | UNLINED W/O DROPS | BUILT | 634. | 139.4 | 35.2 | 68.3 | 5.0 |
| 16 | UNLINED W/O DROPS | UNCHANGED | 940. | 210.0 | 48.5 | 84.0 | 5.2 |
| 17 | UNLINED W/O DROPS | BUILT | 364. | 96.9 | 29.4 | 61.9 | 4.2 |
| 20 | UNLINED W/O DROPS | UNCHANGED | 4500. | 1000.0 | 105.7 | 118.0 | 11.3 |

TABLE 5--Continued

| DROP STRUCTURES | | HIGHWAY BRIDGES | | | RAILWAY BRIDGES | | |
|---|---|---|---|---|---|---|---|
| NUMBER | HEIGHT FT. | SAME | BUILT | EXTEND | SAME | BUILT | EXTEND |
| 0 | 0.0 | 2 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0.0 | 1 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0.0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 5 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 4 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 3 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0.0 | 1 | 0 | 0 | 1 | 0 | 0 |

## TABLE 6

## SUPPLEMENTARY OUTPUT PERTAINING TO LAND USE MEASURES

SUMMARY OF LAND USE MEASURES

| UNIT | AREA OF RESTRICTED LAND USE |
|---|---|
| 11 | 86. ACRES |
| 12 | 128. ACRES |
| 13 | 20. ACRES |
| 14 | 29. ACRES |
| 15 | 21. ACRES |

## TABLE 7

## SUPPLEMENTARY OUTPUT PERTAINING TO FLOOD PROOFING MEASURES

SUMMARY OF FLOOD PROOFING MEASURES

| UNIT | AREA PROTECTED |
|---|---|
| 1 | 484. ACRES |
| 2 | 66. ACRES |
| 9 | 208. ACRES |
| 10 | 257. ACRES |
| 11 | 143. ACRES |
| 13 | 45. ACRES |
| 15 | 33. ACRES |

## TABLE 8

## SUPPLEMENTARY OUTPUT PERTAINING TO DISCOUNTED COSTS

| AVERAGE ANNUAL COST OVER ALL STAGES | |
|---|---|
| ITEM | DOLLARS / YEAR |
| COST OF CHANNEL IMPROVEMENT | 1769. |
| COST OF LAND USE | 522. |
| COST OF FLOOD PROOFING | 736. |
| COST OF RESIDUAL FLOODING | 149. |
| COST OF UNCERTAINTY | 0. |
| TOTAL COST | 3177. |

can be used to examine the relative advantage of one flood control measure over another, thus enabling the user to better judge the sensitivity of the optimum project to changes in input variables.

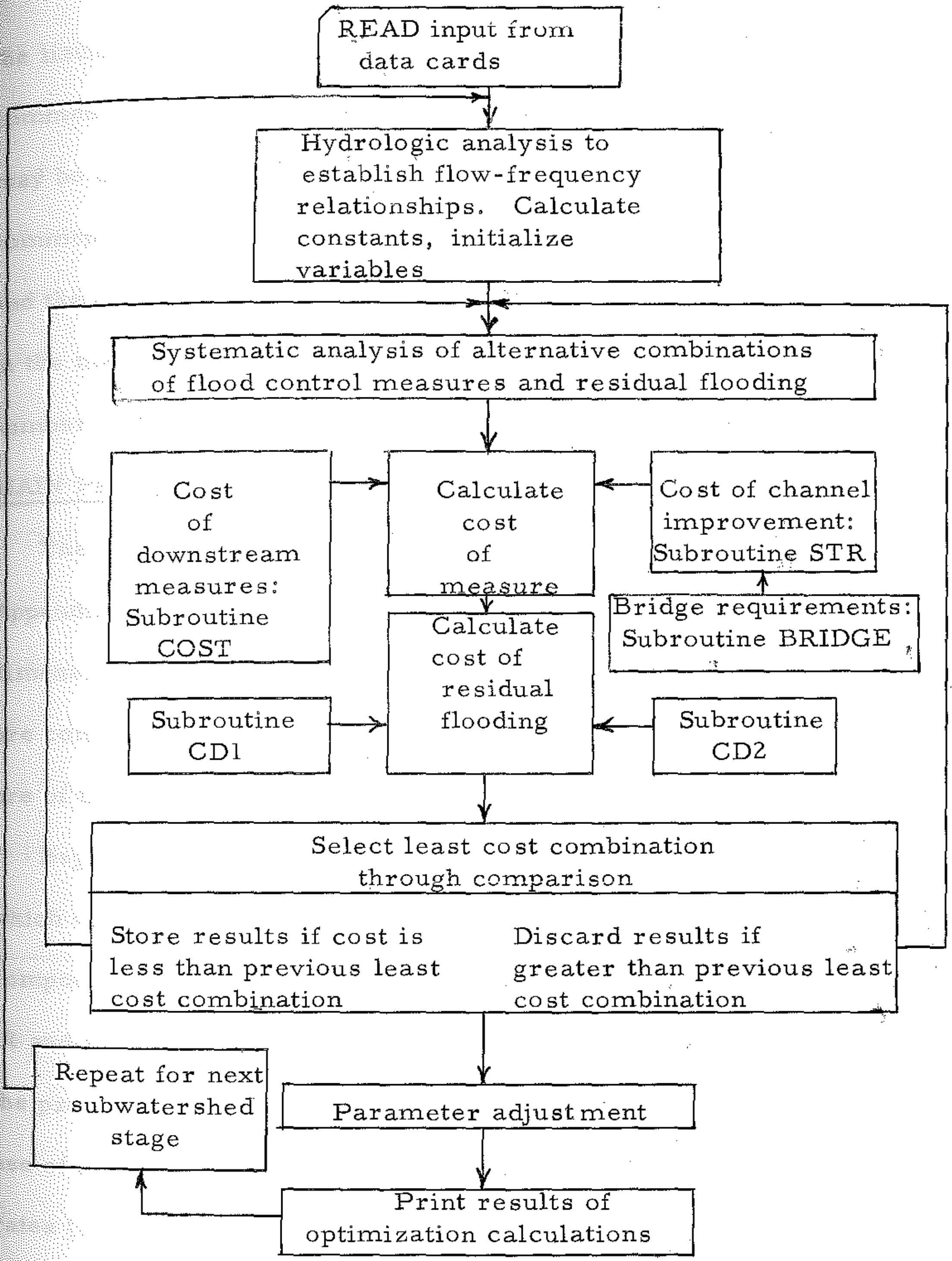
## Chapter III

## PROGRAM FEATURES: FLOW CHART AND DISCUSSION

This chapter is devoted to a discussion of the mechanical features of the flood control planning program. The program has been written into a generalized form so that it may be modified and improved as the necessity arises. The main program controls the overall operation, while more laborious calculations are performed within various subroutines. Thus individual operations may be added or modified with subroutines while the main program remains essentially undisturbed.

It is hoped that this chapter presents sufficient detail to enable the reader to understand the methods of computation used in the flood control planning program. Because of the length and complexity of the program, a detailed flow chart of each operation is not presented. It was felt that a lengthy flow chart would tend to confuse rather than clarify the program. Instead, a schematic of the entire operation is presented on Figure 2.

A complete listing of the Fortran IV program can be found in Appendix I of this thesis. The Fortran listing is liberally annotated with comment cards so that the reader may correlate



SCHEMATIC REPRESENTATION OF THE FLOOD CONTROL PLANNING PROGRAM

Figure 2

the listing with the description given in this chapter. Certain comment cards have been numbered so that convenient reference may be made to segments of the Fortran listing. Each numbered comment card applies to all of the Fortran statements between it and the next numbered comment. The numbered comment cards in the main program and in each subroutine begin with the number 1 and are numbered consecutively.

## MAIN PROGRAM

The main program is labeled DK001 in the Fortran listing in Appendix I. It begins with type declarations which set the dimensions of subscripted variables, identify the variables which are common to all routines, and declare which of the variables are of the INTEGER or LOGICAL type.

Beginning with Comment 2, the program initializes factors which will remain constant throughout the program. First of all, compound interest factors are calculated based on discount rates (R and RPI) and discounting periods (TIME and TIMST) read into the program. The discounting factors are calculated through the use of standard formulas except in the case of very low discount rates (less than 0.01%) when simplified formulas are used. Next, the factors (SK1 through SK8) used in computing the cost of channel improvement are calculated and then the factor (CPF) used in computing the cost of flood proofing. Then the program calculates a group of factors (AFW) later used to relate the magnitude of the 43% flood peak and the 0.5% flood peak in cubic feet per second per square mile for TAW square miles to the magnitude of the same peaks for the area of an individaul subwatershed. The relation between these peaks was established by James (8, Fig. 4) and presented as a curve. The program has several coordinates selected from this curve stored in array AFCTR and interpolates the proper value of the area factor for each subwatershed. Next, the program initializes the value of several arrays used later in the program. These are XF4, XF3, XF2, XF1, A4, A3, A2, A1, LOC, T0, ADDCS, OUTPUT, and CAP. These will be discussed more fully as they are employed in calculations.

The program then calculates values of the "reduced variate" for use in Gumbel Equation (14, p. 251). The value of the reduced variate is given by the following equation:

$$P = e^{-e^{-y}} \qquad (2)$$

Where P is the frequency of nonoccurrence of a given hydrologic event, expressed as a decimal; e is the base of natural logarithms; and y is the reduced variate. Solving this relationship for y gives

$$y = \ln\left(\frac{1}{\ln\left(\frac{1}{P}\right)}\right) \tag{3}$$

Using Equation 3 the program calculates values of the reduced variate for each frequency of occurrence from 1/2% through 99 1/2% and for each frequency corresponding to the design peaks specified by array DF. Then the program investigates the state of improvement for each subwatershed channel prior to the beginning of the planning period. If the length of the subwatershed improved channel (SIC) is equal to the length of channel (LC) in the subwatershed the program sets CHANEL(NW) equal to TRUE and determines the top width of the channel through an iterative solution of the Manning equation. If the subwatershed channel is less than fully improved, CHANEL(NW) is set equal to FALSE. Finally, initial conditions are established for several variables and logical parameters.

Comment 3 indicates the entry and return point for calculations pertaining to each stage. As each planning stage is optimized the program returns control to this point and repeats calculations until all stages have been optimized. Between Comment 3 and Comment 4 the program initializes the variables that must be reset at the beginning of each stage.

After Comment 4, the program begins selecting the optimum flood control plan for the most upstream subwatershed and later returns to this point to repeat the calculations for the other subwatersheds. First, the discounted average annual subwatershed urbanization (UN) is calculated for the stage. If land use adjustment has been implemented (indicated by LOC(NW) greater than zero) the program sets UZ equal to the level of urbanization present at the time land use adjustment was initiated.

Next, factors for computing the cost of flood proofing are determined, based on UN and UZ. Then, the program calculates the agricultural income(IA) expected per acre in a year when flooding does not occur and the damage (FA) expected per acre in a year when the crop is flooded. These are based on the amount of crops normally grown in an area having the urbanization determined above (8, Appendix B).

The cost of land use (CLU) in dollars per acre is calculated (8, p.122) and from it a factor (LA) for estimating measure cost.

At this point, beginning with Comment 5, the relationship between flood peak and frequency for the subwatershed under consideration is analyzed. Separate relationships are established for the combination of urbanization and channelization existing at the beginning and at the end of the planning stage. If the channel is unimproved, the relationship is developed for both unimproved and improved conditions so that "with" and "without" comparisons can be made. Based on the percentage of upstream channelization (C) and tributary urbanization (U), the program interpolates from arrays Q43 and QO5, the magnitude of the 43% and 0.5% peak flow, respectively, for an area corresponding to TAW square miles. Then, using the area factors calculated earlier, peak flows QXX and QY, corresponding to the 43% and 0.5% peaks for the area of the subwatershed (AW) are determined. Next, using the Gumbel Analysis (14, p. 251) peak flows can be calculated for any frequency of occurrence. Mathematically,

$$Y = A(X - XF) \qquad (4)$$

where Y is the reduced variate corresponding to the frequency of occurrence of an event of magnitude X; XF represents the mode of the distribution; and A is the dispersion parameter of the sample. Assuming a Gumbel distribution for our flood peaks, we can take the magnitude of the 43% and 0.5% peaks calculated above and their corresponding reduced variates and solve simultaneous equations for A and XF, thereby enabling us to calculate the peak for any other return period. Taking

$$Y43 = A(QXX - XF)$$

and $$Y05 = A(QY - XF)$$

yields $$XF = ((QY * Y43) - (QXX * Y05))/(Y43 - Y05)$$

and $$A = (Y05 - Y43) / (QY - QXX) \qquad (5)$$

Substituting the proper values for the reduced variates for the 43% peak (Y43) and for the 0.5% peak (Y05) enables the program to solve for XF and A. Four sets of XF and A are calculated to describe the relationship between flood peak and frequency for each subwatershed for "with" and "without" conditions of channel improvement, for the beginning and end of the planning stage. The flood peaks for the beginning and end of the stage are then analyzed to obtain a discounted average flow (QDIS). The existing channel capacity (QO) is then subtracted from the discounted flows to obtain a two dimensional array QX which contains peaks in excess of channel capacity for 100 frequencies for "with" and "without" conditions of channel improvement. If the channel is already improved, calculations for unimproved conditions are omitted.

A similar analysis is performed to determine the magnitude of flood peak corresponding to each potential design frequency. A two by NDF array (QQ) is developed to contain discounted total flows for improved and unimproved channel conditions.

Finally, based on the existing channel capacity (QO) the program determines the frequency (F) at which flooding begins in the subwatershed under consideration.

At this point, all preliminary calculations have been made; and starting with Comment 6, the program begins to explore the various possible means of reducing the cost of flooding. Between Comment 6 and Comment 7 the program initializes stage action storage locations and places values in arrays which describe conditions in the subwatershed prior to any improvements during the stage under consideration.

Immediately after Comment 7, the program "calls" Subroutine CD1 (NN) which computes the annual average damage due to flooding. The calling argument NN specifies whether the flows in the QX array for with or those without channelization should be used. The subroutine returns to the main program with CD, the annual average flood damage; and CU, the annual average cost of uncertainty. Unless the input variable UNC is read in as TRUE the value of CU will be zero.

At this point, the cost of flooding (CF) is set equal to the sum of CU and CD, and in turn the total cost of measures plus residual flooding (CT) is set equal to CF, since the cost of measures is zero at this point in calculations. If CT equals zero (i.e. no flood damage occurs), the program shifts control to Statement 1000, bypassing all calculations pertaining to flood control measures.

Now, beginning with Comment 8, the program enters upon a systematic analysis of all possible combinations of flood proofing, land use, and channel improvement in an effort to reduce the total cost of flooding, CT. Each time a new combination is found to be less costly than any previously considered, CT is reduced to the value of the new combination; and a new base value for comparison is established. This procedure is repeated until all alternative combinations have been considered, at which time the least cost combination will have been found. Every attempt is made to eliminate pointless calculations. Frequent checks are employed throughout the analysis to determine as early as possible that a given alternative will not be cheaper than one previously considered. In this manner extra computation is reduced to a minimum in an effort to reduce computing time.

Between Comment 8 and Comment 9 flood proofing alone is considered. The program begins with the lowest design level of protection specified by array DF and proceeds until NDF alternatives have been investigated. After determining the level of protection (P) to consider the program selects the proper design flow, (QP) from array QQ and calculates the cost of the measure (CP). If CP is greater than CT, proofing obviously will not be an optimum selection since greater levels of protection will cost even more, and the measure already costs more than the flood damage; thus control is directed out of the loop and the program will go to consider the cost of land use measures. PP will be set TRUE so that proofing will not be considered further for this subwatershed during the current stage. In the event that CP is less than CT, the logical variable PG is set TRUE. This variable is not used in this loop but is a decision parameter in later loops and will be explained more fully as it is used.

Now the program again calls Subroutine CD1 and calculates the residual flood damage that would still occur if proofing were implemented. A temporary total cost (CTT) is set equal to the sum of CP, CD, and CU. If CTT is less than CT, the measure is less expensive than any previously considered; and the program stores information describing the measure in array OUTPUT, which is later used to report a summary of the optimum measures.

The program will repeat this procedure until NDF levels of protection have been considered for proofing, unless a check indicates that further computation is useless. It may be noted that at Statement 202 in this loop the program compares CTT to the sum of CP, CD, and CU; and if CTT is less than the sum of CP, CD, and CU, control is directed out of the loop. This can be explained by reference to Figure 1. It can be seen that if the cost of the measure plus the cost of residual flooding is increasing, the minimum point on curve C has been passed; and all further analysis is wasted.

Beginning with Comment 9, land use measures alone are considered. The analysis of this alternative is analogus to the analysis for flood proofing alone. The only major difference is that residual damages are calculated by Subroutine CD2 rather than CD1. For any combination of measures that include land use, residual damages will be calculated by CD2; for those not considering land use, residual damages will be calculated by CD1.

Between Comment 10 and Comment 11, flood proofing is considered in combination with the land use adjustment considered between Comment 9 and Comment 10. In this case, all comparisons are made with the cost of land use (CL) plus the cost of flood proofing(CP). If CP + CL is found to exceed the total cost of the measure and residual flooding for the least cost alternative previously considered and if PG is FALSE, PP will be set TRUE and proofing will not be considered further for the subwatershed during the current stage. PG being FALSE indicates that in no case previously considered has the cost of proofing alone (CP) been less than the total cost of flooding, and as such, will not prove to be optimum in combination with any other measure.

Beginning with Comment 11 and ending with Comment 15, the program considers; (A) channel improvement alone; (B) channel improvement plus flood proofing; (C) channel improvement plus land use adjustment; and (D) all three measures in combination. The cost of channel improvement (CS) is calculated by Subroutine STR and compared to CT. If this comparison does not disqualify it from further consideration, residual damages are calculated; and a second comparison is made. However, with channel improvement, the cost of induced downstream flooding must first be evaluated before it can be concluded that channel improvement is less costly than nonstructural measures. This is performed by calling Subroutine COST which returns to the main program with the approximate cost (CDST) of dealing with the larger flood peaks induced in the downstream subwatersheds by channelization. When this cost is calculated, the logical variable CDSTE is set TRUE in the main program and prevents CDST from being recalculated unnecessarily. The cost of downstream flooding is not added to the subwatershed being optimized because the added cost will accrue to the downstream subwatersheds as an increase in the cost of flooding.

It should be noted that several temporary storage locations are used to retain information regarding channel improvements. The information stored in temporary locations includes LINING (NW), the type of improved channel; ST, the level of protection provided by the channel; ND, the number of drop structures; FD, the height of the drop structures; HN, the number of new highway bridges; HE, the number of modified highway bridges; RN, the number of new railway bridges; RE, the number of modified railway bridges; T, the channel top width; W, the channel right-of-way width; and A, the channel cross-sectional area.

The terminus for the series of nested DO-loops that control the comparison of alternative combinations of measures is Statement 1000 in the main program. After the loop indexing is satisfied, program control passes from this statement to begin a series of "housekeeping" operations required to update the arrays containing information describing the subwatershed just optimized. This series of operations is performed between Comment 15 and Comment 16. The specific operations are indicated by intermediate comment cards in the Fortran IV listing.

After completion of the above, the program increments NW and returns to Statement 49 to optimize the next subwatershed, and continues to do so until each subwatershed has been optimized.

Beginning with Comment 16 the program proceeds to print a summary of measures for the stage just completed. A typical example of the summary can be found on Table 4.

Between Comment 17 and Comment 18 the program prints some structural details. A typical example of this summary can be found on Table 5. Summaries are also printed for land use adjustment and flood proofing, typical examples being given on Tables 6 and 7, respectively.

Finally, the total discounted annual costs are printed on Table 8 after all stages have been completed and includes the total costs of channel improvement, flood proofing, land use, uncertainty cost, residual flooding, and the total cost of flooding. At this point, program execution is completed.

## SUBROUTINE PLACEA

The subroutine is used to interpolate intermediate values from a two dimensional array. The subroutine is referenced by a calling statement in either the main program or Subroutine COST. Specifically, the subroutine interpolates QX1 from array QO5 for intermediate values of tributary urbanization (U) and channelization (C).

## SUBROUTINE CD2

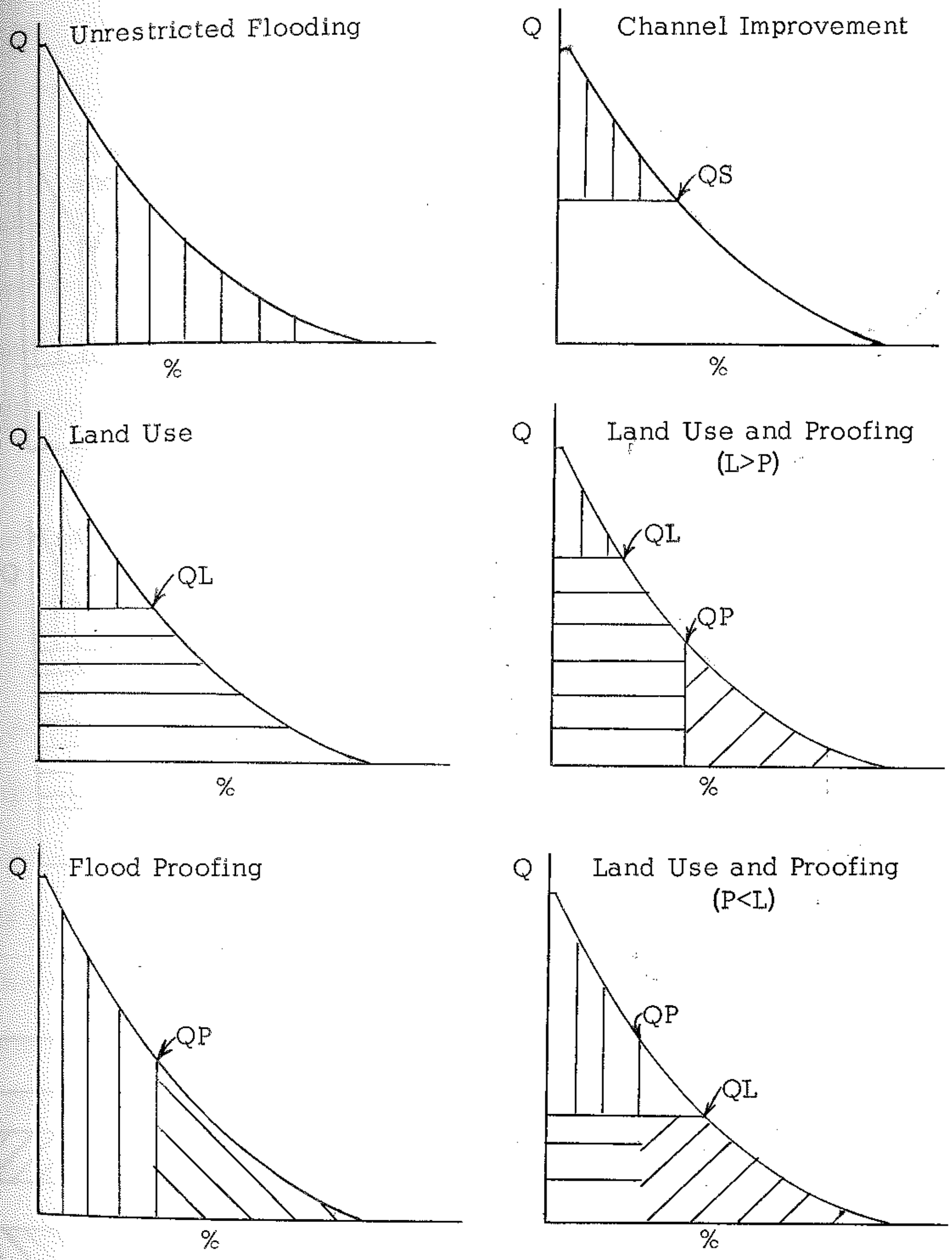
Residual damages are calculated by this subroutine. The full effects of unrestricted flooding can be calculated within this routine as can the damages residual to flood proofing and channel improvement, or damages residual to a combination of both. The only calling argument required is an index (NN), the value of which may be 1 or 2; two if the program is considering channel improvement or if the channel is already improved, one if the channel is unimproved.

Between Comment 1 and Comment 2, the subroutine calculates a series of constants (C1 through C8) which reduce repetitive calculations in the subroutine.

Between Comment 2 and Comment 3, the subroutine calculates the average annual discounted flood damage based on the design channel flow specified by QS, the design flow for flood proofing specified by QP, and the design flow for land use adjustment specified by QL. Using the set of discounted flows (QX) calculated in the main program for 100 frequencies of occurrence, the subroutine calculates 100 ordinates for a damage frequency curve and sums the area under the curve to obtain the average damage.

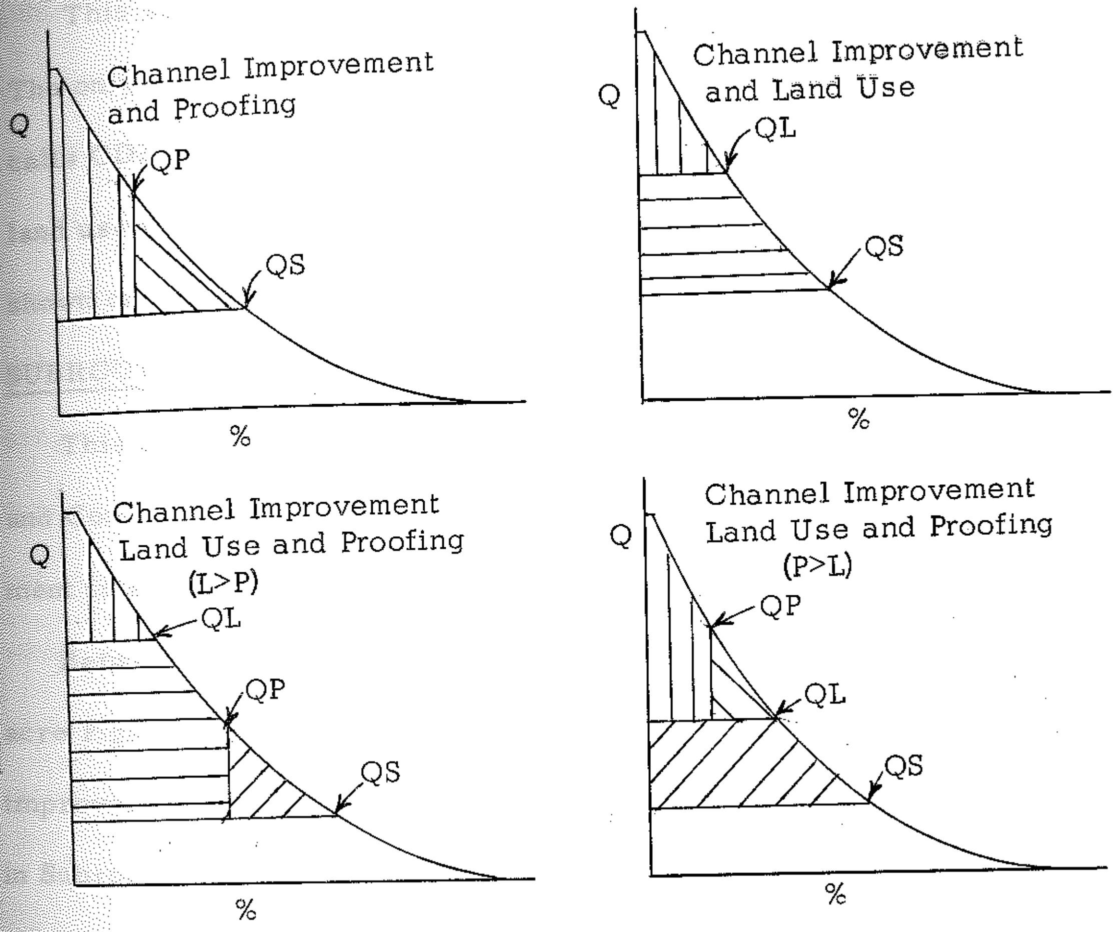
The series of idealized curves, shown on Figure 3 have been prepared to illustrate the possible relationships between flood proofing, channel improvement, land use adjustment, and flood damage. These curves represent the various conditions that may occur and illustrate the assumptions inherent in the damage-frequency calculations performed between Comment 2 and Comment 3 (8, pp. 125-127). The program assumes the flood proofing will eliminate 8/9 of urban damages and none of the agricultural damages, and will essentially lose its effectiveness once the measures are overtopped by flooding. Channel improvement is assumed to eliminate all urban and agricultural damages from floods smaller than the design peak flow. Location adjustment is assumed to eliminate flood damages to the restricted development except for large floods causing inundation outside the restricted area.

Beginning with Comment 3, the program calculates the cost of uncertainty, based on the standard deviation of the ordinates of the damage frequency curve. This cost is calculated by the Thomas Uncertainty Fund (12, pp. 150-152) illustrated by Equation 1 with a capital recovery factor (CRFSM) added to convert present worth to annual cost.



Typical Damage-Frequency Curves

Figure 3



Q--Damage producing flow in CFS.

%--Flood frequency.

☐ Zero Damages accrue

▨ Full damages to agricultural buildings and crops plus 1/9 of urban damages for pre-existing development.

▧ Full damages to Agricultural buildings and crops plus 1/9 of urban damages for full development.

▤ Full damages to agricultural buildings and crops plus full urban damages to pre-existing development.

▥ Full damages to agricultural buildings and crops plus full urban damages to full development.

Figure 3--Continued

## SUBROUTINE CD1

This subroutine is very nearly identical to Subroutine CD2. The only real difference between the two is that the main program calls CD2 when land use is being evaluated and calls CD1 when land use is not being evaluated. The damage-frequency curves shown on Figure 3 that exclude land use apply to CD1.

## SUBROUTINE STR

This subroutine is referenced by a CALL between Comment 11 and Comment 12 in the main program each time channel improvement is evaluated for a potential design frequency.

Between Comment 1 and Comment 2 in the subroutine per acre right-of-way cost is determined for the proposed channel improvement. Since right-of-way costs may also be evaluated in Subroutine COST, a check is first made to determine if this has been done so that its computation will not be repeated unnecessarily. Based on the analysis by James (8, p. 109) right-of-way cost for new channels is determined to be equal to the full value of land plus 1/3 the value of urban structures. The 1/3 is arbitrary and is intended to reflect freedom in design to adjust alignment to avoid structures. For enlarging already improved channels right-of-way cost is determined to be equal to full land and urban structure value. This is because no adjustment is possible for channel alignment and because structure development tends to be extended to the limits of an improved channel.

Secondly, a weighted average design flow is determined by applying the factor FQ, which was read into the program.

Next, the subroutine determines the types of channel improvement to consider or omit from consideration based on the value of LINING (NW). This value is originally read into the program and may be changed within this subroutine as the channel type is changed.[1] If the channel type to be considered is any type but rectangular lined, this subroutine calls Subroutine BRIDGE which determines the number and lengths of railway and highway bridges that will have to be built or modified to accommodate the potential improved channel.

Assuming that an unlined channel is to be evaluated, the subroutine would proceed to calculate its cost between Comment 4 and Comment 5. First of all, dimensions for the channel are calculated for the weighted average design flow. Based on a design criteria established for the Morrison Creek area (8, p. 214), the channel is designed for a minimum bottom width to depth ratio of 4 (BDMIN) unless the required channel depth exceeds 12 feet, in which case the bottom width to depth ratio is allowed

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[1] See p. 35 ARRAY LINING.

to increase by increments of 0.5 up to a maximum ratio of 10 (BDMAX), after which this ratio is maintained at 10 and the minimum channel size that would accommodate the design flow rate is selected. To determine the appropriate width and depth for a given flow, Manning's equation is used with an iterative procedure, since it is not possible to solve directly for the two quantities. Given the Manning equation,

$$Q = \frac{1.49}{n} A R^{0.667} S^{0.5} \qquad (6)$$

where Q is the discharge, in cfs, at a section having an area A in sq. ft; R is the hydraulic radius of the section, in ft; n is the value of Manning's roughness; and s is the average slope of the hydraulic grade line, assumed to be equal to the bottom slope of the channel for steady uniform flow.

For a trapazoidal section

$$Q = \frac{1.49}{n} \left[ \frac{(H(B+ZH))^{1.667}}{(B+2H\sqrt{1+Z^2})^{0.667}} \right] S^{0.5}$$

where H is the depth of flow in the section, B is the bottom width of the section, Z is the side slope of the section, and all other terms have been defined previously.

Letting X = B/H and substituting gives,

$$Q = \frac{1.49}{n} H^{2.667} \left[ \frac{(X+Z)^{1.667}}{(X+2\sqrt{1+Z^2})^{0.667}} \right] S^{0.5}$$

Solving for H gives,

$$H = \frac{Qn}{1.49} \left[ \frac{(X+2\ \ 1+Z^2)^{0.667}}{\sqrt{S}\ \ (X+Z)^{1.667}} \right]^{0.375} \qquad (7)$$

Equation 7 is the form of the Manning equation used in the iterative procedure for determining the channel dimensions commensurate with the design criteria. Initially, the subroutine sets X equal to BDMIN and solves Equation 7 for H. If H exceeds a maximum value of HMAX, X is allowed to increment; and H decreases. Whenever H becomes less than HMAX, the value of X is used with H to solve for B. If X increments to a value equal to BDMAX, the incrementing is caused to cease and the current value of H is used to calculate B.

After the channel dimensions are selected, a check is made to determine if the tractive force developed by the design flow is greater than that which is allowable for the soil type within the unlined channel.

The tractive force is calculated from the following equation (15, p. 168)

$$TFF = \gamma HS$$

where TFF is the tractive force developed, in p. s. f; $\gamma$ is the unit weight of water, taken to be 62.4 lb/ft$^3$, and S is the slope of the hydraulic gradient.

If the developed tractive force is within the limit of allowable tractive force, the subroutine proceeds to calculate the remaining channel dimensions and calculates the cost of the channel improvements (CS) by an equation developed by James (8, pp. 105-106) for a trapezoidal unlined channel. Then, based on the value of LINING(NW), the subroutine either returns to the main program with the cost of the unlined channel or continues to evaluate other types of channel improvement.

If the developed tractive force exceeds the maximum allowable, the program determines the cost of an unlined channel with drop structures. The slope of the hydraulic gradient is reduced by 10% increments until the developed tractive force is reduced to a value equal to or less than the allowable tractive force for the channel. This is accomplished by an iterative procedure similar to that described above for the unlined channel without drop structures. The number of drop structures required (ND) is then calculated to correspond to a preset "rule-of-thumb" which allows for one drop structure if the height of fall is less than or equal to 5 ft., two drop structures if the height of fall is between 5 and 10 ft., or a sufficient number of drop structures so that their average fall is about 4 ft. if the fall is greater than 10 ft.

Based on the channel characteristics calculated above a cost is computed for the unlined channel with drop structures and the subroutine again decides whether to return to the main program with the cost of channel improvement (CS) or to continue to evaluate other types of channel improvement.

Between Comment 5 and Comment 6, the subroutine determines the cost of constructing or enlarging the channel as an unreinforced concrete lined trapezoidal channel. The channel dimensions for a new channel are determined by the iterative procedure using Equation 7. The cost of building a new trapezoidal lined channel (CSL) is also calculated similarly to the cost for the trapezoidal unlined channel, the only difference between the two computations being the inclusion of a term accounting for the cost of the concrete lining.

The cost of enlarging an already improved trapezoidal lined channel is calculated by first determining the dimensions of the existing channel and increasing the depth of the channel by 10% increments until a channel size is reached which will accommodate the design flow. Then, dimensions for the enlarged channel are calculated, the cost of enlarging the channel is determined, and the subroutine returns the cost of the improvement (CS) to the main program.

After calculating the cost of improving an existing unimproved channel as a trapezoidal lined channel the subroutine automatically goes to Comment 7 to evaluate building a reinforced concrete lined rectangular channel. The rectangular channel is designed for a bottom width to depth ratio equal to BDMIN. All dimensions are calculated from a solution of the Manning equation corresponding to this design criterion. The cost of building the rectangular lined channel is calculated from an equation similar to that used for trapezoidal lined channels, the only difference between the two equations being the substitution of a factor allowing for the cost of reinforced concrete lining.

If the subroutine has been directed to consider enlarging an existing improved rectangular lined channel, it will do so by determining the dimensions of the existing channel and increasing the size of the channel until it is able to accommodate the weighted average design flow. A cost is calculated for the additional required lining only and the subroutine returns to the main program with this cost.

## SUBROUTINE BRIDGE

This subroutine is referenced by a CALL statement located between Comment 2 and Comment 3 within Subroutine STR. The calling argument (Q) communicates the magnitude of the design flow for channel improvement to the Subroutine BRIDGE.

Beginning with Comment 1, BRIDGE initializes conditions by setting equal to zero HA, the number of highway bridges having adequate capacity for the design flow; RE, the number of railway bridges that will have to be modified; RN, the number of railway bridges that will have to be built new; HE, the number of highway bridges that will have to be modified; and HN, the number of highway bridges that will have to be built new. Subroutine BRIDGE determines the proper numerical values to be associated with these variables and returns to STR with the information.

The basic instrument of the subroutine is the storage array CAP which contains a running tabulation of the bridges existing in each subwatershed at all times. Any and all changes in CAP made necessary by the adoption of structural measures are made at the end of the optimization calculations in the main program.

Certain assumptions are implicit in the analysis performed by this subroutine. The assumptions are made in an attempt to represent within the computer model changes that would occur during the natural course of development of a watershed. The capacities of existing highway and railway bridges read into the program are assumed to be the maximum flow the bridge can accommodate even with modification. Therefore, any old structure whose capacity is exceeded by the design flow is assumed to be replaced by a new structure. New structures built during the period of analysis are assumed to be constructed in such a manner as to make future modifications economical. Thus, any new structure whose capacity is exceeded by the design flow in later stages is assumed to be modified, and Subroutine STR calculates the cost of modification rather than the cost of replacement.

Based on these assumptions, the subroutine calculates between Comment 2 and Comment 3, the number of old highway bridges that are adequate and the number that will have to be replaced by new structures. Between Comment 3 and Comment 4, the same items are determined for railway bridges.

Between Comment 4 and Comment 5, the subroutine determines, both for highway and railway bridges, the number of structures built during the period of analysis, that will have to be modified to accommodate the design flow.

The analysis assumes that increased urbanization will increase the number of highway bridges present in the subwatershed. A "rule-of-thumb" is employed to suggest the number of bridges that might normally occur. For subwatershed urbanization less than 25%, no influence is assumed; for urbanization between 25% and 50%, a minimum of two highway bridges per mile of channel length is assumed; for urbanization greater than 50%, a minimum of three highway bridges per mile of channel is assumed. These conditions are described mathematically in the subroutine so that an integer value is calculated for the required number of highway bridges.

It would seem to be unjustified to include in the cost of channel improvement, the costs of constructing new bridges required by new roads built across new channels to serve new urban development unless the road were built prior to the channel. Thus, in the event that the channel is improved previous to the stage under consideration, a cost of modification is allowed for those bridges required by increased urbanization.

However, if the channel is unimproved in a previous stage but is being considered for improvement the subroutine assumes that the cost of channel improvement will include the cost of building the required number of new highway bridges. It is felt that increased urbanization will have no affect on the number of required railway bridges.

Beginning with Comment 5, the subroutine determines the number of additional highway bridges required by urbanization within the subwatershed and returns to Subroutine STR.

## SUBROUTINE COST

The purpose of this subroutine is to determine the cost of increased flooding in downstream subwatersheds caused by improving an upstream channel. Ideally, this cost should be determined by optimizing flood control in the downstream subwatershed with and without the improved upstream channel. This would complicate the computer program and add so much to the computation time that an approximate method yielding sufficiently accurate results has been substituted (8, p. 127).

The induced cost of downstream flooding is nearly equal to the cost of enlarging the downstream channel to accommodate the increase in the flood peak of its design frequency. For downstream channels that are in an improved condition, the design frequency is known; and it is a simple matter to calculate the increased flood occurring at the same design frequency. For unimproved downstream channels the design frequency must be estimated if it is anticipated that the channel may be improved during the planning stage for which downstream costs are being evaluated. For this purpose a correlation was established between the amount of subwatershed urbanization and the corresponding design frequency for improved channels. From this correlation a probable design frequency is estimated for each downstream subwatershed containing an unimproved channel. It must be emphasized that the correlation developed is peculiar to the Morrison Creek Watershed and should be revised for any other watershed.

After being referenced by a CALL statement in the main program the subroutine first determines for which downstream subwatersheds induced costs are to be evaluated. Beginning with Comment 2, the subroutine systematically evaluates for each downstream subwatershed, the affects of increased channelization. During this analysis, the amount of urbanization in the downstream subwatershed is held constant, while the amount of tributary channelization is increased in accordance with the proposed upstream improvement.

Between Comment 3 and Comment 4, the subroutine evaluates the situation in the downstream subwatershed with regard to bridges and right-of-way cost. Both of these items are determined consistent with earlier stated assumptions and limitations.

Beginning with Comment 4, flow-frequency relationships are established for the downstream subwatershed. If the downstream subwatershed is already improved, its dimensions are known. If it is not improved, a probable design frequency is selected; and corresponding dimensions are calculated. In either case, dimensions must then be calculated for the additional flow that would result if the upstream channel were to be improved.

Unless otherwise specified by array LINING, the subroutine will determine the induced cost for unimproved channels by calculating the additional cost as if they are unlined channels without drop structures. These above calculations are performed between Comment 4 and Comment 5.

Beginning with Comment 5, induced costs for unlined channels with drop structures are evaluated. The allowable slope and resulting dimensions are calculated in a manner identical to that used in Subroutine STR.

Between Comment 6 and Comment 7, induced costs for trapezoidal lined channels are evaluated. Similarly, between Comment 7 and the end of the subroutine induced costs for rectangular lined channels are evaluated.

The cost of induced downstream flooding is summed as each subwatershed is evaluated, and the subroutine returns the total cost (CDST) to the calling point in the main program where it is then used in the decision of whether or not to implement upstream channel improvement.

## Chapter IV

## SENSITIVITY STUDIES: RESULTS AND CONCLUSIONS

A detailed analysis has been performed on data for the Morrison Creek Watershed. The purpose of the analysis has been twofold. First, the extensive use of the flood control planning program served as a vehicle for "debugging" by forcing the computations into all the optional portions of the program. Secondly, the results of the analysis provide further insight into the more sensitive relationships between the values assigned input variables and the composition of the optimum project provided by the flood control planning program. The results help indicate the relative merits of the alternative measures and pinpoint the best direction for future research.

As indicated earlier, the intended use of the flood control planning program is not to provide a fully designed project, but to select the optimum combination of flood control measures and residual flooding, from which a detailed design may properly be made. Studies have shown that the "mix" of flood control measures employed for the optimum project may be rather insensitive to changes in certain input factors while being highly sensitive to changes in other input factors. While trends may be predicted from a superficial study, the exact nature and extent of the influence extended by input variables in a complex and dynamic system may be determined only through careful analysis. For an analysis of this type to be of any consequence, the "optimum" project must be determined and redetermined for a wide range of input variable values, a requirement that can be met only through the use of computer methods as explored in this thesis. From a practical viewpoint, it is well worth knowing the more sensitive relationships so that data describing these relationships may be gathered more carefully. From a more basic viewpoint, this same knowledge can be used to select the more worthwhile refinements in current data gathering and analytic procedures.

A complete presentation of the results of the computerized sensitivity studies for Morrison Creek is not practical because of the volume of output produced. In order to study the sensitivity of costs, a stage by stage summary of the economic cost of channel improvement, land use adjustment, flood proofing, residual flood damage, uncertainty cost, and total cost of flooding is presented along with the average annual discounted total over the entire period of analysis for each type of cost. In order to study the sensitivity of the amount of measure use,

## TABLE 9-A

## DISTRIBUTION OF COSTS FOR STANDARD PROJECT CONDITIONS

| | Stage 1<br>$ | Stage 2<br>$ | Stage 3<br>$ | Stage 4<br>$ | Stage 5<br>$ | Discounted Totals |
|---|---|---|---|---|---|---|
| S | 90,114 | 116,348 | 130,680 | 164,920 | 181,690 | 123,557 |
| L | 9 | 3,485 | 8,490 | 3,377 | 6,432 | 3,537 |
| P | 5,214 | 7,216 | 11,009 | 14,400 | 17,185 | 9,242 |
| F | 26,542 | 36,372 | 41,034 | 51,588 | 55,860 | 38,028 |
| U | 0 | 0 | 0 | 0 | 0 | 0 |
| T | 121,879 | 163,420 | 191,218 | 234,285 | 261,156 | 174,363 |

## TABLE 9-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR STANDARD PROJECT CONDITIONS

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| | acre-yr. | acre-yr. | acre-yr. | acre-yr. | acre-yr. | acre-yr. |
| L | 9,000 | 1,080 | 6,850 | 1,330 | 1,440 | 19,700 |
| P | 10,170 | 5,380 | 5,290 | 2,520 | 2,710 | 26,070 |
| | cfs.-mi. | cfs.-mi. | cfs.-mi. | cfs.-mi. | cfs.-mi. | cfs.-mi. |
| S | 18,606[a] | 5,347[a] | 741[a] | 5,686 | 2,344[a] | 32,724 |

[a] These figures include only the amount of channel actually built during the stage.

S--Channel Improvement
L--Land Use
P—Flood Proofing
F--Residual Flooding
U--Uncertainty
T--Total During Stage

the acre-years of flood proofing and land use adjustment implemented, and the cfs-miles of channel built during each stage are also presented on tables in this chapter. An acre-year is one acre of flood plain protected by the measure for a year. A cfs-mile is the product of the additional channel capacity provided and the length of the channel.

Absolute quantities are presented on Tables 9-A and 9-B for Standard Project Conditions as defined by the input data presented in Chapter II on Table 1. The following tables present the results of the sensitivity studies. The value of the changed input variable for other conditions is indicated on its appropriate table. All figures other than those pertaining to Standard Project Conditions have been reduced to normalized values, using Standard Project Conditions as the base of 1.00.

## RESULTS AND CONCLUSIONS

### COST OF CHANNEL IMPROVEMENT

Referring to Tables 10-A and 10-B, it can be seen that the sensitivity of the optimum "mix" of measures to changes in the cost of channel improvement was tested by using SF equal to 0.5 and 2.0. This has the affect of making the unit cost of channel improvement one half and twice as much as for Standard Project Conditions.

## TABLE 10-A

## DISTRIBUTION OF COSTS FOR VARYING COST OF CHANNEL IMROVEMENT[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: SF=0.5 | | | | | | |
| S | 0.936 | 0.939 | 0.869 | 0.767 | 0.734 | 0.863 |
| L | 0.899 | 0.000[b] | 0.000[b] | 1.000 | 1.000 | 0.316 |
| P | 0.542 | 0.323 | 0.384 | 0.358 | 0.363 | 0.392 |
| F | 0.644 | 0.487 | 0.706 | 0.759 | 0.886 | 0.677 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.856 | 0.791 | 0.768 | 0.743 | 0.749 | 0.786 |
| Project Conditions: SF=2.0 | | | | | | |
| S | 1.246 | 1.238 | 1.103 | 1.112 | 1.055 | 1.164 |
| L | 1.111 | 1.000 | 1.000 | 3.811 | 4.047 | 1.928 |
| P | 1.000 | 2.315 | 2.417 | 2.834 | 2.910 | 2.314 |
| F | 1.270 | 1.237 | 1.666 | 1.351 | 1.572 | 1.401 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.241 | 1.619 | 1.295 | 1.309 | 1.362 | 1.292 |

## TABLE 10-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES[a] FOR VARYING COST OF CHANNEL IMPROVEMENT

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: SF=0.5 | | | | | | |
| S | 1.266 | 1.090 | 1.528 | 0.512 | 0.555 | 1.061 |
| L | 0.931 | 0.731 | 0.650 | 1.000 | 1.000 | 0.832 |
| P | 0.543 | 0.476 | 0.499 | 0.802 | 0.812 | 0.573 |
| Project Conditions: SF=2.0 | | | | | | |
| S | 0.941 | 0.587 | 0.000 | 0.848 | 0.237 | 0.795 |
| L | 1.064 | 0.981 | 1.169 | 2.165 | 2.153 | 1.250 |
| P | 1.000 | 1.868 | 1.892 | 2.413 | 2.384 | 1.640 |

[a] SF=1.0 for Standard Project Conditions

[b] Small amount implemented

The results of this study indicate that the economic justification of structural measures is rather insensitive to changes in the cost of the measure itself. When the cost of the measure was halved, only 6% more cfs-miles of improved channel was provided; and when the measure cost was doubled the amount of improved channels provided was only decreased by approximately 20%. In actuality, considerably more influence was exerted on the optimum amount of land use and flood proofing used in conjunction with channel improvement. In subwatersheds where the level of channel improvement remained unchanged; the amounts of land use adjustment and flood proofing provided also remained essentially unchanged.

A closer look at the physical characteristics of the Morrison Creek area reveals that for the larger, more highly urbanized subwatersheds, channel improvement is so clearly optimum that a change in the cost of the measure serves at most, only to shift the optimum level of protection slightly, or to cause construction to become optimum in an earlier or later stage.

## COST OF LAND USE ADJUSTMENT

The affects of changes in the cost of land use adjustment are documented on Tables 11-A and 11-B. Again, the cost of the measure was varied by setting LF equal to 0. 5 and 2. 0,

## TABLE 11-A

## DISTRIBUTION OF COSTS FOR VARYING COST OF LAND USE ADJUSTMENT

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: LF=0.5 | | | | | |
| S | 1.000 | 0.880 | 1.046 | 0.874 | 0.951 | 0.951 |
| L | 1.000 | 3.456 | 0.623 | 6.966 | 4.480 | 2.852 |
| P | 1.000 | 1.067 | 0.622 | 0.541 | 0.388 | 0.717 |
| F | 1.000 | 1.048 | 0.935 | 0.956 | 0.918 | 0.978 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.000 | 0.981 | 0.979 | 0.959 | 0.994 | 0.983 |
| | Project Conditions: LF=2.0 | | | | | |
| S | 1.000 | 1.000 | 1.000 | 1.000 | 1.005 | 1.002 |
| L | 1.000 | 0.000[b] | 0.000[b] | 0.000 | 0.000 | 0.000[b] |
| P | 1.000 | 1.355 | 1.740 | 1.221 | 1.610 | 1.392 |
| F | 1.000 | 1.032 | 1.064 | 1.026 | 1.096 | 1.039 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.000 | 1.001 | 1.012 | 1.009 | 1.040 | 1.010 |

## TABLE 11-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING COST OF LAND USE ADJUSTMENT[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: LF=0.5 | | | | | |
| S | 1.000 | 0.776 | 2.630 | 0.431 | 1.140 | 0.861 |
| L | 1.000 | 3.389 | 1.182 | 2.789 | 2.674 | 1.438 |
| P | 1.000 | 1.229 | 1.023 | 2.218 | 1.753 | 1.248 |
| | Project Conditions: LF=2.0 | | | | | |
| S | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| L | 1.000 | 0.731 | 0.734 | 0.000 | 0.000 | 0.752 |
| P | 1.000 | 0.989 | 1.030 | 1.000 | 0.963 | 1.000 |

[a] LF=1.0 for Standard Project Conditions.

[b] Small amount implemented.

thus causing the unit cost of the measure to be one-half and twice as much, respectfully, as for Standard Project Conditions.

The total cost of flooding was effected only slightly by varying the cost of the measure itself. Logically enough, the cost of flooding was decreased when the cost of the measure was increased. The optimum "mix" of measures and residual flooding was totally uneffected in the first stage of analysis.

The most profound change was seen to be in the amount of the land use measure that was applied. The acre-years of the measure implemented was increased by over 40% when the cost of the measures was decreased and was seen to decrease by 25% when the cost of the measure was increased. Land use adjustment becomes totally unfeasible in the fourth and fifth stages when the measure cost was increased. The optimum level of channel improvement was totally uneffected by an increased cost of the land use measure. For decreased land use cost, channel improvement was delayed slightly in several cases and was prevented entirely in subwatersheds that did not become highly urbanized during the period of analysis.

Land use adjustment seems to have its biggest advantage as a complementary measure used with one of the other types of flood control measures. The reduced cost of land use adjustment caused proofing to be used in conjunction with land use measures where no measure was applicable for Standard Project Conditions. In actuality, the land use measure was not given a fair trial in the Morrison Creek Watershed because several subwatersheds were so highly urbainzed prior to the analysis as to make land use adjustment impractical.

## COST OF FLOOD PROOFING

The amount of flood proofing that can be economically justified was seen to be extremely sensitive to the cost of the measure. This is clearly shown on Tables 12-A and 12-B. When the cost of the measure was decreased to one-half of that for Standard Project Conditions the amount of flood proofing implemented was doubled. When the cost of the measure was doubled, flood proofing became totally unfeasible during the analysis. The overall cost of flooding was not severely effected by the variations in the cost of flood proofing even though the amount of the measure that was implemented varied considerably.

When the cost of flood proofing was decreased, the "mix" shifted greatly in favor of flood proofing, with the amount of land use adjustment and channel improvement decreasing drastically. However, when flood proofing costs were increased, channel improvement and land use did not change to any great

## TABLE 12-A

## DISTRIBUTION OF COSTS FOR VARYING COST OF FLOOD PROOFING[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: PF=0.5 | | | | | |
| S | 0.601 | 0.636 | 0.721 | 0.642 | 0.775 | 0.666 |
| L | 1.000 | 0.000[b] | 0.000[b] | 0.000 | 0.000 | 0.001 |
| P | 4.298 | 5.297 | 3.750 | 4.104 | 3.334 | 4.147 |
| F | 0.779 | 1.178 | 1.123 | 1.151 | 1.173 | 1.186 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.908 | 0.949 | 0.950 | 0.958 | 1.009 | 0.950 |
| | Project Conditions: PF=2.0 | | | | | |
| S | 1.031 | 0.982 | 0.991 | 0.988 | 0.989 | 0.997 |
| L | 1.000 | 1.616 | 1.000 | 1.000 | 1.000 | 1.150 |
| P | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| F | 1.161 | 1.197 | 1.195 | 1.397 | 1.456 | 1.264 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.015 | 1.000 | 0.978 | 1.017 | 1.024 | 1.006 |

## TABLE 12-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING COST OF FLOOD PROOFING

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: PF=0.5 | | | | | |
| S | 0.821 | 0.507 | 5.296 | 0.521 | 1.517 | 0.869 |
| L | 1.000 | 0.731 | 0.688 | 0.000 | 0.000 | 0.736 |
| P | 1.446 | 2.522 | 1.830 | 3.516 | 2.339 | 2.001 |
| | Project Conditions: PF=2.0 | | | | | |
| S | 1.008 | 0.968 | 1.046 | 1.000 | 1.000 | 1.000 |
| L | 0.994 | 2.343 | 1.000 | 1.000 | 1.000 | 1.000 |
| P | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

[a] PF=1.0 for Standard Project Conditions.

[b] Small amount implemented.

extent. No additional channels were built; however, the level of protection and the stage in which the channel was constructed did change slightly. In one subwatershed, the channel was built in the first stage rather than in the second stage as it was for Standard Project Conditions, and in another subwatershed the channel in the third stage was built to a larger capacity. Similarly, land use measures were implemented in one subwatershed during the second stage, where flood proofing had been optimum during Standard Project Conditions. The design frequency for land use was increased in one instance in the first stage where land use and proofing had been used in combination during Standard Project Conditions. All of the shifts occurred in subwatersheds where land use had been just slightly more economical than the measure that replaced it when its cost was increased.

## DEPTH-DAMAGE RELATIONSHIP

Calculation of the amount of flood damage to urban and agricultural structures is based on the variable COEFDM. The relationship assumes linearity between the depth of flooding and the amount of damage occurring. Work has been done to establish more sophisticated relationships which may be applicable in other situations (13). Damage to agricultural

## TABLE 13-A

## DISTRIBUTION OF COSTS FOR VARYING DEPTH-DAMAGE RELATIONSHIP[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: COEFDM=0.025 | | | | | |
| S | 0.644 | 0.541 | 0.636 | 0.590 | 0.903 | 0.640 |
| L | 1.000 | 0.000 | 0.000[b] | 0.000 | 0.000 | 0.000[b] |
| P | 0.104 | 0.000 | 0.023 | 0.000 | 0.000 | 0.019 |
| F | 1.031 | 1.389 | 1.285 | 1.535 | 1.327 | 1.296 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.769 | 0.786 | 0.840 | 0.850 | 0.880 | 0.818 |
| | Project Conditions: COEFDM=0.100 | | | | | |
| S | 1.618 | 1.346 | 1.415 | 1.381 | 1.470 | 1.~~879~~ 454 |
| L | 0.750 | 4.210 | 1.000 | 2.126 | 1.000 | 1.879 |
| P | 1.266 | 2.125 | 2.766 | 1.323 | 1.650 | 1.676 |
| F | 0.496 | 0.435 | 0.599 | 0.716 | 0.572 | 0.556 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.183 | 1.160 | 1.138 | 1.167 | 1.137 | 1.199 |

## TABLE 13-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING DEPTH-DAMAGE RELATIONSHIP[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| | Project Conditions: COEFDM=0.025 | | | | | |
| S | 0.838 | 0.156 | 12.140 | 0.000 | 2.068 | 0.739 |
| L | 0.990 | 0.164 | 1.511 | 0.000 | 0.000 | 0.603 |
| P | 0.120 | 0.000 | 0.069 | 0.000 | 0.000 | 0.051 |
| | Project Conditions: COEFDM=0.100 | | | | | |
| S | 1.301 | 0.697 | 3.980 | 0.763 | 1.325 | 1.108 |
| L | 0.650 | 2.234 | 1.000 | 1.150 | 1.000 | 1.092 |
| P | 1.163 | 1.603 | 1.222 | 1.203 | 1.182 | 1.254 |

[a] COEFDM=0.052 for Standard Project Conditions.

[b] Small amount implemented.

crops is assumed to be independent of the depth of flooding. COEFDM equals the damage per foot of flood depth per dollar of market value of flood-plain structures. The value for COEFDM of 0.052 used for Standard Project Conditions was developed by James (8, p. 87, Eq. 20) for average flood-plain development when the flood water contains little sediment, has a relatively low velocity, and does not exceed four feet in depth. For different conditions in the flood-plain or for different flood water characteristics than those of Morrison Creek, a different value of COEFDM would have to be established.

For the sensitivity studies, values for COEFDM of 0.052 and 0.100 were used. This set the unit damage per depth of flooding at approximately one-half and twice that used for Standard Project Conditions. The results of this study are shown on Tables 13-A and 13-B. For the lower value of COEFDM, the optimum "mix" shifted greatly in favor of allowing the flood damage to occur, with less structural and nonstructural flood control measures being applied. The opposite affect occurred when the damage from a given flood depth was increased; with a considerable reduction in the cost of residual damages being effected, while the percentage of the cost allocated to flood control measures increased greatly. Again, flood proofing was most sensitive to a reduction in damages, with only 5% of the amount of flood proofing justified under Standard Project Conditions being applied if COEFDM equals 0.025. Where COEFDM was increased to 0.100, flood proofing again showed the most sensitivity to its change, however both structural and nonstructural were also implemented to a higher degree than under Standard Project Conditions.

## VALUE OF OPEN SPACE AMENITIES

The value of open space amenities is expressed in the input data by IPP. The value of open space within an urban area should certainly be worth something to society, and because of this, the benefits to land use adjustment should include some value over and above the amount realized by the reduction of physical flood damage. Also, the unit value should logically increase as the amount of remaining open space decreases. For this reason, the value of open space amenities as calculated within the flood control planning program have been made a function of watershed urbanization (UN) and the coefficient IPP. The product of these two terms is equivalent to the single term used to evaluate open space amenities in the equation developed by James (8, p. 122 and Eq. 36). The

## TABLE 14-A

## DISTRIBUTION OF COSTS FOR VARYING VALUE OF OPEN SPACE AMENITIES[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: IPP=200 | | | | | | |
| S | 1.000 | 0.880 | 1.046 | 0.874 | 0.951 | 0.951 |
| L | 12.778 | 0.378 | 4.242 | 4.475 | 1.745 | 1.945 |
| P | 1.000 | 1.067 | 0.590 | 1.143 | 0.955 | 0.945 |
| F | 0.985 | 1.048 | 0.934 | 1.016 | 0.991 | 0.997 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.998 | 0.983 | 0.968 | 0.974 | 0.976 | 0.981 |
| Project Conditions: IPP=1000 | | | | | | |
| S | 0.952 | 0.738 | 0.657 | 0.547 | 0.706 | 0.734 |
| L | 101.778 | 0.009 | 0.205 | 0.667 | 1.762 | 0.591 |
| P | 0.843 | 1.291 | 0.904 | 1.242 | 0.447 | 0.952 |
| F | 1.042 | 0.833 | 0.948 | 0.800 | 0.731 | 0.883 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.975 | 0.768 | 0.713 | 0.648 | 0.721 | 0.776 |

## TABLE 14-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING VALUE OF OPEN SPACE AMENITIES[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: IPP=200 | | | | | | |
| S | 1.000 | 0.776 | 2.630 | 0.431 | 1.140 | 0.912 |
| L | 1.275 | 3.389 | 1.388 | 3.413 | 3.215 | 1.717 |
| P | 1.000 | 1.229 | 1.000 | 2.246 | 1.719 | 1.242 |
| Project Conditions: IPP=1000 | | | | | | |
| S | 0.982 | 0.000 | 0.000 | 0.097 | 2.221 | 0.735 |
| L | 2.143 | 28.250 | 3.804 | 19.864 | 9.764 | 5.906 |
| P | 1.011 | 2.173 | 2.251 | 5.286 | 4.458 | 2.274 |

[a] IPP=0 for Standard Project Conditions.

value assigned open space amenities is admittedly subjective and is only intended to give an indication of the affects of open space amenities on the types and amount of flood control measures that can be economically justified in a flood control program.

The results of this study are presented on Tables 14-A and 14-B. IPP was arbitrarily assigned values of 200 and 1000, thus making open space amenities equal to $200 and $1000 per acre per year in a fully urbanized subwatershed. The affect of assigning a positive value to open space amenities was to increase the use of nonstructural measures, both land use adjustment and flood proofing, while decreasing the use of structural measures. Land use and flood proofing seemingly have more merit when used together, as the restriction in urban development encourages the use of flood proofing to reduce damages to pre-existing urban development. For IPP equal to 1000, land use was implemented during at least one stage for 17 of the 20 subwatersheds analyzed. The remaining 3 subwatersheds were improved prior to the period of the study to the extent that flooding never began more commonly than 1/2% during the entire period of analysis.

## RIGHT-OF-WAY VALUE

The cost of right-of-way for structural measures is controlled by the variable RWF. For Standard Project Conditions, the variable RWF was set equal to 0.5 and 2.0. This has the affect of evaluating channel improvement with right-of-way cost equal to one-half and twice the value assigned to Standard Project Conditions.

The sensitivity of the optimum "mix" to changes in right-of-way cost indicated the same general trends as varying the total cost of channel improvement. The results of the study performed on right-of-way cost are presented on Tables 15-A and 15-B. The amount of channel improvement implemented increased slightly for decreased right-of-way cost and decreased approximately 20% for the increased right-of-way cost. The percentage of the total cost allocated to channel improvement decreased in both cases; in one case because the cost of channel improvement itself decreased, in the other case because a lesser amount was found to be optimum. A pronounced affect was evident in the more highly urbanized subwatersheds for which right-of-way cost was comparatively high or for which channel improvement has only moderate advantage over nonstructural measures or unrestricted

## TABLE 15-A

## DISTRIBUTION OF COSTS FOR VARYING RIGHT-OF-WAY VALUE[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: RWF=0.5 | | | | | | |
| S | 0.688 | .884 | 0.701 | 0.774 | 0.684 | 0.747 |
| L | 0.991 | 0.226 | 1.000 | 0.248 | 1.000 | 0.428 |
| P | 1.000 | 0.742 | 1.000 | 0.981 | 1.000 | 0.939 |
| F | 0.943 | 0.640 | 0.818 | 0.801 | 0.942 | 0.818 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.757 | 0.768 | 0.741 | 0.760 | 0.773 | 0.760 |
| Project Conditions: RWF=2.0 | | | | | | |
| S | 0.967 | 0.898 | 0.757 | 1.018 | 0.880 | 0.903 |
| L | 15.852 | 1.580 | 5.601 | 1.000 | 1.000 | 1.784 |
| P | 1.364 | 6.155 | 8.171 | 3.766 | 4.752 | 5.684 |
| F | 1.487 | 1.484 | 1.988 | 1.777 | 2.132 | 1.730 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.345 | 1.342 | 1.366 | 1.389 | 1.407 | 1.366 |

## TABLE 15-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING RIGHT-OF-WAY VALUE[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: RWF=0.5 | | | | | | |
| S | 1.050 | 1.531 | 0.478 | 1.107 | 0.544 | 1.039 |
| L | 0.965 | 0.691 | 1.000 | 0.892 | 1.000 | 0.939 |
| P | 1.000 | 0.814 | 1.000 | 0.913 | 1.000 | 0.947 |
| Project Conditions: RWF=2.0 | | | | | | |
| S | 0.821 | 0.310 | 0.224 | 2.454 | 0.166 | 0.786 |
| L | 1.017 | 1.866 | 1.218 | 1.000 | 1.000 | 1.161 |
| P | 0.966 | 2.010 | 2.401 | 1.378 | 1.622 | 1.580 |

[a] RWF=1.0 for Standard Project Conditions.

flooding.

## COST OF UNCERTAINTY

The affect of the cost of uncertainty was evaluated using the procedure advanced by H. A. Thomas (12, pp. 150-152) discussed earlier in this paper. For Standard Project Conditions the logical variable UNC was read into the program as FALSE. This reduces calculations performed in Subroutines CD1 and CD2 while producing the same results as putting VA into the program equal to zero, amounting to a probability of exceedance for the equalization fund equal to 50%. For purposes of evaluating the effects of uncertainty, the program was used with VA equal to 1.645 and 2.575, conforming to probabilities of exceedance equal to 5% and 0.5%, respectively.

The results of this study are presented on Tables 16-A and 16-B. As could be anticipated, the results clearly indicate that the less risk one is willing to take, the more he must pay on an annual basis to reduce the risk. In general, the optimum amount of flood control provided must increase, and the allowable level of residual flooding must decrease as the probability of exceeding an insured situation decreases. The average level of protection provided by originally constructed

## TABLE 16-A

## DISTRIBUTION OF COSTS FOR VARYING COST OF UNCERTAINTY [a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: VA=1.645 ($\alpha$=5%) | | | | | | |
| S | 1.132 | 1.490 | 1.509 | 1.474 | 1.451 | 1.397 |
| L | 0.500 | 1.954 | 1.000 | 2.126 | 1.000 | 1.459 |
| P | 1.215 | 1.161 | 1.155 | 0.764 | 1.156 | 1.044 |
| F | 0.809 | 0.190 | 0.311 | 0.370 | 0.456 | 0.440 |
| U | 0.302[b] | 0.125[b] | 0.246[b] | 0.295[b] | 0.378[b] | 0.263[b] |
| Project Conditions: VA=2.575 ($\alpha$=0.5%) | | | | | | |
| S | 1.670 | 1.324 | 1.509 | 1.466 | 1.438 | 1.485 |
| L | 0.500 | 5.229 | 1.000 | 3.301 | 1.000 | 2.362 |
| P | 1.364 | 2.488 | 2.340 | 0.762 | 1.576 | 1.488 |
| F | 0.268 | 0.224 | 0.297 | 0.354 | 0.451 | 0.308 |
| U | 0.145[b] | 0.200[b] | 0.308[b] | 0.398[b] | 0.551[b] | 0.298[b] |
| T | 1.186 | 1.169 | 1.179 | 1.221 | 1.264 | 1.199 |

## TABLE 16-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING COST OF UNCERTAINTY[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: VA=1.645 ($\alpha$=5%) | | | | | | |
| S | 1.180 | 1.154 | 2.225 | 0.857 | 0.886 | 1.138 |
| L | 0.357 | 1.099 | 1.000 | 1.150 | 1.000 | 0.851 |
| P | 1.135 | 1.080 | 1.073 | 1.081 | 1.061 | 1.093 |
| Project Conditions: VA=2.575 ($\alpha$=0.5%) | | | | | | |
| S | 1.380 | 0.556 | 7.835 | 0.726 | 0.847 | 1.134 |
| L | 0.357 | 2.398 | 1.000 | 1.252 | 1.000 | 1.047 |
| P | 1.191 | 1.833 | 1.190 | 1.167 | 1.202 | 1.292 |

[a] VA=0.000 (   =50%) for Standard Project Conditions.

[b] Cost of uncertainty expressed as a multiple of residual flood damage for Standard Project Conditions.

channels was 3.33% with Standard Project Conditions, 1.05%, with VA equal to 1.645 and, 0.89% with VA equal to 2.575. By increasing VA to a sufficiently large value, it is possible to vary the level of protection according to intangible values received from preventing periodic flooding of urban areas.

From the figures presented on Table 16-B the optimum amount of land use adjustment apparently decreased with VA equal to 1.645 and then increased when VA was increased to 2.575. This does not actually mean that land use adjustment should become less favorable until the cost of uncertainty has reached a given amount. Inspection of the optimization calculations reveals that location was used during Standard Project Conditions at a frequency slightly more rare than the level of protection provided by improved channels during the first stage. However, when VA was increased to 1.645, the channels in question were improved to provide a level of protection equal to 1/2% in the first stage, thus eliminating the opportunity to gain additional benefits through land use adjustment. The increased land use adjustment justified in the remaining stages of the analysis was not able to make up for the deficit provided in stage one. When VA was increased to 2.575 this occurrence was repeated in the first stage, but enough additional land use justified in later stages to provide an overall increase in the amount implemented, thus giving rise to the apparent discrepancies indicated above.

## DISCOUNT RATE

The results of the sensitivity study performed to determine the affects of discount rate on the selection of the optimum flood control project are presented on Tables 17-A and 17-B. For Standard Project Conditions the discount rate of 3.0% was used. The sensitivity study was performed using rates of 0.01%, 7.0%, and 15.0%.

The affects of discount rate were explored by James (8, p. 170), and this study correlates very well with his observations. A low discount rate encourages the application of structural measures, while a higher discount rate favors nonstructural measures. However, at very high discount rates the use of nonstructural measures tends to be restricted even more than that of structural measures. The cost of channel improvement is proportional to the sum of the capital recovery factor (CRFSM) based on the interest rate R over a period equal to TIMST and the maintenance cost. The cost of flood proofing is proportional to the sum

## TABLE 17-A

## DISTRIBUTION OF COSTS FOR VARYING DISCOUNT RATE [a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: R=0.01% | | | | | | |
| S | 0.885 | 0.793 | 0.844 | 0.877 | 0.867 | 0.908 |
| L | 1.250 | 1.775 | 0.600 | 0.161 | 0.000 | 0.456 |
| P | 0.648 | 0.552 | 0.517 | 0.627 | 0.635 | 0.832 |
| F | 0.309 | 0.220 | 0.303 | 0.395 | 0.513 | 0.409 |
| U | -- | -- | -- | -- | -- | -- |
| T | 0.659 | 0.626 | 0.620 | 0.643 | 0.648 | 0.710 |
| Project Conditions: R=7.0% | | | | | | |
| S | 1.016 | 1.040 | 1.168 | 1.738 | 1.631 | 1.050 |
| L | 1.250 | 0.000 | 0.353 | 1.213 | 1.213 | 0.347 |
| P | 2.310 | 2.975 | 2.386 | 1.176 | 1.133 | 1.428 |
| F | 1.968 | 2.354 | 2.267 | 1.512 | 1.654 | 1.825 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.424 | 1.495 | 1.599 | 1.576 | 1.551 | 1.326 |
| Project Conditions: R=15.0% | | | | | | |
| S | 1.897 | 1.693 | 1.660 | 1.434 | 1.927 | 1.528 |
| L | 1.250 | 0.000 | 0.000 [b] | 2.112 | 0.000 | 0.045 |
| P | 1.968 | 0.862 | 2.707 | 1.511 | 1.309 | 0.922 |
| F | 2.217 | 3.149 | 3.149 | 3.216 | 3.914 | 1.975 |
| U | -- | -- | -- | -- | -- | -- |
| T | 2.020 | 2.096 | 2.204 | 2.322 | 2.403 | 1.604 |

[a] R=3.0% for Standard Project Conditions.

[b] Small amount implemented.

## TABLE 17-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING DISCOUNT RATE

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: R=0.01% | | | | | | |
| S | 1.175 | 1.124 | 5.573 | 1.539 | 1.162 | 1.247 |
| L | 1.124 | 1.711 | 0.457 | 0.332 | 0.000 | 0.713 |
| P | 1.050 | 1.087 | 0.378 | 0.370 | 0.208 | 0.680 |
| Project Conditions: R=7.0% | | | | | | |
| S | 0.757 | 0.466 | 10.643 | 0.893 | 0.000 | 0.769 |
| L | 1.078 | 0.164 | 2.025 | 0.996 | 0.996 | 1.103 |
| P | 1.184 | 1.741 | 0.946 | 0.942 | 0.943 | 1.149 |
| Project Conditions: R=15.0% | | | | | | |
| S | 0.623 | 0.285 | 0.000 | 0.808 | 1.906 | 0.597 |
| L | 1.160 | 0.164 | 1.184 | 0.653 | 0.000 | 0.712 |
| P | 0.381 | 0.055 | 0.931 | 0.600 | 0.273 | 0.435 |

of the capital recovery factor (CRF) for a time period equal to TIME and its annual maintenance cost. Due to the differences between TIMST and TIME, the cost of channel improvement increases more rapidly with an increasing discount rate than does the cost of flood proofing. The discount rate effects the cost of land use measures because CRF is also used to estimate the average annual land use cost over the stage. Flood damages vary with interest rate because they accrue to the discounted average annual subwatershed urbanization.

Table 17-B indicates as anticipated, that for discount rates less than that used for Standard Project Conditions the optimum level of structural measures increases; while the optimum level of nonstructural measures decreases. As R is increased to 7.0%, the opposite affect is seen to occur. However, when R was increased to 15.0%, the optimum level of flood control measures showed a general decrease while the economically optimum level of residual flood damages was seen to increase to its highest point. It appears that an increasing discount rate tends to favor nonstructural measures over structural measures until a certain rate is reached, after which the increased cost of all measures reflects unfavorably

on them.

## RATE OF URBAN GROWTH

The sensitivity of the optimum "mix" of flood control measures and residual flooding to changes in the overall anticipated rate of urban growth was also studied. The program was not used to examine the affects of variations in the projected growth pattern, however, such variations could be logically expected to accelerate the installation of structural measures in subwatersheds where the relative growth rate was increased and favor nonstructural measures where the relative growth rate was decreased.

For the analysis, a planning period of 30 years was adopted; and the affects of the rate of urban growth were determined by varying the lengths of the planning stages. The costs of structural measures were discounted over a 50 year life, while the costs of nonstructural measures were discounted over a time period equal to the length of each planning stage. Variations in the rate of growth were effected by analyzing six 5-year stages and two 15-year stages while using the same degree of subwatershed urbanization at the end of each stage. Standard Project Conditions were established by optimizing three 10-year stages. The use of shorter

## TABLE 18-A

## DISTRIBUTION OF COSTS FOR VARYING RATE OF URBAN GROWTH[a]

| | Discounted Totals |
|---|---|
| **Project Conditions: TIME=6, NSTEMX=5** | |
| S | 1.030 |
| L | 2.579 |
| P | 1.385 |
| F | 1.366 |
| U | -- |
| T | 1.167 |
| **Project Conditions: TIME=15, NSTEMX=2** | |
| S | 0.917 |
| L | 0.135 |
| P | 1.853 |
| U | -- |
| T | 0.919 |

## TABLE 18-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING RATE OF URBAN GROWTH[a]

| | Totals |
|---|---|
| **Project Conditions: TIME=6, NSTEMX=5** | |
| S | 1.010 |
| L | 1.964 |
| P | 0.819 |
| **Project Conditions: TIME=15, NSTEMX=2** | |
| S | 0.775 |
| L | 0.207 |
| P | 1.579 |

[a] TIME=10, NSTEMX=3 for Standard Project Conditions.

stages with the same input data for USUBW, UTOTR, AND VALUE, simulates a more rapid growth rate. The use of a longer stage length simulates a slower growth rate.

The results of this study are presented on Tables 18-A and 18-B. Because differences in the lengths of planning stages mean that the stages do not cover comparable periods, within stage comparisons were omitted from these tables. The totals over the entire planning period are presented in a manner identical to that used for all tables in this chapter.

In general, the cost of providing a given level of channel improvement is independent of the rate of urban growth because of the constant life adopted for structural measures. The variation in rate of urban growth effects the unit cost of flood proofing because of variation in the discounted average annual urbanization over the stage which must be flood proofed. Flood proofing costs also vary because of changes in the discount factors resulting from different stage lengths. Unit costs will be slightly higher for shorter discounting periods and slightly lower for longer discounting periods. Based on the formula developed by James (8, p. 122, and Eq. 36), the unit cost of land use adjustment should decrease as the planning stage becomes shorter and increase for longer planning stages.

Because of the variation in unit cost described above, channel improvement was used relatively more than flood proofing for the shorter planning stage. The total amount spent on all three measures increased for the shorter planning stage because the higher discounted average annual stage urbanization increased the cost of flood proofing and residual damage. As expected, the per acre cost of land use adjustment was decreased, and the amount implemented was seen to be nearly doubled when compared to Standard Project Conditions. When the length of the planning stage was increased, the opposite affects were noted; giving increased support to the conclusions reached above.

## COMBINATION OF FLOOD CONTROL MEASURES

A final sensitivity study was conducted to examine the relative merits of the various types of flood control measures, used individually or in combination. The analysis was performed through setting TRUE individually or in combination the input values of STF, LTF, and PTF, as described on Table 3. All combinations of the three types of flood control measures were evaluated. The cost of unrestricted flooding was also determined.

The results of this study are presented on Tables 19-A

## TABLE 19-A

## DISTRIBUTION OF COSTS FOR VARYING COMBINATIONS OF FLOOD CONTROL MEASURES[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: Channel Improvement and Land Use Adjustment | | | | | | |
| S | 1.085 | 0.855 | 1.072 | 1.095 | 1.067 | 1.029 |
| L | 1.000 | 0.581 | 1.075 | 0.258 | 0.242 | 0.475 |
| P | -- | -- | -- | -- | -- | -- |
| F | 1.039 | 1.039 | 1.056 | 1.260 | 1.376 | 1.206 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.026 | 1.013 | 1.029 | 1.008 | 0.993 | 1.015 |
| Project Conditions: Channel Improvement | | | | | | |
| S | 1.158 | 0.834 | 0.930 | 0.939 | 1.221 | 1.000 |
| L | -- | -- | -- | -- | -- | -- |
| P | -- | -- | -- | -- | -- | -- |
| F | 1.001 | 1.708 | 1.400 | 1.644 | 1.477 | 1.375 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.054 | 0.998 | 1.045 | 1.060 | 1.079 | 1.044 |
| Project Conditions: Channel Improvement and Flood Proofing | | | | | | |
| S | 1.073 | 0.774 | 0.862 | 0.868 | 0.897 | 0.897 |
| L | -- | -- | -- | -- | -- | -- |
| P | 1.000 | 3.985 | 4.961 | 2.364 | 2.804 | 2.779 |
| F | 1.020 | 1.295 | 1.158 | 1.178 | 1.247 | 1.170 |
| U | -- | -- | -- | -- | -- | -- |
| T | 1.049 | 1.015 | 1.086 | 1.089 | 1.161 | 1.073 |
| Project Conditions: Flood Proofing and Land Use Adjustment | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | 1.500 | 18.714 | 22.438 | 15.843 | 12.892 | 16.612 |
| P | 24.929 | 40.426 | 37.312 | 15.213 | 13.228 | 21.796 |
| F | 4.190 | 5.038 | 4.746 | 5.076 | 5.323 | 4.817 |
| U | -- | -- | -- | -- | -- | -- |
| T | 2.546 | 3.296 | 3.828 | 4.088 | 4.351 | 3.529 |

TABLE 19-A--Continued

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Discounted Totals |
|---|---|---|---|---|---|---|
| Project Conditions: Flood Proofing | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | -- | -- | -- | -- | -- | -- |
| P | 29.833 | 60.708 | 65.770 | 24.257 | 24.126 | 34.362 |
| F | 4.418 | 5.826 | 5.745 | 5.983 | 6.635 | 5.611 |
| U | -- | -- | -- | -- | -- | -- |
| T | 2.822 | 3.642 | 4.437 | 4.581 | 4.976 | 3.979 |
| Project Conditions: Land Use Adjustment | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | 1.500 | 18.294 | 10.252 | 15.843 | 12.892 | 14.112 |
| P | -- | -- | -- | -- | -- | -- |
| F | 8.283 | 11.203 | 12.359 | 12.906 | 14.096 | 11.423 |
| U | -- | -- | -- | -- | -- | -- |
| T | 3.045 | 4.120 | 5.019 | 5.444 | 5.981 | 4.569 |
| Project Conditions: Unrestricted Flooding | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | -- | -- | -- | -- | -- | -- |
| P | -- | -- | -- | -- | -- | -- |
| U | -- | -- | -- | -- | -- | -- |
| T | 3.299 | 4.400 | 5.517 | 5.840 | 6.483 | 4.940 |

[a] Standard Project Conditions include channel improvement, land use adjustment, and flood proofing.

## TABLE 19-B

## DISTRIBUTION OF FLOOD CONTROL MEASURES FOR VARYING COMBINATIONS OF FLOOD CONTROL MEASURES[a]

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: Channel Improvement and Land Use Adjustment | | | | | | |
| S | 1.036 | 0.686 | 21.379 | 0.956 | 0.504 | 1.134 |
| L | 1.014 | 0.279 | 2.092 | 0.456 | 0.460 | 0.909 |
| P | -- | -- | -- | -- | -- | -- |
| Project Conditions: Channel Improvement | | | | | | |
| S | 1.127 | 0.098 | 13.452 | 0.452 | 4.294 | 1.043 |
| L | -- | -- | -- | -- | -- | -- |
| P | -- | -- | -- | -- | -- | -- |
| Project Conditions: Channel Improvement and Flood Proofing | | | | | | |
| S | 1.097 | 0.098 | 13.173 | 0.436 | 2.013 | 0.925 |
| L | -- | -- | -- | -- | -- | -- |
| P | 0.834 | 1.766 | 1.134 | 1.118 | 1.108 | 1.131 |
| Project Conditions: Flood Proofing and Land Use Adjustment | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | 1.371 | 3.662 | 3.418 | 3.168 | 3.154 | 2.749 |
| P | 2.079 | 4.469 | 4.458 | 4.375 | 4.348 | 3.651 |

TABLE 19-B--Continued

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Totals |
|---|---|---|---|---|---|---|
| Project Conditions: Flood Proofing | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | -- | -- | -- | -- | -- | -- |
| P | 2.034 | 4.202 | 4.348 | 4.255 | 4.194 | 3.527 |
| Project Conditions: Land Use Adjustment | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | 1.371 | 2.940 | 2.798 | 3.168 | 3.154 | 2.533 |
| P | -- | -- | -- | -- | -- | -- |
| Project Conditions: Unrestricted Flooding | | | | | | |
| S | -- | -- | -- | -- | -- | -- |
| L | -- | -- | -- | -- | -- | -- |
| P | -- | -- | -- | -- | -- | -- |

[a] Standard Project Conditions include channel improvement, land use adjustment, and flood proofing.

and 19-B. For the most part, the results are self explanatory and need little interpretation. As would be expected, Standard Project Conditions, which consider all three types of measures, produced the lowest annual flood cost. Channel improvement in combination with land use proved to be the next best alternative. This is somewhat suprising, in view of the fact that pre-existing urban development in the Morrison Creek Subwatershed is not especially conducive to the land use measure. Apparently, the inavailability of flood proofing to reduce flood damage forced the use of channel improvement in earlier stages when right-of-way cost was less. The fact that the reduction in total cost by including flood proofing is only 1.5%, further demonstrates the small economic advantage of this type of measure. Channel improvement alone proved to be the next best approach to reducing the cost of flooding in the Morrison Creek area. Channel improvement in combination with flood proofing was slightly more costly than channel improvement alone. Under certain conditions, flood proofing is slightly more favorable than channel improvement; thus delaying channel construction to a later stage when right-of-way cost has increased and proofing has become uneconomical because of the increased urban development.

Nonstructural measures alone do not prove to be entirely satisfactory, at least in a watershed having high potential urban development. Supplementing channel improvement with nonstructural measures, turned out to reduce total cost by only 4.4%. Naturally enough, unrestricted flooding is shown to be by far the most costly policy to follow.

## SENSITIVITY OF FLOOD CONTROL MEASURES TO INDIVIDUAL SUBWATERSHED CHARACTERISTICS

The foregoing discussion has been devoted to examination of the sensitivity of the Morrison Creek Watershed as a whole to changes in the optimum "mix" of flood control measures caused by specific variations in the input data. In a heterogeneous area such as the Morrison Creek Watershed, the sensitivity of the optimum "mix" within particular positions of the total watershed tend to be obscured by the aggregate sensitivity. In particular, the conditions which favor or disfavor the application of particular flood control measures considered by the study have not yet been brought into a clear picture because the sensitivity of the output is a function of subwatershed characteristics. To overcome this deficiency, three subwatersheds representing diverse local situations have been examined in detail, with particular attention having been given to identifying characteristics effecting the

2

applicability of alternative flood control measures.

The channel through Subwatershed 5 drains the largest area tributary to any of the three subwatersheds being studied in detail, 35.4 sq. mi., and this subwatershed is thus subject to the most severe flooding. This subwatershed enters the planning program with 36% of the land urbanized and reaches 100% urbanization during the third planning stage. Flooding begins at about an 85% frequency. The pressures of urbanization are so great in this subwatershed that land use adjustment is never applicable under normal conditions. Similarly, the area is so highly urbanized that economies of scale always cause channel improvement to be favored over flood proofing. Except when STF was set TRUE, channel improvement was always optimum in the first stage. The level of protection provided by the optimum channel ranged from 0.5% for Standard Project Conditions to 4% at a discount rate of 15% to 10% in the case described below. Flood proofing was never optimum in this subwatershed and land use adjustment was only optimum when IPP was set equal to 1000. Under this condition, a channel was built to provide protection against the 1% flood and land use adjustment was used at a level of 0.5% protection to supplement channel improvement in the first planning stage.

When channel improvement was eliminated from consideration, flood proofing was implemented to provide a 6% level of protection during all planning stages. Flood proofing only reduced the cost of flooding slightly and fell short of the benefits provided by channel improvement.

Subwatershed 9 was chosen for analysis because it represents physical conditions nearly opposite to those of Subwatershed 5. Subwatershed 9 is in an upstream area, with all the flood water originating within the subwatershed itself.
The initial subwatershed channel is only capable of carrying 40 cfs. from a drainage area of 3.9 sq. mi., hence flooding begins at about 73%. This subwatershed is initially only 1% urbanized, with potential urban development rising only to 45% during the period of analysis. Even with frequent flooding, potential damages are so small that channel improvement was selected only once during the entire range of Sensitivity Studies. This occurred when the discount rate was set equal to 0.01%. Under this condition, which is most favorable to the selection of structural measures as a means of reducing flood damage, a channel was built in the fourth planning stage to contain the 4% flood. Land use adjustment and flood proofing were also provided during this stage to

protect against the 3% flood. No additional measures were provided during the last planning stage. During all other project conditions considered, flood proofing was the measure most likely to be selected. The level of protection shifted drastically for slight changes in input data and proofing was completely eliminated during the project conditions more unfavorable to its selection. When PF was equal to 2.0, COEFDM equal to 0.025 (reducing damages), and when R was equal to 15%, proofing was never found to be optimum. Land use adjustment was ocasionally used to complement flood proofing. The land use measure was never optimum before the third stage, except for IPP equal to 1000, and was always continued for the remaining planning stages. Land use adjustment was not optimum during the initial planning stages because the rural environment precluded urban development even without formal application of the measure and hence few benefits could be found from its use.

Subwatershed 12 represents physical conditions that do not consistently favor structural measures over nonstructural measures, or vice versa, but gradually shift with time from nonstructural to structural measures. Subwatershed 12 is less urbanized than Subwatershed 5, more urbanized than Subwatershed 9; floods slightly more frequently than 9, less frequently than 5; and contains less area than 5, and more than 12. Under most project conditions a channel was built during the first stage to provide protection ranging from the 10% flood to the 0.5% flood and was usually enlarged during a larger stage. A channel was not built until the second stage when R was equal to 7% or 15%, under which conditions land use adjustment and flood proofing were applied in the first stage instead of the usual structural measures. Land use adjustment was usually provided during the first stage as a supplement to channel improvement. Increased urban growth in later stages usually increased land value to a point where land use adjustment was no longer advantageous. It is interesting to note, that when land use was not implemented, channel enlargement was delayed to a later stage because construction within the intervening period increased right-of-way cost to the point where enlargement was not so early feasible.

It is hoped that the above discussion, and this paper in general, will contribute to the understanding and eventual increased effectiveness of the considered flood control measures.

# Appendix I

## FORTRAN IV PROGRAM LISTING

```
$IBFTC DK0001  DECK
C     UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
C      ECONOMIC ANALYSIS OF ALTERNATIVE FLOOD CONTROL MEASURES
      COMMON A,A0(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
     1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
     2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
     3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,Q0(25),QS,QP,QL,QX(2,100),
     4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
     5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),T0(25),TIC(25),TCL
     6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
     7A,W,W0(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
      REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
     1ND,LF
      LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF,TRACE,C
     1HECK
      DIMENSION SUBA(25),ADDCS(25),            D1(7,8),D(3,25),Y(100),DF
     1(10),YY(10),QQ(2,10),XF4(25),XF3(25),XF2(25),XF1(25),A4(25),A3(25)
     2,A2(25),A1(25),IMPROV(25),IHN(25),IHE(25),IRN(25),IRE(25)
COMMENT  1--READ ALL INPUT FOR FLOOD CONTROL PLANNING PROGRAM
      READ(5,4) AQR,BDMAX,BDMIN,BW,COEFDM,CCY,CSM,CX,CIN,CBR,CRR,CLSF,
     1CLMIN,DD,ESM,FM,FP,HMAX,IPP,MFP,MANNU,MANNT,MANNR,MIN,MCH,MTLCH,
     2NIN,RPI,R,RWF,TIMST,TIME,TAW,VF,VLURST,VLAGST,VA,ZU,ZT,PF,LF,SF
      READ(5,5) NID,NSTEMX,NDF,MW
      READ(5,7) UNC,PTF,LTF,STF,TRACE,CHECK
      READ(5,8) ((AFCTR(I,J),J=1,11),I=1,3)
      READ(5,2) ((D1(I,J),J=1,7),I=1,8)
      READ(5,4) (DF(I),I=1,NDF)
      READ(5,8) ((Q43(IC,JU),JU=1,11),IC=1,11)
      READ(5,8) ((Q05(IC,JU),JU=1,11),IC=1,11)
      READ(5,4) (A0(I),I=1,MW)
      READ(5,4) (AW(I),I=1,MW)
      READ(5,3) ((CAP(I,J),J=1,8),I=1,MW)
      READ(5,1) ((D(I,J),I=1,3),J=1,MW)
      READ(5,4) (FQ(I),I=1,MW)
      READ(5,6) (INDEX(I,1),I=1,MW)
      READ(5,6) (INDEX(I,2),I=1,MW)
      READ(5,6) (ID(I),I=1,NID)
      READ(5,4) (K1(I),I=1,MW)
```

```
      READ(5,4) (K2(I),I=1,MW)
      READ(5,4) (LC(I),I=1,MW)
      READ(5,6) (LINING(I),I=1,MW)
      READ(5,4) (QO(I),I=1,MW)
      READ(5,4) (S(I),I=1,MW)
      READ(5,4) (SUBA(I),I=1,MW)
      READ(5,4) (SIC(I),I=1,MW)
      READ(5,4) (TCL(I),I=1,MW)
      READ(5,4) (TF(I),I=1,MW)
      READ(5,4) (TIC(I),I=1,MW)
      READ(5,1) ((USUBW(I,J),J=1,6),I=1,MW)
      READ(5,1) ((UTOTR(I,J),J=1,6),I=1,MW)
      READ(5,1) ((VALUE(I,J),J=1,6),I=1,MW)
      READ(5,4) (WO(I),I=1,MW)
    1 FORMAT(6F8.0)
    2 FORMAT(7F8.0)
    3 FORMAT(8F8.0)
    4 FORMAT(10F7.0)
    5 FORMAT(4I5)
    6 FORMAT(20I3)
    7 FORMAT(6L5)
    8 FORMAT(11F6.0)
COMMENT  2--CALCULATE FLOOD PLAIN AND SUBWATERSHED CONSTANTS
C     CALCULATE COMPOUND INTEREST FACTORS. USE SPECIAL INTEREST
C     FORMULAS IF DISCOUNT RATE IS ZERO
      PWF=1./((1.+RPI)**TIME)
      SPWF=((1.+RPI)**TIME-1.)/(RPI*(1.+RPI)**TIME)
      IF(R .GE. 0.0001)  GO TO 90
      CRF=1./TIME
      CRFSM=1./TIMST
      GSF=-0.5+TIME/2.0
      SPWFAC=TIME
      GO TO 91
   90 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.+R)**TIME-1.)/(R*(1.+R)**TIME)
   91 CRFAC=CRFSM
C     CALCULATE FACTORS FOR COMPUTING COST OF STRUCTURAL MEASURES AND
C     FLOOD PROOFING
      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=195.6*CSM*ESM*CCY*(CRFSM+MIN)
      CPF=0.5*DD*VF*FP*(CRF+MFP)*VLURST
C     CALCULATE AREA FACTOR FOR EACH SUBWATERSHED, FIRST FOR 43 AND
C     THEN FOR 0.5 PERCENT FLOOD
      DO 105 K=1,MW
```

```
      DO 103 I=1,10
      IF(AFCTR(1,I) .LE. AW(K) .AND. AFCTR(1,I+1) .GT. AW(K)) GO TO 104
  103 CONTINUE
  104 AFW(1,K)=AFCTR(2,I)+(ALOG(AW(K))-ALOG(AFCTR(1,I)))/(ALOG(AFCTR(1,I
     1+1))-ALOG(AFCTR(1,I)))*(AFCTR(2,I+1)-AFCTR(2,I))
      AFW(2,K)=AFCTR(3,I)+(ALOG(AW(K))-ALOG(AFCTR(1,I)))/(ALOG(AFCTR(1,I
     1+1))-ALOG(AFCTR(1,I)))*(AFCTR(3,I+1)-AFCTR(3,I))
  105 CONTINUE
      DO 107 I=1,MW
C     INITIALIZE FACTORS IN GUMBEL EQUATION
      XF4(I)=0.
      XF3(I)=0.
      XF2(I)=0.
      XF1(I)=0.
      A4(I)=0.
      A3(I)=0.
      A2(I)=0.
      A1(I)=0.
C     INITIALIZE ARRAYS LOC, TO, ADDCS, OUTPUT, AND CAP
      LOC(I)=-1
      TO(I)=0.
      ADDCS(I)=0.
      DO 106 K=1,13
  106 OUTPUT(I,K)=0.0
      DO 107 J=9,11
  107 CAP(I,J)=0.
C     CALCULATE REDUCED VARIATES FOR USE WITH GUMBEL ANALYSIS.  -Y- FOR
C     FLOOD PEAKS USED IN COMPUTING ANNUAL DAMAGES. -YY- FOR POTENTIAL
C     DESIGN FLOODS
      DO 108 I=1,100
      P=I
      PN=1.00-(P-0.5)/100.
      TEMP = 1./ALOG(1./PN)
      Y(I) = ALOG(TEMP)
  108 CONTINUE
      DO 109 I=1,NDF
      PN=1.00-(DF(I))
      TEMP=1./ALOG(1./PN)
      YY(I)=ALOG(TEMP)
  109 CONTINUE
C     DETERMINE INITIAL STATE OF IMPROVEMENT FOR SUBWATERSHED CHANNELS.
C     IF TOTAL CHANNEL LENGTH IS IMPROVED SET CHANEL(NW) TRUE. OTHERWISE
C     SET CHANEL(NW) FALSE.  DETERMINE CHANNEL TOP WIDTH FOR
C     IMPROVED CHANNELS
      DO 111 NW=1,MW
      IF(SIC(NW) .EQ. LC(NW))  GO TO 110
      CHANEL(NW)=.FALSE.
      GO TO 111
  110 CHANEL(NW)=.TRUE.
      X=BDMIN
   25 H=((Q0(NW)*MANNU*(X+2.*(SQRT(1.+ZU**2)))**0.667)/(SQRT(S(NW))*1.49
     1*(X+ZU)**1.667))**0.375
```

```
      IF(H .LE. HMAX .OR. X .GE. BDMAX)  GO TO 26
      X=X+0.5
      GO TO 25
   26 B=X*H
      TO(NW)=B+2.*ZU*H
  111 CONTINUE
      NSTAGE=1
C     INITIALIZE PROGRAM VARIABLES
      IEXIT=0
      ACP=0.
      ACS=0.
      ACU=0.
      ACD=0.
      ACF=0.
      ACL=0.
      PP=PTF
      LL=LTF
      SS=STF
COMMENT  3--ENTRY POINT FOR EACH STAGE
  112 DO 113 NW=1,MW
C     INITIALIZE RIGHT-OF-WAY COST, CONDITION OF CHANNEL IMPROVEMENT,
C     NEW AND EXTENDED HIGHWAY AND RAILWAY BRIDGES
      IHN(NW)=0
      IHE(NW)=0
      IRN(NW)=0
      IRE(NW)=0
      IMPROV(NW)=1
  113 RC(NW)=-1.
C     INITIALIZE TOTAL ANNUAL COST OF MEASURES
      TSWCS=0.
      TSWCL=0.
      TSWCP=0.
      TSWCD=0.
      TSWCU=0.
      TSWCF=0.
C     BEGIN CALCULATIONS FOR MOST UPSTREAM SUBWATERSHED
      NW=1
COMMENT  4--ENTRY POINT FOR INDIVIDUAL SUBWATERSHED OPTIMIZATION
C     CALCULATIONS
      IF (CHECK .AND. (.NOT. TRACE))  WRITE(6,1008)
 1008 FORMAT(1H1//30X,42HFOLLOWING OPTIMIZATION THROUGH INNER LOOPS  /1X,
     14H BEG,13X,8HCHANNELS,16X,8HLOCATION,16X,8HPROOFING,12X,7HCOST OF,
     22X,7HCOST OF,5X,5HTOTAL/11X,2H S,9X,2HQS,8X,2HCS,1X,2H L,9X,2HQL,
     38X,2HCL,1X,2H P,9X,2HQP,8X,2HCP,4X,25HFLOODING UNCERTAINTY COST  )
C     DISCOUNTED AVERAGE SUBWATERSHED URBANIZATION DURING STAGE
   49 UN=USUBW(NW,NSTAGE)+(GSF*(USUBW(NW,NSTAGE+1)-USUBW(NW,NSTAGE)))/
     1TIME
      UZ=USUBW(NW,NSTAGE)
      IF(LOC(NW) .GT. 0)  GO TO 53
      GO TO 54
   53 MN=LOC(NW)
      UZ=USUBW(NW,MN)
```

```
C     FACTORS FOR COMPUTING FLOOD PROOFING COST
   54 PA=CPF *UN*K2(NW)*K1(NW)**2
      PB=CPF *UZ*K2(NW)*K1(NW)**2
      PC=PA-PB
C     LOCATE URBAN INTERVAL FOR SUBWATERSHED.  CALCULATE AGRICULTURAL
C     INCOME -FA- AND AGRICULTURAL DAMAGE -IA--($/ACRE)
      DO 48 NU=1,7
      IF(UN .GE. D1(NU,1) .AND. UN .LT. D1(NU,2))  GO TO 50
   48 CONTINUE
   50 FA=D1(NU,6)*D(1,NW)+D1(NU,7)*D(2,NW)+D1(NU,8)*D(3,NW)
      IA=D1(NU,3)*D(1,NW)+D1(NU,4)*D(2,NW)+D1(NU,5)*D(3,NW)
C     CALCULATE COST OF LAND USE MEASURES-($/ACRE)
      CLU=CRF*(VALUE(NW,NSTAGE)-PWF*VALUE(NW,NSTAGE+1)-SPWF*(IA+IPP*UN))
      IF(CLU .LT. CLMIN)  CLU=CLMIN
      LA=CLU*K1(NW)*K2(NW)
COMMENT  5--HYDROLOGY...FLOOD FLOWS IN CFS ARE CALCULATED AT 1 PERCENT
C     INTERVALS FOR EACH FREQUENCY OF OCCURANCE FROM 1/2 PERCENT THROUGH
C     99 1/2 PER CENT BY THE GUMBEL METHOD.  FLOWS ARE CALCULATED AT THE
C     BEGINNING AND END OF EACH STAGE AND DISCOUNTED TO OBTAIN MEAN
C     FLOWS DURING THE STAGE.  DETERMINE FREQUENCY AT WHICH
C     FLOODING BEGINS
   24 IF(CHANEL(NW))  GO TO 31
C     CALCULATE END OF STAGE FLOWS FOR UNIMPROVED CHANNEL CONDITIONS.
      C=TIC(NW)/TCL(NW)
      U=UTOTR(NW,NSTAGE+1)
      CALL PLACEA(QX1,U,C,Q43)
      CALL PLACEA(QY1,U,C,Q05)
      QXX=(AW(NW)*AFW(1,NW)*QX1)/TAW
      QY=(AW(NW)*AFW(2,NW)*QY1)/TAW
      XF4(NW)=((QY*0.579)-(QXX*5.296))/(-4.718)
      A4(NW)=(4.718)/(QY-QXX)
C     CALCULATE BEGINNING OF STAGE FLOWS FOR UNIMPROVED CHANNEL.
      U=UTOTR(NW,NSTAGE)
      CALL PLACEA(QX1,U,C,Q43)
      CALL PLACEA(QY1,U,C,Q05)
      QXX=(AW(NW)*AFW(1,NW)*QX1)/TAW
      QY=(AW(NW)*AFW(2,NW)*QY1)/TAW
      XF3(NW)=((QY*0.579)-(QXX*5.296))/(-4.718)
      A3(NW)=(4.718)/(QY-QXX)
C     CALCULATE END OF STAGE FLOWS FOR IMPROVED CHANNEL CONDITIONS.
   31 C=(TIC(NW)+LC(NW)-SIC(NW))/TCL(NW)
      U=UTOTR(NW,NSTAGE+1)
      CALL PLACEA(QX1,U,C,Q43)
      CALL PLACEA(QY1,U,C,Q05)
      QXX=(AW(NW)*AFW(1,NW)*QX1)/TAW
      QY=(AW(NW)*AFW(2,NW)*QY1)/TAW
      XF2(NW)=((QY*0.579)-(QXX*5.296))/(-4.718)
      A2(NW)=(4.718)/(QY-QXX)
C     CALCULATE BEGINNING OF STAGE FLOWS FOR IMPROVED CHANNEL
      U=UTOTR(NW,NSTAGE)
      CALL PLACEA(QX1,U,C,Q43)
      CALL PLACEA(QY1,U,C,Q05)
```

```
      QXX=(AW(NW)*AFW(1,NW)*QX1)/TAW
      QY=(AW(NW)*AFW(2,NW)*QY1)/TAW
      XF1(NW)=((QY*0.579)-(QXX*5.296))/(-4.718)
      A1(NW)=(4.718)/(QY-QXX)
   47 IF(CHANEL(NW))  GO TO 39
C     CALCULATE DISCOUNTED FLOWS IN EXCESS OF CHANNEL CAPACITY FOR
C     UNIMPROVED CHANNELS.
      DO 38 I=1,100
      Q3=Y(I)/A3(NW)+XF3(NW)
      Q4=Y(I)/A4(NW)+XF4(NW)
      QDIS=Q3+(GSF*(Q4-Q3))/TIME
      QX(1,I)=QDIS-Q0(NW)
      IF(QX(1,I)  .LT. 0.)  QX(1,I)=0.
   38 CONTINUE
C     CALCULATE DISCOUNTED FLOWS IN EXCESS OF CHANNEL CAPACITY FOR
C     IMPROVED CHANNELS.
   39 DO 40 I=1,100
      Q1=Y(I)/A1(NW)+XF1(NW)
      Q2=Y(I)/A2(NW)+XF2(NW)
      QDIS=Q1+(GSF*(Q2-Q1))/TIME
      QX(2,I)=QDIS-Q0(NW)
      IF(QX(2,I)  .LT. 0.)  QX(2,I)=0.
   40 CONTINUE
C     CALCULATE DISCOUNTED DESIGN FLOOD FLOWS FOR SELECTED ALTERNATIVE
C     LEVELS OF PROTECTION.  IF CHANNEL IS UNIMPROVED CALCULATE FLOWS
C     FOR BOTH UNIMPROVED AND IMPROVED CONDITIONS,  IF CHANNEL IS
C     IMPROVED CALCULATE FLOWS FOR IMPROVED CONDITIONS ONLY.
      IF(CHANEL(NW))  GO TO 43
      DO 42 I=1,NDF
      QTEMP4=YY(I)/A4(NW)+XF4(NW)
      QTEMP3=YY(I)/A3(NW)+XF3(NW)
   42 QQ(1,I)=QTEMP3+(GSF*(QTEMP4-QTEMP3))/TIME
   43 DO 44 I=1,NDF
      QTEMP2=YY(I)/A2(NW)+XF2(NW)
      QTEMP1=YY(I)/A1(NW)+XF1(NW)
   44 QQ(2,I)=QTEMP1+(GSF*(QTEMP2-QTEMP1))/TIME
C     USING GUMBELS EQUATION CALCULATE THE FREQUENCY AT WHICH FLOODING
C     BEGINS.
      II=1
      IF(CHANEL(NW))  II=2
      YDIF=YY(1)-YY(NDF)
      XF=(QQ(II,NDF)*YY(1)/(YDIF))-(QQ(II,1)*YY(NDF)/(YDIF))
      AG=-YDIF/(QQ(II,NDF)-QQ(II,1))
      YF=AG*Q0(NW)-AG*XF
      IF(YF .LT. 5.296)  GO TO 45
      F=0.
      GO TO 46
   45 TEMP=EXP(-YF)
      PN=EXP(-TEMP)
      F=1.-PN
   46 CONTINUE
COMMENT  6--INITIALIZE TEMPORARY STORAGE LOCATIONS.  SET INITIAL
```

```
C       CONDITIONS OF IMPROVEMENTS MADE WITHIN STAGE FOR SUBWATERSHED
        NDTEMP=0.
        FDTEMP=0.
        ATEMP=0.
        HETEMP=0.
        HTEMP=0.
        RTEMP=0.
        RETEMP=0.
        STEMP=0.
        TTEMP=0.
        WTEMP=0.
        LGTEMP=LINING(NW)
        ST=0.
        ND=0.
        FD=0.
        HN=0.
        HE=0.
        RN=0.
        RE=0.
        T=0.
        W=0.
        A=0.
C       SET INITIAL DESIGN FLOOD FOR PROOFING, LAND USE, AND CHANNEL
C       IMPROVEMENT EQUAL TO CHANNEL CAPACITY AND INITIALIZE COST OF
C       MEASURES FOR SUBWATERSHED STAGE
        QP=Q0(NW)
        QL=Q0(NW)
        QS=Q0(NW)
        CTT=0.
        CT=0.
C       SET LOGICAL DECISION PARAMETERS.  CDSTE EQUAL TO FALSE INDICATES
C       THAT DOWNSTREAN COSTS HAVE NOT BEEN CALCULATED FOR STAGE.  LG,PG,
C       AND SG EQUAL TO FALSE INDICATES THAT PROOFING, LAND USE, AND
C       CHANNEL IMPROVEMENT HAVE NOT YET BEEN PROVEN TO BE UNECONOMICAL
C       DURING SUBWATERSHED STAGE.  SET LEVEL OF PROTECTION TO CORRESPOND
C       TO BEGINNING FREQUENCY OF FLOODING
        CDSTE=.FALSE.
        LG=.FALSE.
        SG=.FALSE.
        PG=.FALSE.
        OUTPUT(NW,1)=F
        IF(CHANEL(NW))  OUTPUT(NW,2)=F
        OUTPUT(NW,3)=Q0(NW)
COMMENT  7--CALCULATE COST OF UNRESTRICTED FLOODING
        NN=1
        IF(CHANEL(NW))  NN=2
        CALL CD1(NN)
        CF=CD+CU
        CT=CF
        OUTPUT(NW,11)=CD
        OUTPUT(NW,12)=CU
        OUTPUT(NW,13)=CT
```

```
      IF (TRACE)  WRITE(6,1009)
 1009 FORMAT(1H1//30X,42HFOLLOWING OPTIMIZATION THROUGH INNER LOOPS  /1X,
     14H BEG,13X,8HCHANNELS,16X,8HLOCATION,16X,8HPROOFING,12X,7HCOST OF,
     22X,7HCOST OF,5X,5HTOTAL/11X,2H S,9X,2HQS,8X,2HCS,1X,2H L,9X,2HQL,
     38X,2HCL,1X,2H P,9X,2HQP,8X,2HCP,4X,25HFLOODING UNCERTAINTY COST  )
      IF(CHECK) WRITE(6,1007) NW,(OUTPUT(NW,I),I=1,13)
 1007 FORMAT(1X,I2,2HBG,2PF5.1,3(2PF4.0,0PF10.0,F10.0),3F10.0)
      IF(CT .EQ. 0.)  GO TO 1000
      IF(PP)  GO TO 207
COMMENT  8--DETERMINE THE OPTIMUM LEVEL OF FLOOD PROOFING
      PT=1.
      DO 206 IP=1,NDF
      IF(TRACE) WRITE(6,1001) NW
 1001 FORMAT(1X,I2,3H  A,3H  P)
      P=DF(IP)
      IF(F .LT. P)  GO TO 206
      QP=QQ(1,IP)
      IF(CHANEL(NW))  QP=QQ(2,IP)
      CP=PF*PA*(QP-QS)**0.75
      IF(CP .EQ. 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(NN)
      IF(PT .GE. 2. .AND. CTT .GT. 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(NW,5)=0.0
      OUTPUT(NW,6)=0.0
      OUTPUT(NW,7)=0.0
      OUTPUT(NW,8)=P
      OUTPUT(NW,9)=QP
      OUTPUT(NW,10)=CP
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,13)=CT
      IF(CHECK) WRITE(6,1002) NW,(OUTPUT(NW,I),I=1,13)
 1002 FORMAT(1X,I2,2H A,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
  205 PT=PT+1.
  206 CONTINUE
  207 IF(LL)  GO TO 220
COMMENT  9--DETERMINE THE OPTIMUM LEVEL OF LAND USE ADJUSTMENT
      DO 215 IL=1,NDF
      IF(TRACE) WRITE(6,1003) NW
```

```
 1003 FORMAT(1X,I2,3H  B,3H  L)
      L=DF(IL)
      IF(F .LT. L) GO TO 215
      P=0.
      CP=0.
      QP=Q0(NW)
      QL=QQ(1,IL)
      IF(CHANEL(NW))  QL=QQ(2,IL)
      CL=LF*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(NN)
      CTT=CD+CL+CU
      IF(CTT .LT.  CT)  GO TO 208
      GO TO 2080
  208 CT=CTT
      OUTPUT(NW,5)=L
      OUTPUT(NW,6)=QL
      OUTPUT(NW,7)=CL
      OUTPUT(NW,8)=0.0
      OUTPUT(NW,9)=0.0
      OUTPUT(NW,10)=0.0
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,13)=CT
      IF(CHECK) WRITE(6,1004) NW,(OUTPUT(NW,I),I=1,13)
 1004 FORMAT(1X,I2,2H B,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
 2080 IF(PP)  GO TO 215
COMMENT 10--DETERMINE THE OPTIMUM COMBINATION OF FLOOD PROOFING AND
C     LAND USE ADJUSTMENT
      PT=1.
      DO 214 IP=1,NDF
      IF(TRACE) WRITE(6,1005) NW
 1005 FORMAT(1X,I2,3H  C,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=PF*PB*(QP-QS)**0.75
      IF(QP .GT. QL) CP=CP+PF*PC*((QP-QS)**0.375-(QP-QL)**0.375)**2
      IF(CP .EQ. 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(NN)
      IF(PT .GE. 2.)  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(NW,5)=L
      OUTPUT(NW,6)=QL
      OUTPUT(NW,7)=CL
      OUTPUT(NW,8)=P
      OUTPUT(NW,9)=QP
      OUTPUT(NW,10)=CP
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,13)=CT
      IF(CHECK) WRITE(6,1006) NW,(OUTPUT(NW,I),I=1,13)
 1006 FORMAT(1X,I2,2H C,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
 213  PT=PT+1.
 214  CONTINUE
      IF(LL)  GO TO 220
 215  CONTINUE
 220  IF(SS)  GO TO 1000
COMMENT II--DETERMINE THE OPTIMUM LEVEL OF CHANNEL IMPROVEMENT
      DO 999 IS=1,NDF
      IIS=IS+1
      IF(TRACE) WRITE(6,1011) NW
 1011 FORMAT(1X,I2,3H  D,3H  S)
C     IEXIT TERMINATES PROGRAM IF ERROR CAUSES EXCESSIVE LOOPING
      IEXIT=IEXIT+1
      IF(IEXIT .GT. 10*MW*NSTEMX)  GO TO 893
      ST=DF(IS)
      IF(F .LT.ST)  GO TO 999
      QP=QQ(2,IS)
      QL=QP
      QS=QP
      CALL STR
      IF(CS .GT. CT)  GO TO 1000
      CALL CDI(2)
      IF(CS+CD+CU .GT. CT)  GO TO 227
      IF(CHANEL(NW) .OR. SG)  GO TO 221
      GO TO 222
 221  CDST=0.0
      GO TO 223
 222  IF(CDSTE)  GO TO 223
      CALL COST
      CDSTE=.TRUE.
 223  CTT=CS+CD+CU
      IF(CS+CDST .GT. CT)  GO TO 1000
      IF(CTT+CDST .LT. CT)  GO TO 224
      GO TO 227
 224  CT=CTT
      SG=.TRUE.
      OUTPUT(NW,2)=ST
```

```
      OUTPUT(NW,3)=QS
      OUTPUT(NW,4)=CS
      DO 225 M=5,10
  225 OUTPUT(NW,M)=0.
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,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(6,1012) NW,(OUTPUT(NW,I),I=1,13)
 1012 FORMAT(1X,I2,2H D,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
  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,I2,3H  E,5H  S+P)
COMMENT 12--DETERMINE OPTIMUM LEVEL OF FLOOD PROOFING USED TO SUPPLEMEN
C     CHANNEL IMPROVEMENT
      P=DF(IP)
      QP=QQ(2,IP)
      CP=PF*PA*(QP-QS)**0.75
      IF(CP .EQ. 0.)  GO TO 238
      IF(CP+CS .GT. CT)  GO TO 238
      CALL CD1(2)
      IF(PT .GE. 2.)  GO TO 228
      GO TO 229
  228 IF(CTT .LT. CD+CP+CS+CU)  GO TO 238
  229 CTT=CD+CP+CS+CU
      IF(SG .OR. CHANEL(NW))  GO TO 230
      GO TO 232
  230 IF(CTT .LT. CT)  GO TO 231
      GO TO 236
  232 IF(.NOT. CDSTE)  GO TO 233
      GO TO 234
  233 CALL COST
      CDSTE=.TRUE.
      IF(CS+CDST .GT. CT)  GO TO 1000
  234 IF(CTT+CDST .LT. CT)  GO TO 231
      GO TO 236
  231 CT=CTT
      SG=.TRUE.
      OUTPUT(NW,2)=ST
```

```
      OUTPUT(NW,3)=QS
      OUTPUT(NW,4)=CS
      OUTPUT(NW,5)=0.0
      OUTPUT(NW,6)=0.0
      OUTPUT(NW,7)=0.0
      OUTPUT(NW,8)=P
      OUTPUT(NW,9)=QP
      OUTPUT(NW,10)=CP
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,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(NW,I),I=1,13)
 1014 FORMAT(1X,I2,2H E,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
  236 PT=PT+1.
  237 CONTINUE
  238 IF(LL)  GO TO 999
COMMENT  I3--DETERMINE OPTIMUM LEVEL OF LAND USE ADJUSTMENT
C     TO SUPPLEMENT CHANNEL IMPROVEMENT
      DO 249 IL=IIS,NDF
      IF(TRACE) WRITE(6,1015) NW
 1015 FORMAT(1X,I2,3H  F,5H  S+L)
      L=DF(IL)
      QL=QQ(2,IL)
      CL=LF*LA*(QL-QS)**0.375
      IF(CL+CS .GT. CT)  GO TO 999
      CALL CD2(2)
      CTT=CD+CL+CS+CU
      IF(SG .OR. CHANEL(NW))  GO TO 239
      GO TO 241
  239 IF(CTT .LT. CT)  GO TO 240
      GO TO 226
  241 IF(.NOT. CDSTE)  GO TO 242
      GO TO 243
  242 CALL COST
      CDSTE=.TRUE.
      IF(CS+CDST .GT. CT)  GO TO 1000
  243 IF(CTT+CDST .LT. CT)  GO TO 240
      GO TO 226
  240 CT=CTT
      SG=.TRUE.
      OUTPUT(NW,2)=ST
```

```
      OUTPUT(NW,3)=QS
      OUTPUT(NW,4)=CS
      OUTPUT(NW,5)=L
      OUTPUT(NW,6)=QL
      OUTPUT(NW,7)=CL
      OUTPUT(NW,8)=0.0
      OUTPUT(NW,9)=0.0
      OUTPUT(NW,10)=0.0
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,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(NW,I),I=1,13)
 1016 FORMAT(1X,I2,2H F,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
  226 IF(PP)  GO TO 249
COMMENT 14--DETERMINE OPTIMUM LEVEL OF PROTECTION PROVIDED BY ALL
C     THREE TYPES OF MEASURES IN COMBINATION
      PT=1.
      DO 2499 IP=IIS,NDF
      IF(TRACE) WRITE(6,1017) NW
 1017 FORMAT(1X,I2,3H  G,7H  S+L+P)
      P=DF(IP)
      QP=QQ(2,IP)
      CP=PF*PB*(QP-QS)**0.75
      IF(QP .GT. QL) CP=CP+PF*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(2)
      IF(PT .GE. 2.)  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(SG .OR. CHANEL(NW))  GO TO 2471
      GO TO 2472
 2471 IF(CTT .LT. CT)  GO TO 247
      GO TO 248
 2472 IF(.NOT. CDSTE)  GO TO 2473
      GO TO 2474
 2473 CALL COST
      CDSTE=.TRUE.
      IF(CS+CDST .GT. CT)  GO TO 1000
 2474 IF(CTT+CDST .LT. CT)  GO TO 247
```

```
      GO TO 248
  247 CT=CTT
      SG=.TRUE.
      OUTPUT(NW,2)=ST
      OUTPUT(NW,3)=QS
      OUTPUT(NW,4)=CS
      OUTPUT(NW,5)=L
      OUTPUT(NW,6)=QL
      OUTPUT(NW,7)=CL
      OUTPUT(NW,8)=P
      OUTPUT(NW,9)=QP
      OUTPUT(NW,10)=CP
      OUTPUT(NW,11)=CD
      OUTPUT(NW,12)=CU
      OUTPUT(NW,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(6,1018) NW,(OUTPUT(NW,I),I=1,13)
 1018 FORMAT(1X,I2,2H G,2PF5.2,3(2PF4.2,0PF10.0,F10.0),3F10.0)
  248 PT=PT+1.
 2499 CONTINUE
  249 CONTINUE
  999 CONTINUE
 1000 CONTINUE
COMMENT 15--AT THIS POINT TOTAL ECONOMIC COST OF FLOODING FOR THE
C     SUBWATERSHED UNDER CONSIDERATION HAS BEEN MINIMIZED THROUGH THE
C     OPTIMUM COMBINATION OF FLOOD CONTROL MEASURES AND RESIDUAL
C     FLOODING.
C     INITIAL CONSTANTS ARE NOW SET TO PROPER VALUES, NECESSARY CHANGES
C     ARE MADE IN ARRAYS, AND THE PROGRAM EITHER RETURNS TO OPTIMIZE THE
C     NEXT SUBWATERSHED, OR PRINTS A SUMMARY OF SELECTED MEASURES FOR
C     THE CURRENT STAGE AND BEGINS ANEW FOR THE NEXT STAGE, CONTINUING
C     UNTIL EACH SUBWATERSHED HAS BEEN OPTIMIZED FOR EACH STAGE.
C     SET PP,LL,AND SS TO FALSE TO CONSIDER PROOFING, LAND USE, AND
C     CHANNEL IMPROVEMENT FOR THE NEXT DOWNSTREAM SUBWATERSHED
      IF(PTF)  GO TO 282
      PP=.FALSE.
  282 IF(LTF)  GO TO 283
      LL=.FALSE.
C     ACCOUNT FOR LAND USE
      IF(OUTPUT(NW,5) .GT. 0.)  GO TO 260
      LOC(NW)=-1
      GO TO 283
```

```
  260 IF(LOC(NW) .LT. 0)  LOC(NW)=NSTAGE
  283 IF(STF)  GO TO 271
      SS=.FALSE.
C     ACCOUNT FOR CHANNEL LINING
      LINING(NW)=LGTEMP
C     ACCOUNT FOR BRIDGES BUILT AND EXTENDED DURING STAGE
      IHN(NW)=HTEMP
      IHE(NW)=HETEMP
      IRE(NW)=RETEMP
      IRN(NW)=RTEMP
      NDT(NW)=NDTEMP
      FDA(NW)=NDTEMP
C     ADD CONTINUING COSTS OF CHANNEL IMPROVEMENT MADE DURING PREVIOUS
C     STAGES
      OUTPUT(NW,4)=OUTPUT(NW,4)+ADDCS(NW)
      OUTPUT(NW,13)=OUTPUT(NW,13)+ADDCS(NW)
      ADDCS(NW)=OUTPUT(NW,4)
      IF(STEMP .GT. 0.0)  GO TO 262
      GO TO 271
C     DETERMINE IF SUBWATERSHED CHANNEL REMAINS UNCHANGED. WAS INITIALLY
C     IMPROVED, OR WAS ENLARGED DURING STAGE
  262 IF(QO(NW) .LT. OUTPUT(NW,3) .AND. .NOT. CHANEL(NW)) IMPROV(NW)=2
      IF(QO(NW) .LT. OUTPUT(NW,3) .AND. CHANEL(NW)) IMPROV(NW)=3
C     ADJUST CHANNEL DIMENSIONS
      QO(NW)=OUTPUT(NW,3)
      TO(NW)=TTEMP
      WO(NW)=WTEMP
      AO(NW)=ATEMP
      CHANEL(NW)=.TRUE.
C     ADJUST AMOUNT OF CHANNELIZATION
      N=INDEX(NW,1)
      J=INDEX(NW,2)
      IF(N .EQ. 0)  GO TO 264
      DO 263 I=N,J
      NWD=ID(I)
      TIC(NWD)=TIC(NWD)+(LC(NW)-SIC(NW))
  263 CONTINUE
  264 TIC(NW)=TIC(NW)+(LC(NW)-SIC(NW))
      SIC(NW)=LC(NW)
C     ADJUST FOR BRIDGE CHANGES DURING STAGE
C     CAP(NW,9)-NUMBER OF CHANGED HIGHWAY BRIDGES
C     CAP(NW,10)-NUMBER OF CHANGED RAILWAY BRIDGES
C     CAP(NW,11)-CAPACITY OF ALL CHANGED BRIDGES-(IN CFS)
      CAP(NW,11)=OUTPUT(NW,3)
      IF(CAP(NW,9) .LT. HETEMP)  GO TO 265
      CAP(NW,9)=CAP(NW,9)+HTEMP
      GO TO 266
  265 CAP(NW,9)=HETEMP+HTEMP
  266 CAP(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(NW,3)*FQ(NW))  CAP(NW,I)=-1.
```

```
  269 DO 270 I=7,8
      IF(CAP(NW,I) .LT. 0.)  GO TO 271
  270 IF(CAP(NW,I) .LT. OUTPUT(NW,3)*FQ(NW))  CAP(NW,I)=-1.
  271 NW=NW+1
      IF(NW .GT. MW)  GO TO 884
C     RETURN TO NEXT SUBWATERSHED, SAME STAGE
      GO TO 49
COMMENT 16--PRINT SUMMARY OF MEASURES AND COSTS FOR EACH STAGE
  884 WRITE(6,885) NSTAGE
  885 FORMAT(1H1//////18H SUMMARY FOR STAGE I2)
      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      )
      DO 5000 NW=1,MW
      WRITE(6,888) NW,(OUTPUT(NW,I),I=1,13)
  888 FORMAT(1X,I2,2PF7.2,4X,F4.1,0P2F8.0,4X,2PF4.1,0P2F8.0,4X,2PF4.1,0P
     12F8.0,3F11.0/)
 5000 CONTINUE
C     TABULATE AND PRINT TOTAL ANNUAL COSTS FOR STAGE
      DO 891 NW=1,MW
      TSWCS=TSWCS+OUTPUT(NW,4)
      TSWCL=TSWCL+OUTPUT(NW,7)
      TSWCP=TSWCP+OUTPUT(NW,10)
      TSWCD=TSWCD+OUTPUT(NW,11)
      TSWCU=TSWCU+OUTPUT(NW,12)
      TSWCF=TSWCP+TSWCL+TSWCS+TSWCU+TSWCD
  891 CONTINUE
      WRITE (6,892) TSWCS, TSWCL,TSWCP,TSWCD,TSWCU,TSWCF
  892 FORMAT(1X,11HTOTAL COSTS,14X,F8.0,16X,F8.0,16X,F8.0,3X,F8.0,3X,F8.
     10,3X,F8.0////)
COMMENT 17--EVALUATE AND PRINT SUMMARY OF CHANNEL IMPROVEMENTS
      IF(STF)  GO TO 739
      WRITE(6,700)
  700 FORMAT(1H1,40X,31HSUMMARY OF CHANNEL IMPROVEMENTS//128H UNIT      T
     1YPE OF         CURRENT     CAPACITY  X-SECTION   TOP     ROW  DEPTH  D
     2ROP STRUCTURES  HIGHWAY BRIDGES   RAILROAD BRIDGES      )
      WRITE(6,701)
  701 FORMAT(10X,7HCHANNEL,7X,7HMEASURE,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./)
      DO 703 NW=1,MW
      IF(.NOT. CHANEL(NW))  GO TO 703
      KD=NDT(NW)
      FD=FDA(NW)
      IF(LINING(NW) .LE. 2)                      HO=(TO(NW)-SQRT(TO(N
     1W)**2-4.0*ZU*AO(NW)))/(2.0*ZU)
      IF(LINING(NW) .EQ. 3)  HO=(TO(NW)-SQRT(TO(NW)**2-4.0*ZT*AO(NW)))/(
     12.0*ZT)
```

```
      IF(LINING(NW) .EQ. 4)  HO=AO(NW)/TO(NW)
      ICAP9=CAP(NW,9)
      ICDIF=IHN(NW)+IHE(NW)
      IUH=ABS(ICAP9-ICDIF)
      DO 704 I=1,6
      IF(CAP(NW,I) .LT. 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(NW) .EQ. 1) IUR=CAP(NW,10)
      DO 706 I=7,8
      IF(CAP(NW,I) .LT. 0.)  GO TO 707
  706 IUR=IUR+1
  707 III=LINING(NW)
      GO TO (711,712,713,714),III
  711 IF(IMPROV(NW)-2) 715,716,717
  712 IF(IMPROV(NW)-2) 718,719,720
  713 IF(IMPROV(NW)-2) 721,722,723
  714 IF(IMPROV(NW)-2) 724,725,726
  715 WRITE(6,727) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  716 WRITE(6,728) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  717 WRITE(6,729) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  718 WRITE(6,730) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  719 WRITE(6,731) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  720 WRITE(6,732) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  721 WRITE(6,733) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  722 WRITE(6,734) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  723 WRITE(6,735) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  724 WRITE(6,736) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
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```
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  725 WRITE(6,737) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
      GO TO 703
  726 WRITE(6,738) NW,QO(NW),AO(NW),TO(NW),WO(NW),HO,KD,FD,IUH,IHN(NW),
     1IHE(NW),IUR,IRN(NW),IRE(NW)
  703 CONTINUE
  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)
  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)
  729 FORMAT(1X,I2,2X,17HUNLINED W/O DROPS,2X,9HEXTENDED ,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)
  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)
  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)
  732 FORMAT(1X,I2,2X,17HUNLINED W DROPS  ,2X,9HEXTENDED ,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)
  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)
  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)
  735 FORMAT(1X,I2,2X,17HTRAPEZOIDAL LINED,2X,9HEXTENDED ,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)
  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)
  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)
  738 FORMAT(1X,I2,2X,17HRECTANGULAR LINED,2X,9HEXTENDED ,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)
COMMENT 18--EVALUATE AND PRINT SUMMARY OF LAND USE MEASURES
  739 IF(LTF)  GO TO 743
      WRITE (6,740)
  740 FORMAT(1H////,40X,28HSUMMARY OF LOCATION MEASURES//,35X,4HUNIT,10X
     1,27HAREA OF RESTRICTED LAND USE    )
      DO 741 NW=1,MW
      IF(LOC(NW) .LT. 0)  GO TO 741
      AREA=K1(NW)*K2(NW)*(OUTPUT(NW,6)-OUTPUT(NW,3))**0.375
      WRITE(6,742)  NW,AREA
  742 FORMAT(36X,I2,15X,F10.0,6H ACRES)
  741 CONTINUE
COMMENT 19--EVALUATE AND PRINT SUMMARY OF FLOOD PROOFING MEASURES
  743 IF(PTF)  GO TO 747
      WRITE(6,744)
  744 FORMAT(1H////,40X,34HSUMMARY OF FLOOD PROOFING MEASURES//,35X,4HUN
     1IT,10X,14HAREA PROTECTED )
      DO 745 NW=1,MW
      IF(OUTPUT(NW,9) .EQ. 0.)  GO TO 745
      AREA=K1(NW)*K2(NW)*(OUTPUT(NW,9)-OUTPUT(NW,3))**0.375
      WRITE(6,746) NW,AREA
```

```
COMMENT 20--TABULATE AND STORE ANNUAL AVERAGE COSTS FOR STAGES
C     COMPLETED THEN INCREMENT-NSTAGE- AND RETURN TO OPTIMIZE FLOOD
C     CONTROL MEASURES FOR NEXT STAGE OR PRINT SUMMARY OF ANNUAL
C     AVERAGE COSTS AND END PROGRAM
  746 FORMAT(36X,I2,15X,F10.0,6H ACRES )
  745 CONTINUE
  747 XTIME=NSTAGE-1
      PWFAC=1./((1.+R)**(TIME*XTIME))
      ACP=ACP+CRFAC*SPWFAC*PWFAC*TSWCP
      ACS=ACS+CRFAC*SPWFAC*PWFAC*TSWCS
      ACU=ACU+CRFAC*SPWFAC*PWFAC*TSWCU
      ACD=ACD+CRFAC*SPWFAC*PWFAC*TSWCD
      ACL=ACL+CRFAC*SPWFAC*PWFAC*TSWCL
      NSTAGE=NSTAGE+1
      IF(NSTAGE .GT. NSTEMX)  GO TO 889
      DO 272 I=1,MW
      DO 272 J=4,13
  272 OUTPUT(I,J)=0.0
COMMENT 21--RETURN TO NEXT STAGE
      GO TO 112
C     PRINT DISCOUNTED ANNUAL COSTS FOR ENTIRE STUDY PERIOD
  889 ACF=ACP+ACL+ACS+ACU+ACD
      WRITE(6,1050) ACS,ACL,ACP,ACD,ACU,ACF
 1050 FORMAT(1H1,40X,35HAVERAGE ANNUAL COST OVER ALL STAGES//45X,4HITEM,
     118X,12HDOLLARS/YEAR/35X,27HCOST OF CHANNEL IMPROVEMENT,7X,F8.0/35X
     2,16HCOST OF LAND USE,18X,F8.0/35X,22HCOST OF FLOOD PROOFING,12X,F8
     3.0/35X,25HCOST OF RESIDUAL FLOODING,9X,F8.0/35X,19HCOST OF UNCERTA
     4INTY,15X,F8.0/35X,10HTOTAL COST,24X,F8.0)
      GO TO 894
C     PRINT ONLY IF PROGRAM CAUGHT IN LOOP
  893 WRITE(6,9999) NW,NSTAGE
 9999 FORMAT(1X,50HLOOP D HAS CYCLED IN EXCESS OF MW*NSTAGE*NDF.  NW=I2,
     110H    NSTAGE=I2)
  894 STOP
      END
```

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$IBFTC DK0002  DECK
C     UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
C     UU AND CC ARE INDEPENDENT VARIABLES.  A IS THE INTERPOLATED
C     VALUE OF THE DEPENDENT VARIABLE RETURNED TO THE POINT OF CALL.
C     X IS A TWO DIMENSIONAL ARRAY
      SUBROUTINE PLACEA(A,UU,CC,X)
      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))
      A=QA+(U-UJ)*(QB-QA)
      RETURN
      END
```

```
$IBFTC DK0003   DECK
C      UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C      VERSION OF MAY 20, 1966
       SUBROUTINE CD1(NN)
C      RESIDUAL DAMAGE PROCEDURE WHEN LOCATION EQ 0
C      ARGUMENT (I) LOCATES QX WITH OR WITHOUT CHANNELIZATION
       REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
      IND
       LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF
       COMMON A,A0(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
      1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
      2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
      3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,Q0(25),QS,QP,QL,QX(2,100),
      4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
      5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),TO(25),TIC(25),TCL
      6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
      7A,W,WO(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
       DIMENSION DFQR(100)
COMMENT  1--INITIALIZE VARIABLES, CALCULATE CONSTANTS
       QSS=QS-Q0(NW)
       QPP=QP-Q0(NW)
       IF(JUMP1.EQ. 10*NW+NSTAGE)  GO TO 7
       C1=0.0555*COEFDM*VLURST*UN*K2(NW)*K1(NW)**2
       C2=0.4445*COEFDM*VLURST*UN*K2(NW)*K1(NW)**2
       C3=0.5*COEFDM*VLAGST*(1.-UN)*K2(NW)*K1(NW)**2
       C4=FA*(1.-UN)*K2(NW)*K1(NW)
       JUMP1=10*NW+NSTAGE
COMMENT  2--CALCULATE RESIDUAL FLOOD DAMAGE CORRESPONDING TO EACH PER
C      CENT FREQUENCY OF OCCURANCE FROM 1/2 PER CENT THROUGH 99 1/2 PER
C      CENT.  SUM TO GET AVERAGE ANNUAL DAMAGE
     7 DO 1 J=1,100
       QXC = 0.
       IF(QX(NN,J) .GT. QSS)  QXC=QX(NN,J)-QSS
       IF(QXC .LE. 0.)  GO TO 2
       QXP = 0.
       IF(QX(NN,J) .GT. QPP)  QXP=QX(NN,J)-QSS
       DFQR(J)=C1*QXC**0.75+C2*QXP**0.75+C3*QXC**0.75+C4*QXC**0.375
     1 CONTINUE
       GO TO 4
     2 DO 3 K=J,100
       DFQR(K) = 0.
     3 CONTINUE
     4 CD = 0.
       DO 5 I=1,100
     5 CD=CD+DFQR(I)
       CD = CD/100.
       CU=0.0
COMMENT  3--IF EFFECTS OF UNCERTAINTY ARE NOT BEING CONSIDERED RETURN TO
C      CALLING POINT IN MAIN PROGRAM, OTHERWISE CALCULATE UNCERTAINTY
C      COST BEFORE RETURNING
       IF( .NOT. UNC)  RETURN
       SUMSQ=0.
```

```
      DO 6 M=1,100
      SUMSQ=SUMSQ+(DFQR(M)-CD)**2
    6 CONTINUE
      SIGMA=SQRT(SUMSQ/99.)
      CU=VA*SIGMA*CRFSM/SQRT(2.*R)
      RETURN
      END
```

```
$IBFTC DK0004   DECK
C     UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
      SUBROUTINE CD2(NN)
C     RESIDUAL DAMAGE PROCEDURE WHEN LOCATION GT 0.
C     ARGUMENT (I) LOCATES QX WITH OR WITHOUT CHANNELIZATION
      REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
     1ND
      LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF
      COMMON A,A0(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
     1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
     2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
     3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,Q0(25),QS,QP,QL,QX(2,100),
     4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
     5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),TO(25),TIC(25),TCL
     6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
     7A,W,W0(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
      DIMENSION DFQR(100)
COMMENT  1--INITIALIZE VARIABLES, CALCULATE CONSTANTS
      QSS=QS-Q0(NW)
      QPP=QP-Q0(NW)
      QLL=QL-Q0(NW)
      IF(JUMP2.EQ. 10*NW+NSTAGE)  GO TO 9
      UB = UZ
      C1=0.0555*COEFDM*VLURST*UB*K2(NW)*K1(NW)**2
      C2=0.4445*COEFDM*VLURST*UB*K2(NW)*K1(NW)**2
      C3=0.5*COEFDM*VLAGST*(1.-UB)*K2(NW)*K1(NW)**2
      C4=FA*(1.-UB)*K2(NW)*K1(NW)
      C5=0.0555*COEFDM*VLURST*(UN-UB)*K2(NW)*K1(NW)**2
      C6=0.4445*COEFDM*VLURST*(UN-UB)*K2(NW)*K1(NW)**2
      C7=-0.5*COEFDM*VLAGST*(UN-UB)*K2(NW)*K1(NW)**2
      C8=-FA*(UN-UB)*K1(NW)*K2(NW)
      JUMP2=10*NW+NSTAGE
COMMENT  2--CALCULATE RESIDUAL FLOOD DAMAGE CORRESPONDING TO EACH PER
C     CENT FREQUENCY OF OCCURANCE FROM 1/2 PER CENT THROUGH 99 1/2 PER
C     CENT.  SUM TO GET AVERAGE ANNUAL DAMAGE
    9 DO 3 J=1,100
      QXC = 0.
      IF(QX(NN,J) .GT. QSS)  QXC=QX(NN,J)-QSS
      IF(QXC .LE. 0.)  GO TO 4
      QXP = 0.
      IF(QX(NN,J) .GT. QPP)  QXP=QX(NN,J)-QSS
      QLS = 0.
      IF(QLL .GT. QSS)  QLS=QLL-QSS
      QB1=0.0
      IF(QXC .GT. QLS)  QB1=QXC**0.375-QLS**0.375
      QB2=0.0
      IF(QXP .GT. QLS)  QB2=QXP**0.375-QLS**0.375
      DFQR(J)=(C1+C3)*QXC**0.75+C2*QXP**0.75+C4*QXC**0.375+(C5+C7)*QB1**
     12+C6*QB2**2+C8*QB1
    3 CONTINUE
      GO TO 6
```

```
    4 DO 5 K=J,100
      DFQR(K) = 0.
    5 CONTINUE
    6 CD = 0.
      DO 7 I=1,100
    7 CD=CD+DFQR(I)
      CD = CD/100.
      CU=0.
COMMENT  3--IF EFFECTS OF UNCERTAINTY ARE NOT BEING CONSIDERED RETURN TO
C     CALLING POINT IN MAIN PROGRAM, OTHERWISE CALCULATE UNCERTAINTY
C     COST BEFORE RETURNING
      IF(.NOT. UNC)  RETURN
      SUMSQ=0.0
      DO 8 M=1,100
      SUMSQ=SUMSQ+(DFQR(M)-CD)**2
    8 CONTINUE
      SIGMA=SQRT(SUMSQ/99.)
      CU=VA*SIGMA*CRFSM/SQRT(2.*R)
      RETURN
      END
```

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$IBFTC DK0005  DECK
      UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
C     SUBROUTINE STR
      REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
     1ND
      LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF
      COMMON A,AO(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
     1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
     2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
     3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,Q0(25),QS,QP,QL,QX(2,100),
     4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
     5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),TO(25),TIC(25),TCL
     6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
     7A,W,W0(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
      ND=NDT(NW)
      FD=FDA(NW)
COMMENT  1--DETERMINE RIGHT-OF-WAY COST FOR CHANNEL IMPROVEMENT IF NOT
C     ALREADY CALCULATED FOR STAGE
      IF(RC(NW) .GE. 0.)  GO TO 2
      LT=NSTAGE
      IF(LOC(NW) .GT. 0)  LT=LOC(NW)
      IF(CHANEL(NW))  GO TO 1
C     R-O-W COST FOR NEW CHANNELS EQUALS FULL LAND VALUE + 1/3 AVERAGE
C     URBAN STRUCTURE VALUE
      RC(NW)=(VALUE(NW,NSTAGE)+0.333*VLURST*USUBW(NW,LT))*RWF
      GO TO 2
C     R-O-W COST FOR ENLARGING CHANNELS EQUALS FULL LAND AND
C     STRUCTURE VALUE
    1 RC(NW)=(VALUE(NW,NSTAGE)+VLURST*USUBW(NW,LT))*RWF
COMMENT  2--DETERMINE SUBWATERSHED WEIGHTED DESIGN FLOW
    2 Q=QS*FQ(NW)
COMMENT  3--DETERMINE CHANNEL TYPE TO CONSIDER AS INDICATED BY
C     LINING(NW).  DETERMINE BRIDGE REQUIREMENTS FOR ALL BUT
C     RECTANGULAR LINED CHANNELS
      IF(LINING(NW) .NE. 4  .OR. .NOT. CHANEL(NW))  CALL BRIDGE(Q)
      IF(LINING(NW) .EQ. 3)  GO TO 100
      IF(LINING(NW) .EQ. 4)  GO TO 200
COMMENT  4--CONSIDER UNLINED CHANNEL
C     DETERMINE DEPTH OF FLOW 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 ACTUAL TRACTIVE FORCE.  IF IN EXCESS OF CRITICAL TRACTIVE
C     FORCE GO TO CONSIDER DROP STRUCTURES
    4 TFF=62.4*H*S(NW)
      IF(TFF .GT. TF(NW))  GO TO 5
C     CALCULATE DIMENSIONS FOR UNLINED CHANNEL WITHOUT DROP STRUCTURES
      B=X*H
```

```
      T=B+2.*ZU*H
      A=0.5*H*(B+T)
      W=B+2.4*H*ZU+30.
C     CALCULATE UNLINED CHANNEL COST
      CS=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC(NW)*(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
C     IF LINING(NW) EQUALS 1. DO NOT CONSIDER ANY OTHER TYPE OF
C     CHANNEL. RETURN TO MAIN PROGRAM
      IF(LINING(NW) .EQ. 1)  GO TO 12
      LINING(NW)=1
      TT=T
      AA=A
      WW=W
C     GO TO CONSIDER TRAPEZOIDAL LINED CHANNELS
      GO TO 100
   12 CS=CS*SF
      RETURN
C     DETERMINE MAXIMUM ALLOWABLE CHANNEL SLOPE
C           (REDUCE BY 10 PER CENT INCREMENTS)
    5 SLOPE=S(NW)
    6 X=1.1*X
      SLOPE=0.9*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 DIMENSIONS FOR UNLINED CHANNEL WITH DROP STRUCTURES
      B=X*H
      T=B+2.*ZU*H
      A=0.5*H*(B+T)
      W=B+2.4*H*Z+30.
C     CALCULATE AMOUNT OF FALL PROVIDED FOR BY DROP STRUCTURES
      F=5280.*LC(NW)*(S(NW)-SLOPE)
C     DETERMINE NUMBER AND HEIGHT OF DROP STRUCTURES
      IF(F .GT. 5.0)  GO TO 7
      FD=F
      ND=1.0
      GO TO 9
    7 IF(F .GT. 10.0)  GO TO 8
      FD=0.5*F
      ND=2.0
      GO TO 9
    8 ND=AINT(0.25*F+0.5)
      FD=F/ND
C     CALCULATE COST OF BUILDING NEW OR ENLARGING EXISTING DROP STRUCTURES
    9 CS=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC(NW)*(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      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*HO
      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     IF LINING(NW) EQUALS 2, DO NOT CONSIDER ANY OTHER TYPE OF CHANNEL,
C     RETURN TO MAIN PROGRAM
   10 IF(LINING(NW) .EQ. 2)  GO TO 13
C     IF LINING(NW) EQUALS 0 STORE TEMPORARY CHANNEL DIMENSIONS AND
C     GO TO CONSIDER TRAPEZOIDAL LINED CHANNELS
      IF(LINING(NW) .EQ. 0)  GO TO 11
      LINING(NW) =2
   13 CS=CS*SF
      RETURN
   11 LINING(NW)=2
      TT=T
      AA=A
      WW=W
COMMENT  5--CONSIDER TRAPEZOIDAL LINED CHANNELS
C     IF CHANNEL IS IMPROVED GO TO EVALUATE ENLARGING, OTHERWISE
C     EVALUATE IMPROVING AS TRAPEZOIDAL LINED CHANNEL
  100 IF(CHANEL(NW))  GO TO 103
C     DETERMINE DEPTH OF FLOW FOR NEW TRAPEZOIDAL LINED CHANNEL
      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
C     CALCULATE DIMENSIONS FOR NEW TRAPEZOIDAL LINED CHANNEL
  102 B=X*H
      T=B+2.*ZT*H
      A=0.5*H*(B+T)
      W=B+2.4*H*ZT+25.
      P=B+2.2*H*SQRT(1.+ZT*ZT)
C     CALCULATE COST OF NEW TRAPEZOIDAL LINED CHANNEL
      CSL=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC(NW)*(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CSL=CSL+SK7*P*LC(NW)
C     IF TRAPEZOIDAL LINED CHANNELS ARE NOT ECONOMICAL AND IF AN
C     UNLINED CHANNEL IS EXISTING OR HAS BEEN PROVEN TO BE ECONOMICAL,
C     PREPARE TO RETURN TO MAIN PROGRAM
      IF(CSL.GT.CS .AND. LINING(NW).EQ.1 .OR. LINING(NW).EQ.2) GO TO 300
C     TRAPEZOIDAL LINED CHANNEL IS ECONOMICAL-CONTINUE
      IF(LINING(NW) .EQ. 3)  GO TO 150
      LINING(NW)=3
C     STORE TEMPORARY CHANNEL DIMENSIONS
      TT=T
      AA=A
      WW=W
      CS=CSL
      GO TO 200
  150 CS=CSL
```

```
      RETURN
C     EVALUATE 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)
C     DETERMINE AMOUNT OF NECESSARY ENLARGMENT
C             (ENLARGE BY 10 PER CENT INCREMENTS)
      Q1=QO(NW)
      HT=HO
      H1=1.1*HO
  104 Q2=(1.49*SQRT(S(NW))*((BO+ZT*H1)*H1)**1.667)/(MANNT*(BO+2.0*H1*SQR
     1T(1.+ZT*ZT))**0.667)
      IF(Q2 .GE. Q)  GO TO 105
      Q1=Q2
      HT=H1
      H1=1.1*H1
      GO TO 104
C     CALCULATE DIMENSIONS FOR ENLARGED TRAPEZOIDAL LINED CHANNEL
  105 H=HT+((H1-HT)*(Q-Q1))/(Q2-Q1)
      B=BO
      T=B+2.*ZT*H
      A=0.5*H*(B+T)
      W=B+2.4*H*ZT+25.
      P=B+2.2*H*SQRT(1.+ZT*ZT)
C     CALCULATE COST OF ENLARGING AS TRAPEZOIDAL LINED CHANNEL
      CS=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC(NW)*(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CS=CS+SK7*(P-PO)*LC(NW)
      CS=CS*SF
      RETURN
COMMENT  6--CONSIDER RECTANGULAR LINED CHANNELS
C     IF CHANNEL IS IMPROVED GO TO EVALUATE ENLARGING, OTHERWISE
C     EVALUATE IMPROVING AS RECTANGULAR LINED CHANNEL
  200 IF(CHANEL(NW))  GO TO 201
C     DETERMINE DEPTH OF FLOW FOR NEW RECTANGULAR LINED CHANNEL
      X=BDMIN
      H=(Q*MANNR*(X+2.0)**0.667 /(SQRT(S(NW))*1.49*X**1.667))**0.375
C     CALCULATE DIMENSIONS FOR NEW RECTANGULAR LINED CHANNEL
      T=X*H
      A=H*T
      W=T+20.0
      P=T+2.1*H
C     CALCULATE COST OF NEW RECTANGULAR LINED CHANNEL
      CSR=SK1*LC(NW)*(A-AO(NW))+SK2*LC(NW)+SK3*RC(NW)*(W-WO(NW))*LC(NW)+
     1SK4*(HN*T+HE*(T-TO(NW)))+SK5*(RN*T+RE*(T-TO(NW)))
      CSR=CSR+SK8*(P+2.0)*LC(NW)
      IF(CSR .GT. CS .AND. LINING(NW) .NE. 4)  GO TO 300
C     IF RECTANGULAR LINED CHANNELS ARE ECONOMICAL SET LINING(NW) EQUAL
C     TO 4 AND RETURN TO MAIN PROGRAM
      LINING(NW)=4
      CS=CSR*SF
      RETURN
```

2

```
C     EVALUATE ENLARGING RECTANGULAR LINED CHANNELS
  201 HO=AO(NW)/TO(NW)
      BO=TO(NW)
C     DETERMINE AMOUNT OF NECESSARY ENLARGEMENT
C           (ENLARGE BY 10 PER CENT INCREMENTS)
      Q1=QO(NW)
      HT=HO
      H1=1.1*HO
  202 Q2=(1.49*SQRT(S(NW))*(BO*H1)**1.667)/(MANNR*(BO+2.0*H1)**0.667)
      IF(Q2 .GE. Q)  GO TO 203
      Q1=Q2
      HT=H1
      H1=1.1*H1
      GO TO 202
C     CALCULATE DIMENSIONS FOR ENLARGED RECTANGULAR LINED CHANNEL
  203 H=HT+((H1-HT)*(Q-Q1))/(Q2-Q1)
C     CALCULATE COST OF ENLARGING AS RECTANGULAR LINED CHANNEL
      CS=SK8*2.0*(H-HO)*LC(NW)
      CS=CS*SF
      RETURN
  300 T=TT
      A=AA
      W=WW
      CS=CS*SF
      RETURN
      END
```

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$IBFTC DK0006  DECK
C     UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
      SUBROUTINE BRIDGE(Q)
      REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
     IND
      LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF
      COMMON A,AO(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
     1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
     2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
     3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,QO(25),QS,QP,QL,QX(2,100),
     4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
     5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),TO(25),TIC(25),TCL
     6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
     7A,W,WO(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
COMMENT  1--INITIALIZE CONDITIONS
      HA=0.
      RE = 0.
      HE =0.
      RN = 0.
      HN = 0.
COMMENT  2--INVESTIGATE AFFECTS OF DESIGN FLOW ON HIGHWAY BRIDGES
C     EXISTING PRIOR TO PERIOD UNDER STUDY
      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
COMMENT  3--INVESTIGATE AFFECTS OF DESIGN FLOW ON RAILWAY BRIDGES
C     EXISTING PRIOR TO PERIOD UNDER STUDY
    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
COMMENT  4--CONSIDER EXTENDING HIGHWAY AND RAILWAY BRIDGES BUILT DURING
C     PERIOD UNDER STUDY
    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)  RETURN
COMMENT  5--CONSIDER AFFECTS OF URBANIZATION ON HIGHWAY
C     BRIDGE REQUIREMENTS
      IF(USUBW(NW,NSTAGE) .LT. .25)  RETURN
      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 BR = NBR
```

```
      IF(.NOT. CHANEL(NW))  GO TO 9
      IF(BR .GT. HN+HE+HA)  HE=BR-(HN+HA)
      RETURN
    9 IF(BR .GT. HN+HE+HA)  HN=BR-(HE+HA)
      RETURN
      END
```

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$IBFTC DK0007  DECK
C     UNIVERSITY OF KENTUCKY FLOOD CONTROL PLANNING PROGRAM I
C     VERSION OF MAY 20, 1966
      SUBROUTINE COST
C     CALCULATE EFFECTS OF CHANNELIZATION ON DOWNSTREAM WATERSHEDS
      REAL K1,K2,MANNU,MANNR,MANNT,L,IA,IPP,LA,LC,MFP,MIN,MCH,NIN,MTLCH,
     1ND
      LOGICAL CHANEL,UNC,LLL,PP,LL,SS,CDSTE,LG,SG,PG,PTF,LTF,STF
      COMMON A,AO(25),AFCTR(3,11),AW(25),AFW(2,25),AF,BDMIN,BDMAX,COEFDM
     1,CHANEL(25),CU,CD,CAP(25,11),CS,CDST,CRFSM,FA,FQ(25),HE,HMAX,HN,IN
     2DEX(25,2),ID(100),K1(25),K2(25),LINING(25),LF,LOC(25),LC(25),NW,NS
     3TAGE,MANNU,MANNT,MANNR,OUTPUT(25,13),PF,QO(25),QS,QP,QL,QX(2,100),
     4Q43(11,11),Q05(11,11),R,RN,RE,RWF,RC(25),SF,SIGMA,SK1,SK2,SK3,SK4,
     5SK5,SK6,SK7,SK8,S(25),SIC(25),TAW,T,TIME,TF(25),TO(25),TIC(25),TCL
     6(25),UNC,UN,UZ,USUBW(25,6),UTOTR(25,6),VLURST,VLAGST,VALUE(25,6),V
     7A,W,WO(25),ZT,ZU,ND,FD,NDT(25),FDA(25)
COMMENT  1--DETERMINE NUMBER OF DOWNSTREAM SUBWATERSHEDS TO BE
C     CONSIDERED.  IF NONE EXIST, SET CDST EQUAL TO ZERO AND RETURN
C     TO MAIN PROGRAM
      N = INDEX(NW,1)
      J = INDEX(NW,2)
      CDST = 0.
      IF(N .EQ. 0) RETURN
COMMENT  2--COSTS ARE EVALUATED SYSTEMATICALLY FOR EACH DOWNSTREAM SUBWATERSHE
      LLL=.FALSE.
      DO 17 I=N,J
      NWD = ID(I)
C     DOWNSTREAM FLOW IS INCREASED BY AN INCREASE IN CHANNELIZATION
C     FROM C TO CI.  URBANIZATION IS HELD CONSTANT
      C = TIC(NWD)/TCL(NWD)
      U=UTOTR(NWD,NSTAGE)
      CI=(TIC(NWD)+(LC(NW)-SIC(NW)))/TCL(NWD)
COMMENT  3--INCREASED FLOW WILL REQUIRE ADDITIONAL RIGHT-OF-WAY AND
C     LARGER BRIDGE CAPACITIES FOR ALL BUT RECTANGULAR CHANNELS.
      IF(LINING(NWD) .EQ. 4)  GO TO 21
      BH = 0.
      BR = 0.
C     SUM AFFECTED BRIDGES IN DOWNSTREAM SUBWATERSHED
      DO 12 J=1,6
      IF(CAP(NWD,J) .GE. 0.)  BH=BH+1.
   12 CONTINUE
      DO 13 J=7,8
      IF(CAP(NWD,J) .GE. 0.)  BR=BR+1.
   13 CONTINUE
      BH = BH+CAP(NWD,9)
      BR = BR+CAP(NWD,10)
C     DETERMINE RIGHT-OF-WAY COST FOR SUBWATERSHED IF NOT
C     PREVIOUSLY DETERMINED DURING STAGE
      IF(RC(NWD) .GE. 0.0)  GO TO 21
      LT=NSTAGE
      IF(LOC(NWD) .GT. 0)  LT=LOC(NWD)
      IF(CHANEL(NWD))  GO TO 20
```

```
      RC(NWD)=(VALUE(NWD,NSTAGE)+0.333*VLURST*USUBW(NWD,LT))*RWF
      GO TO 21
   20 RC(NWD)=(VALUE(NWD,NSTAGE)+VLURST*(USUBW(NWD,LT)))*RWF
COMMENT  4--DETERMINE DOWNSTREAM FLOW FOR WITH AND WITHOUT CONDITIONS
C     OF UPSTREAM IMPROVED CHANNEL
   21 CALL PLACEA(QX1,U,C,Q43)
      CALL PLACEA(QY1,U,C,Q05)
      QXX=(AW(NWD)*AFW(1,NWD)*QX1)/TAW
      QY=(AW(NWD)*AFW(2,NWD)*QY1)/TAW
      XF=((QY*0.578)-(QXX*5.296))/(-4.718)
      A=(4.718)/(QY-QXX)
      IF(.NOT. CHANEL(NWD))  GO TO 1
C     IF DOWNSTREAM CHANNEL IS IMPROVED, ITS DIMENSIONS
C     ARE KNOWN QUANTITIES
      YF=A*(Q0(NWD)-XF)
      IF(YF .GT. 5.296)  GO TO 17
      QSML=Q0(NWD)*FQ(NWD)
      ASML=A0(NWD)
      TSML=T0(NWD)
      WSML=W0(NWD)
      GO TO 5
C     IF DOWNSTREAM CHANNEL IS NOT IMPROVED, SELECT PROBABLE WEIGHTED
C     AVERAGE CHANNEL DESIGN FLOW BASED ON THE AMOUNT OF URBANIZATION
C     IN THE DOWNSTREAM SUBWATERSHED
    1 P   = 0.04
      IF(U-0.07 .GT. 0.)  P =0.01
      IF(U-0.20 .GT. 0.)   P=0.005
      PN=1.000-P
      TEMP=1./ALOG(1./PN)
      YF=ALOG(TEMP)
      QSML=(YF/A+XF)*FQ(NWD)
      Q=QSML
C     DETERMINE CHANNEL DIMENSIONS FOR THE PROBABLE DESIGN FLOW
   22 X=BDMIN
   23 H=((Q*MANNU*(X+2.*(SQRT(1.+ZU*ZU)))**0.667)/(SQRT(S(NWD))*1.49*(X+
     1ZU)**1.667))**0.375
      IF(H .LE. HMAX .OR.X .GE. BDMAX)  GO TO 24
      X=X+0.5
      GO TO 23
   24 B=X*H
      IF(LLL)  GO TO 25
      TSML=B+2.0*ZU*H
      ASML=0.5*H*(B+TSML)
      WSML=B+2.4*ZU*H+30.0
    5 CALL PLACEA(QX1,U,CI,Q43)
      CALL PLACEA(QY1,U,CI,Q05)
      QXX=(AW(NWD)*AFW(1,NWD)*QX1)/TAW
      QY=(AW(NWD)*AFW(2,NWD)*QY1)/TAW
      XF=((QY*0.579)-(QXX*5.296))/(-4.718)
      A=(4.718)/(QY-QXX)
C     CALCULATE WEIGHTED AVERAGE DESIGN FLOOD PEAK RESULTING FROM
C     INCREASED CHANNELIZATION
```

```
      QLRG=(YF/A+XF)*FQ(NWD)
      IF(LINING(NWD) .NE. 1 .AND. LINING(NWD) .NE. 0 .AND. CHANEL(NWD))
C     RETURN TO CALCULATE CHANNEL DIMENSIONS FOR INCREASED DESIGN FLOW
     1 GO TO 26
      LLL=.TRUE.
      Q=QLRG
      GO TO 22
   25 LLL=.FALSE.
      IF(LINING(NWD) .EQ. 2)  GO TO 27
      TLRG=B+2.0*ZU*H
      ALRG=0.5*H*(B+TLRG)
      WLRG=B+2.4*ZU*H+30.0
C     CALCULATE INDUCED COST FOR UNLINED CHANNEL WITHOUT DROP STRUCTURES
      CDST=CDST+SK1*LC(NWD)*(ALRG-ASML)+SK3*RC(NWD)*LC(NWD)*(WLRG-WSML)+
     1(SK4*BH+SK5*BR)*(TLRG-TSML)
      GO TO 17
   26 IF(LINING(NWD) .NE. 2)  GO TO 29
COMMENT  5--EVALUATE UNLINED CHANNELS WITH DROP STRUCTURES
      LLL=.TRUE.
      Q=QLRG
C     RETURN TO CALCULATE CHANNEL DIMENSIONS FOR INCREASED DESIGN FLOW
      GO TO 22
C     DETERMINE ALLOWABLE CHANNEL SLOPE FOR UNLINED CHANNEL WITH
C     DROP STRUCTURES
   27 SLOPE=S(NWD)
   28 X=1.1*X
      SLOPE=0.9*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(NWD))  GO TO 28
      B=X*H
      TLRG=B+2.0*ZU*H
      ALRG=0.5*H*(B+T)
      WLRG=B+2.4*H*ZU+30.
      F=5280.*LC(NWD)*(S(NWD)-SLOPE)
      ND=AINT(0.25*F+0.5)
      IF(ND .EQ. 0.)  ND=1.0
      FD=F/ND
      HSML=(TSML-SQRT(TSML*TSML-4.0*ZU*ASML))/2.0*ZU
      BSML=TSML-2.0*ZU*HSML
C     CALCULATE INDUCED COST FOR UNLINED CHANNEL WITH DROP STRUCTURES
      CDST=CDST+SK1*LC(NWD)*(ALRG-ASML)+SK3*RC(NWD)*LC(NWD)*(WLRG-WSML)+
     1(SK4*BH+SK5*BR)*(TLRG-TSML)
      CDST=CDST+SK6*ND*(5.2*B*H+4.3*B*FD+9.5*B+5.5*ZU*H*H+2.0*ZU*H*FD+32
     1.0*ZU*H+2.0*ZU*FD+13.0*ZU+14.1*H*H+14.6*H*FD+3.3*FD*FD+14.1*H+0.05
     26*B*H*H+0.188*H*H*H+0.132*FD*H*H+9.9)
      H=HSML
      B=BSML
      CDST=CDST-SK6*ND*(5.2*B*H+4.3*B*FD+9.5*B+5.5*ZU*H*H+2.0*ZU*H*FD+32
     1.0*ZU*H+2.0*ZU*FD+13.0*ZU+14.1*H*H+14.6*H*FD+3.3*FD*FD+14.1*H+0.05
     26*B*H*H+0.188*H*H*H+0.132*FD*H*H+9.9)
```

```
      GO TO 17
   29 IF(LINING(NWD) .EQ. 4)  GO TO 32
COMMENT  6--EVALUATE TRAPEZOIDAL LINED CHANNELS
      HSML=(TSML-SQRT(TSML*TSML-4.0*ZT*ASML))/2.0*ZT
      BSML=TSML-2.0*ZT*HSML
      PSML=BSML+2.2*HSML*SQRT(1.+ZT*ZT)
C     ENLARGE CHANNEL TO ACCOMODATE INCREASED FLOW
C     (INCREASE DEPTH BY 10 PER CENT INCREMENTS)
      Q1=QSML
      HT=HSML
      H1=1.1*HSML
   30 Q2=(1.49*SQRT(S(NWD))*((BSML+ZT*H1)*H1)**1.667)/(MANNT*(BSML+2.*H1
     1*SQRT(1.+ZT*ZT))**0.667)
      IF(Q2 .GE. QLRG)  GO TO 31
      Q1=Q2
      HT=H1
      H1=1.1*H1
      GO TO 30
   31 HLRG=HT+((H1-HT)*(QLRG-Q1))/(Q2-Q1)
      TLRG=BSML+2.*ZT*HLRG
      ALRG=0.5*HLRG*(BSML+TLRG)
      WLRG=BSML+2.4*HLRG*ZT+25.
      PLRG=BSML+2.2*HLRG*SQRT(1.+ZT*ZT)
C     CALCULATE INDUCED COST FOR TRAPEZOIDAL LINED CHANNELS
      CDST=CDST+SK1*LC(NWD)*(ALRG-ASML)+SK3*RC(NWD)* LC(NWD)*(WLRG-WSML)
     1+(SK4*BH+SK5*BR)*(TLRG-TSML)+SK7*(PLRG-PSML)*LC(NWD)
      GO TO 17
COMMENT  7--EVALUATE RECTANGULAR LINED CHANNELS
   32 HSML=ASML/TSML
C     ENLARGE CHANNEL TO ACCOMODATE INCREASED FLOW
C     (INCREASE DEPTH BY 10 PER CENT INCREMENTS)
      Q1=QSML
      HT=HSML
      H1=1.1*HSML
   33 Q2=(1.49*SQRT(S(NW))*(TSML*H1)**1.667)/(MANNR*(TSML+2.0*H1)**0.667
     1)
      IF(Q2 .GE. QLRG)  GO TO 34
      Q1=Q2
      HT=H1
      H1=1.1*H1
      GO TO 33
   34 HLRG=HT+((H1-HT)*(QLRG-Q1))/(Q2-Q1)
C     CALCULATE INDUCED COST FOR RECTANGULAR LINED CHANNELS
      CDST=CDST+SK8*2.0*(HLRG-HSML)*LC(NWD)
   17 CONTINUE
      RETURN
      END
```

```
$ENTRY
  1.15    10.0     4.0    64.0   0.052    60.0    1.15     0.45   900.0    15.0
 300.0    0.70    0.01    1.30    1.25    1.10   0.035     12.0     0.0    0.05
 0.030   0.016   0.012   0.005   0.015    0.01     6.0     0.08    0.03     1.0
  50.0    10.0    43.8    1.50  30000.    180.   1.645      1.5     1.0     1.0
   1.0     1.0
  63      5    10    20
   F      T      T      F      F      T
  1.0     3.0     5.0     7.0    27.0    30.0    35.0    40.0    50.0    60.0    75.0
1.795   1.385   1.265   1.230   1.165   1.130   1.065   1.020   0.985   0.975   0.970
2.060   1.640   1.485   1.415   1.170   1.130   1.065   1.020   0.985   0.975   0.970
   0.00      0.01      0.05      0.10      0.25      0.50      0.75
   0.01      0.05      0.10      0.25      0.50      0.75      1.00
  45.40     45.20     45.00     42.50     33.20     18.80     12.00
  21.20     21.10     21.00     19.80     15.50      8.80      5.60
  13.80     13.80     13.70     12.90     10.10      5.70      3.70
   9.30      9.30      9.30      8.50      8.00      5.00      2.60
  10.70     10.70     10.70      9.90      9.30      4.80      2.90
   8.80      8.80      8.80      8.20      7.10      3.80      2.40
  0.43    0.20    0.15    0.10    0.06    0.04    0.03    0.02    0.01   0.005
  605.   675.   760.   825.   900.   975.  1055.  1130.  1200.  1290.  1390.
  630.   710.   790.   870.   945.  1020.  1105.  1180.  1260.  1345.  1440.
  675.   750.   830.   910.   990.  1070.  1150.  1230.  1315.  1400.  1510.
  710.   785.   870.   950.  1040.  1115.  1200.  1290.  1375.  1475.  1575.
  735.   825.   910.  1000.  1085.  1165.  1265.  1355.  1450.  1555.  1650.
  760.   860.   955.  1050.  1140.  1225.  1330.  1435.  1535.  1640.  1730.
  810.   900.  1005.  1100.  1200.  1305.  1410.  1530.  1630.  1740.  1830.
  850.   950.  1060.  1160.  1280.  1385.  1515.  1625.  1740.  1850.  1960.
  890.  1000.  1125.  1230.  1365.  1490.  1605.  1740.  1850.  1975.  2080.
  940.  1070.  1185.  1325.  1470.  1590.  1730.  1875.  2000.  2140.  2290.
 1000.  1140.  1200.  1440.  1590.  1710.  1880.  2050.  2225.  2450.  2750.
 2350.  2480.  2590.  2720.  2850.  2975.  3120.  3230.  3380.  3540.  3740.
 2400.  2520.  2625.  2745.  2875.  2990.  3125.  3250.  3390.  3575.  3830.
 2470.  2560.  2660.  2785.  2900.  3025.  3160.  3280.  3425.  3660.  0925.
 2540.  2615.  2725.  2840.  2960.  3070.  3190.  3325.  3500.  3775.  4020.
 2610.  2700.  2800.  2925.  3035.  3130.  3260.  3410.  3630.  3910.  4120.
 2720.  2810.  2900.  3025.  3120.  3210.  3375.  3540.  3800.  4050.  4220.
 2840.  2925.  3030.  3130.  3225.  3350.  3500.  3710.  4010.  4220.  4375.
 2975.  3070.  3170.  3275.  3390.  3510.  3690.  3975.  4250.  4440.  4550.
 3180.  3270.  3370.  3490.  3600.  3760.  4050.  4200.  4560.  4690.  4980.
 3450.  3575.  3725.  3950.  4200.  4440.  4640.  4840.  4980.  5150.  5390.
 4300.  4450.  4650.  4900.  5100.  5300.  5500.  5700.  5900.  6220.  6500.
   0.0     0.0    20.0   280.0    80.0    20.0    27.0   300.0     0.0     0.0
   0.0    20.0     0.0    20.0     0.0   210.0    20.0   200.0   475.0  1000.0
 33.16    1.76   37.23   38.91   39.82    1.50    6.09   50.08    6.04    6.90
 13.64   14.58    1.77    2.53    1.21    5.00    5.60    6.09   21.65   72.70
  6500.     5000.       10.       -1.       -1.       -1.       -1.       -1.
    80.       50.       50.       30.       20.       20.       -1.       -1.
  3300.     2800.       -1.       -1.       -1.       -1.    12200.       -1.
  4000.       -1.       -1.       -1.       -1.       -1.    15000.     2000.
  8000.     5000.     5000.       -1.       -1.       -1.       -1.       -1.
   300.       -1.       -1.       -1.       -1.       -1.       -1.       -1.
```

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       0.        0.       -1.       -1.       -1.       -1.       -1.       -1.
    8600.     8500.     8400.     8000.     7100.       -1.       -1.       -1.
    1400.     1000.      700.      600.      500.       60.     2500.       -1.
    2000.     1400.      750.       40.       -1.       -1.     6000.       -1.
    2600.       10.       -1.       -1.       -1.       -1.     7000.       -1.
    5000.     2800.     2000.     1800.       30.       -1.       -1.       -1.
     700.      100.       -1.       -1.       -1.       -1.       -1.       -1.
    1100.      500.      450.       -1.       -1.       -1.     2500.       -1.
       0.       -1.       -1.       -1.       -1.       -1.        0.       -1.
     400.       -1.       -1.       -1.       -1.       -1.       -1.       -1.
    2000.     1000.      600.       90.       -1.       -1.       -1.       -1.
    3700.     2000.       -1.       -1.       -1.       -1.       -1.       -1.
    7000.       -1.       -1.       -1.       -1.       -1.       -1.       -1.
    8500.       -1.       -1.       -1.       -1.       -1.    34000.       -1.
     0.00      0.20      0.80      0.00      0.40      0.60
     0.00      0.15      0.85      0.00      1.00      0.00
     0.00      0.90      0.10      0.00      1.00      0.00
     0.05      0.90      0.05      0.00      0.75      0.25
     0.00      0.60      0.40      0.00      0.80      0.20
     0.00      1.00      0.00      0.00      0.90      0.10
     0.00      1.00      0.00      0.00      1.00      0.00
     0.00      1.00      0.00      0.00      1.00      0.00
     0.00      0.70      0.30      0.00      0.20      0.80
     0.00      0.50      0.50      0.00      0.50      0.50
      1.0       1.0       1.0       1.0       1.0       1.0     0.687     0.955    0.7275       1.0
      1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0    0.8125      0.90
  1  6 11 15 18 20 22 24 25 29 33 36 38 44 49 54 58 61 63  0
  5 10 14 17 19 21 23 24 28 32 35 37 43 48 53 57 60 62 63  0
  3  4  5  8 20  3  4  5  8 20  4  5  8 20  5  8 20  8 20  8
 20  8 20 20 11 12 19 20 11 12 19 20 12 19 20 19 20 14 16 17
 18 19 20 16 17 18 19 20 16 17 18 19 20 17 18 19 20 18 19 20
 19 20 20
     0.22      0.22      0.21      0.13      0.17      0.23      0.14      0.20      0.15      0.22
     0.11      0.19      0.22      0.21      0.23      0.19      0.19      0.31      0.22      0.21
     144.       54.      126.      242.      197.       15.      145.      177.      165.      128.
     112.      137.       37.       76.       25.       23.       26.       17.      104.      115.
      2.5       1.7       1.6       1.3       2.3       1.3       3.0       1.7       3.9       4.4
      1.5       2.0       1.2       1.4       0.8       0.8       0.9       1.0       2.0       2.1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
     200.       25.      100.      920.      300.      100.      150.     1360.       40.       40.
      50.      100.       30.      100.        0.      940.      100.      940.     2280.     4500.
   0.0012    0.0017    0.0009    0.0006    0.0009    0.0010    0.0008    0.0008    0.0012    0.0016
   0.0009    0.0015    0.0013    0.0014    0.0017    0.0006    0.0013    0.0005    0.0005    0.0004
     3.38      1.76      2.31      1.68      0.91      1.50      6.09      2.67      3.87      3.13
     0.70      0.94      1.77      0.76      1.21      1.26      0.60      0.49      0.98      0.97
      0.0       0.0       0.0       1.3       0.9       0.7       0.0       1.2       0.0       0.0
      0.0       0.0       0.0       0.0       0.0       0.8       0.0       1.0       2.0       2.1
     28.5       1.7      31.8      33.1      35.4       1.3       3.0      41.4       3.9       6.3
     11.7      13.7       1.2       2.6       0.8       4.2       5.1       6.1      21.8      65.3
      1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0
      1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0       1.0
      3.2       0.0       3.2       4.5       5.4       0.7       0.0       7.3       0.0       0.0
```

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 0.0      0.0      0.0      0.0      0.0      0.8      0.8      1.8      3.9     13.2
 0.00     0.01     0.04     0.15     0.45     0.75
 0.02     0.04     0.15     0.55     0.80     0.90
 0.08     0.20     0.55     0.80     0.90     1.00
 0.59     0.80     0.90     0.95     1.00     1.00
 0.36     0.80     0.95     1.00     1.00     1.00
 0.24     0.65     0.90     1.00     1.00     1.00
 0.78     0.91     1.00     1.00     1.00     1.00
 0.56     0.70     0.90     1.00     1.00     1.00
 0.01     0.03     0.07     0.12     0.30     0.45
 0.01     0.04     0.09     0.15     0.35     0.55
 0.02     0.35     0.65     0.80     0.85     1.00
 0.07     0.40     0.75     0.85     1.00     1.00
 0.04     0.20     0.50     0.75     0.85     0.95
 0.27     0.55     0.80     0.95     1.00     1.00
 0.20     0.45     0.70     0.85     0.95     1.00
 0.30     0.50     0.75     0.95     1.00     1.00
 0.24     0.60     0.80     0.95     1.00     1.00
 0.50     0.60     0.70     0.85     1.00     1.00
 0.00     0.30     0.60     0.80     1.00     1.00
 0.14     0.30     0.50     0.75     1.00     1.00
 0.08     0.08     0.09     0.15     0.27     0.43
 0.02     0.04     0.15     0.55     0.80     0.90
 0.07     0.08     0.12     0.21     0.33     0.49
 0.10     0.12     0.16     0.24     0.36     0.52
 0.10     0.13     0.18     0.26     0.38     0.53
 0.24     0.65     0.90     1.00     1.00     1.00
 0.78     0.91     1.00     1.00     1.00     1.00
 0.21     0.27     0.34     0.41     0.51     0.62
 0.01     0.03     0.07     0.12     0.30     0.45
 0.00     0.02     0.05     0.08     0.18     0.33
 0.01     0.04     0.09     0.13     0.27     0.42
 0.01     0.06     0.14     0.18     0.30     0.46
 0.04     0.20     0.50     0.75     0.85     0.95
 0.11     0.31     0.59     0.81     0.90     0.97
 0.20     0.45     0.70     0.85     0.95     1.00
 0.18     0.39     0.66     0.86     0.94     0.98
 0.19     0.41     0.67     0.87     0.94     0.98
 0.21     0.43     0.68     0.86     0.95     0.99
 0.07     0.18     0.31     0.40     0.52     0.63
 0.17     0.24     0.33     0.41     0.52     0.63
  840.     990.    1600.    3740.    6350.   10425.
 1040.    1790.    3670.    8490.   12080.   15200.
 2030.    5140.    7340.   11380.   14570.   17030.
 6000.   10850.   14100.   16800.   17700.   18500.
 7810.   12350.   15850.   17350.   18200.   18500.
 6450.   10400.   15500.   17200.   18300.   18500.
11830.   14900.   17050.   17950.   18480.   18500.
 6690.    9430.   12800.   14850.   17650.   18300.
  830.     950.    1180.    1980.    3560.    6670.
  810.    1020.    1650.    3030.    5150.    8730.
 1800.    5120.    7950.   11600.   14400.   17000.
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 2640.    6080.   10680.   13650.   16700.   17900.
 1680.    4360.    6810.   10890.   13930.   16130.
 2900.    7760.   12250.   15150.   17000.   18100.
 2310.    6190.    9780.   13100.   15700.   17550.
 4580.    7460.   12900.   15500.   17700.   18300.
 4910.    7670.   12000.   14400.   17200.   18100.
 5310.    7570.   11350.   13750.   17200.   18100.
 2420.    4910.    7850.   11400.   15300.   17200.
 4120.    5800.    8980.   11430.    1605.   17650.
  0.0     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0     0.0      0.0      0.0      0.0     84.0      0.0     90.0    106.0    118.0
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