...ort No. FHWA-RD-75-54

...LUATION OF FLOOD RISK FACTORS IN THE ...IGN OF HIGHWAY STREAM CROSSINGS

Vol. IV Economic Risk Analysis for Design of Bridge Waterways

M. T. Tseng, A. J. Knepp, R. A. Schmalz

June 1975
Final Report

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of Water Resources Engineers, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification, or regulation.

FHWA DISTRIBUTION NOTICE

Sufficient copies of this report are being distributed by FHWA bulletin to provide a minimum of five copies to each regional office, one copy to each division office, and two copies to each State highway agency. Direct distribution including copies for State highway agencies is being made to the division offices.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-RD-75-54	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF FLOOD RISK FACTORS IN THE DESIGN OF HIGHWAY STREAM CROSSINGS. Vol. IV. Economic Risk Analysis for Design of Bridge Waterways		5. Report Date June 1975 6. Performing Organization Code
7. Author(s) M. T. Tseng, A. J. Knepp, R. A. Schmalz		8. Performing Organization Report No. WRE 20810
9. Performing Organization Name and Address Water Resources Engineers 8001 Forbes Place Springfield, Virginia 22151		10. Work Unit No. 11. Contract or Grant No. DOT-FH-11-7669
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U. S. Department of Transportation Washington, D. C. 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Administrator: Gilbert Trainer
FHWA Contract Manager: J. Sterling Jones
FHWA Project Manager: Roy E. Trent
FHWA Implementation Manager: Dan O'Conner

16. Abstract

An engineering systems analysis technique has been developed to facilitate the economic risk analysis for highway stream crossings. The technique is based on a probabilistic approach, incorporating hydrologic, hydraulic and economic factors in the engineering analysis of bridge waterways. It relates the initial construction costs, flood-related damage and damage to properties from backwater to crossing design and flood frequency. The method of risk analysis is implemented by a model in the form of a computer program using FORTRAN program language.

The other volumes of this study are:

I Experimental Determination of Channel Resistance for Large Scale Roughness
II Analysis of Bridge Backwater Experiments
III Finite Element Model for Bridge Backwater Computation
V Data Report for Spur Dike Experiments

17. Key Words Risk Analysis, Total Economic Response, Sensitivity Analysis, Highway Stream Crossing Design	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	191	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The staff of the Environmental Control Group, Office of Research and Development, Federal Highway Administration, and especially Messrs. R. E. Trent and J. S. Jones have given valuable advice and support on this study. Mr. M. Corry of the Office of Engineering, Federal Highway Administration, also furnished valuable technical information to the study. Field data were provided by the U. S. Geological Survey, Water Resources Division, Jackson District Mississippi, through Mr. V. Schneider; data were also provided by the Virginia State Highway Department through Mr. E. C. Cochran, Jr., and by the Pennsylvania Department of Transportation through Mr. M. Tsai. Dr. G. K. Young of Meta Systems, Inc., reviewed the preliminary draft of this report.

Technical assistance was provided by Messrs. James J. Hanks and Robert S. Taylor of Water Resources Engineers. Phyllis Weiner edited the manuscript and Elizabeth Casey was responsible for the drafting.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

I. INTRODUCTION

This report is the fourth in a series of five volumes comprising the final report for the study entitled *Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings*, authorized by the Federal Highway Administration (FHWA) under Contract No. DOT-FH-11-7669. The overall objective of the study is to develop an engineering systems analysis technique to enhance the decision-making process in the design of highway stream crossings. The method applies economic risk analysis in addition to hydraulic and hydrologic factors to evaluate design alternatives.

Volume IV describes the application of risk analysis to determine the economically optimal design configuration for highway stream crossings. The analysis considers the sum of initial construction costs and the flood risks, in a range of flood sizes, for each design alternative. The sums for all design alternatives are compared and the optimal design scheme selected.

BACKGROUND

The primary purpose of highway drainage facilities, such as bridges and culverts, is to move highway and hydraulic traffic smoothly, each along its own course without interference. Unlike highway traffic, the hydraulic traffic cannot be controlled by enacting statutes or erecting road signs. Consequently, conflicts exist between the highway system and the waterway.

The major source of conflict arises from the modification of natural waterways in both horizontal and vertical dimensions and the consequent alteration of stream characteristics at crossing sites. A major highway system crossing a wide stream valley involves the installation of bridge piers and approach embankments in the stream waterway. The result of such construction is a change of hydraulic behavior near or at the crossing site. Notable changes in hydraulic behavior are (1) an increase in water surface elevation upstream from the bridge, (2) an increase in flow velocity under the bridge, and (3) the possible inundation of bridge decks or overtopping of approach embankments. The obvious effects associated with the construction of highway culverts are ponding in the upstream areas and increase in flow velocity downstream from the culvert exit, and in some cases, roadway overtopping.

Depending upon the extent and nature of stream cross-section modifications at the bridge site, a given flood may or may not result in greater flood damage than under preconstruction conditions. In some cases it is possible that excessive property damage and heavy loss of human life may occur if the crossing is not properly designed. A design engineer thus has an extremely important task in the process of decision-making for his design. For safety reasons, he may lean toward an over-design alternative, but then find that he has exceeded the available project funds. Furthermore, while it is possible to predict the probability of flood events of various sizes over some period of time, it is not possible to predict the specific occurrence of such events, which makes design decisions all the more difficult.

Thus an adequate design scheme is difficult to define, as it may be adequate for floods of magnitude less than the design flood, but not for those floods which are larger than the design flood. Since it is impractical to design a project for extreme flood, a certain amount of risk in terms of structural failure, property damage and loss of life always exists.

It is the designer's objective to design a project which is least costly to society as a whole. To evaluate such costs the cost of initial investment together with the risk, or chance of flood loss, for all flood sizes must be considered. This report illustrates the procedures for performing such analysis.

The analysis procedure developed in this study applies only to highway stream crossings on flood plains with no constraints. The governing design problem is assumed to be to what extent the flow can be constricted without exceeding some acceptable level of flood damage. The need for such analysis is evident from a recent study by Chang (1). Chang reports that the cause of bridge failures according to the Emergency Relief Files is "flow path defficiency." Furthermore, the records of the FHWA indicate that more than 80 percent of the federal aid bridges built between 1953 and 1973 are over water. This report describes a means for assessing the optimum combination of bridge opening and embankment height for a proposed bridge site. It is recognized that there are many bridge situations that do not lend themselves to the optimization procedure developed in this study, including such cases as spans over deep gorges, or spans over a certain future meander cut-off.

GENERAL DESIGN ALTERNATIVES

Consider the case where a highway crosses the flood plain of a major stream. There are several alternative schemes for passing the traffic across the waterway. The most obvious is to build a bridge extending from bank to bank. The initial investment for such a scheme, however, may not be economically feasible if the valley is two or more miles wide.

Another alternative is to design the highway stream crossing with a combination of approach embankment and bridge if the fill height is not excessively great. While such a combination results in significantly lower initial construction costs (assuming earthfill is less expensive per unit length than bridge structure), the relationship of embankment height and length to bridge height and length determines not only cost, but also the ability of the highway crossing to survive a major flood undamaged. Thus fill height may vary considerably depending on the importance of the highway. The trade-off is in terms of lower initial cost versus some probability of potential cost in flood damage both at the bridge site and upstream.[1]

There are two principal choices within this combination scheme. One is to build a high embankment to insure against overtopping. The higher the embankment, the longer the bridge structure must be to allow an adequate flood flow channel. This choice may have a relatively high initial cost, but a lower potential flood damage cost at the site. The second choice is to build a lower embankment and a shorter bridge. While this mode carries a relatively low initial investment, it has a higher potential cost in flood damage in terms of roadway damage and traffic disruption due to embankment overtopping. However, upstream backwater damage may be lower under these conditions than in the first choice and the damage to the bridge structure may be reduced since flow velocity through the bridge opening is lower in this case, assuming overtopping.

Engineering economics offers a method to find the most cost-effective combination of embankment height and bridge length considering the probability of various flood magnitudes. This method is a decision-making tool for evaluating proposed bridge construction investments in dollar terms.

---

[1] Approach embankments crossing flood plains hinder the flood flow passage and have the effect of raising upstream water levels, the so-called backwater, which may cause upstream property damage.

APPLICATION OF RISK ANALYSIS

On interstate projects, bridges and culverts conventionally are constructed to accommodate floods of at least a 50-year frequency or the greatest flood of record, whichever is greater, with runoff based on land development 20 years in the future and backwater limited to upstream property or the highway. Executive Order 11296, issued in August 1966, and Flood Hazard Evaluation Guidelines for Federal Executive Agencies, issued in May 1972, require that the elevation of the 100-year flood at project sites be delineated. Since the publication of these guidelines, the FHWA has issued a new policy for hydraulic design of highway encroachments on flood plains. The new policy is given in Appendix A.

Both the Flood Hazard Evaluation Guidelines and the FHWA design policy indicate the need for analyzing the risk of a given project for more than a single design flood, including the potential risks that may be derived from floods larger than the design flood. Such considerations are needed as is evident by the recent severe effects of Storms Camille and Agnes.

During these two tropical storms, massive damage and inconvenience were reported in the eastern and southeastern United States. The states of Virginia, Maryland and Pennsylvania suffered a total of nearly $75 million in highway and bridge damage by Agnes in June 1972. For this same storm the Pennsylvania Department of Transportation (2) reported that 252 bridges were out of service on that State's highway system, including federal-aid and nonfederal-aid roads. In August 1969, Camille caused Virginia highway damage assessed at $19 million, destroying or damaging 133 bridges and closing 25 miles of primary roads. The Virginia Department of Highways estimates that Camille caused over $133 million to the Commonwealth in personal and property damage (3). Damages on this scale warrant a closer look at the conventional method on which investment decisions for highway stream crossings have been made. Logical, methodical decision-making techniques must be developed and implemented so that the potential damages can be weighed against initial cost.

Risk factor analysis is a method which has been applied in other fields for similar purposes. In risk analysis, as applied to stream crossing designs, the expected value of flood-related damages to the project itself and other losses caused by the waterway construction are evaluated for a complete spectrum of flood frequencies. This value is weighted and added to the initial cost of the project. With this information, an optimum design can be determined. The basic theory of this method is to find a design scheme which is least costly to society rather than to design a project for a predetermined flood occurrence interval.

OBJECTIVE OF STUDY

The primary objective of this study is to develop a method based on risk analysis to select the most cost-effective relationships among the major parameters in the design of highway stream crossings. This method differs from the conventional design method by taking into account flood damages to the structure, to adjacent properties from backwater, and time loss of traffic delay during crossing overtopping and detouring. Each design scheme is evaluated by an annual total cost consisting of annual cost of amortizing the structure, maintenance, and the annual expected value of flood damages (i.e., risk). The method uses dollar costs as a basis for comparing the results associated with each set of design parameters.

Highway statistics indicate that approximately 25 percent of U.S. highway construction costs are allocated to drainage facilities. This amounts to a cost ranging from $50,000 per mile for secondary roads to nearly $1,000,000 per mile on the interstate system. This high cost warrants the development and application of a systematic tool for selecting the most cost-effective designs applicable to each site.

SCOPE OF STUDY

The basic concept of the economic/risk analysis method is to integrate the hydrologic, hydraulic and economic factors to assess the total economic response for a given design scheme. The annual total economic response is equal to the sum of the *annual initial cost*[2] of the project plus the annual risk. Risk is defined as the expected yearly losses associated with flooding; this definition weights the economic effects by their probable outcomes. Flood losses include damage incurred to bridge and embankment structures, backwater damage to property adjacent to the highway crossing, loss of time to highway users when the bridge is impassable during embankment overtopping and the subsequent repair period, and additional cost due to detouring.

All the analyses are to be carried out on a digital computer in FORTRAN. While the method of analysis is intended to be as comprehensive as possible, certain assumptions have been made in the model development. In general, the method is defined within the following framework:

1. The computation of water surface elevation and flow velocities throughout the flow region is performed by a two-dimensional Finite Element Model. These hydraulic computations give solutions for steady state peak flow conditions.

2. Flood hydrographs and their return periods are the hydrologic data needed to conduct the analysis.

---

[2]Defined on page 14 as the total construction cost spread over the amortization period of the structure.

3. Bridge damage and/or loss by floating debris and flow inundation are considered in the model.

4. Property damage due to backwater resulting from the bridge construction is represented by a stage-damage curve, as is conventional.

5. The method of analysis presented in this report cannot be applied to assess the case of irreducibles, such as defense or emergency evacuation routes or for the case where severe budget constraints are imposed on design.

6. Economic factors must be estimated on a case-by-case basis.

II. SITE DATA COLLECTION

The first step of an engineering analysis for a proposed highway stream crossing is to collect the necessary data for that bridge site. Data to be gathered for each site are:

1. Location map showing the proposed highway alignment, embankment and structures, reach of river to be affected by embankment encroachment, and existing embankment encroachment and highway structures, if any.

2. Vicinity map showing flood flow patterns, cross sections of stream, location of proposed bridge opening, alignment of piers, skew of crossing, bends and stream meanders, and vegetation types and density on flood plains.

3. Description of existing bridge structures both upstream and downstream from crossing or encroachment. This should include:

   a. Type of bridge, including span lengths and pier orientation.

   b. Foundation type such as spread footing or piling; foundation depth.

   c. Scour history at abutments; stream aggradation, degradation.

   d. Stream cross section beneath structures, noting stream clearance to superstructure and skew with direction of current during floods.

   e. All available flood history information, including highwater marks with dates and elevation, nature of flooding, damages and source of information.

   f. Photographs showing existing structures, past floods, main channels and flood plains.

g. Information on nature of drift, ice, streambed, bank stability, and land use.

4. List of factors affecting water stage at bridge site.
   a. Highwater from other streams.
   b. Reservoirs - existing or proposed and approximate date of construction.
   c. Flood control projects (give status).
   d. Tides.
   e. Other controls.

5. Geologic data at proposed bridge site.

6. Hydrologic data.
   a. Drainage area above the proposed bridge crossing site.
   b. Streamflow records at the site and/or at nearby stations.
   c. Characteristics of drainage basin including basin slope, soil type, and rainfall.

7. Traffic data.
   a. Average daily traffic (ADT).
   b. Vehicular diversity such as fraction of ADT in passenger cars, commercial vehicles, etc.
   c. Number of occupants per vehicle.
   d. Speed.
   e. Available detour routes and length of detour.
   f. Accident data.

8. Economic data.
   a. Cost of labor and construction materials.
   b. Average personal income.
   c. Type of land development alongside the stream, including agricultural, manufacturing, residential, retail business, selective services and wholesale business.

There are many possible sources for the data listed in the preceding paragraphs. Depending upon the type needed, data may be collected by federal, state or private agencies. Typically, data types 1 and 2 are obtainable from the U. S. Geological Survey (USGS) guadrangle maps. To allow a more detailed description of the site, aerial photographs and specially prepared maps with 1- or 2-foot contours must be used. In some cases, cross sections normal to flood flow are used in lieu of topographic maps. As a minimum, three sections are required: one upstream, one at the site crossing, and one downstream. The type and distribution of ground cover on the flood plains may be obtained from aerial photos and site visits.

Geological data are generally obtainable from either USGS and/or state geological surveys or departments. Boring may be required if no geological data can be obtained from these or other sources.

Traffic data are, of course, gathered by the state highway departments. Most of the economic data are obtainable from national census data.

Streamflow data have been collected at gaging stations throughout the country and published by the USGS. The U. S. Weather Service provides rainfall data for various locations throughout the country.

At a proposed bridge site the streamflow record frequently is either nonexistent or for only a limited period. With such limited information it is difficult to obtain accurate hydrologic data for use in analysis. In order to overcome this shortcoming the FHWA is currently sponsoring research projects to facilitate better prediction computations methods for peak flow from small watersheds. It is anticipated that once these results become available they will be incorporated into the model developed in this report. For the purpose of model development in this study, however, the hydrologic data which are available at the present time have been used for analysis.

III. METHOD OF ANALYSIS

The general concept and approach for applying risk analysis to a series of design schemes for a highway stream crossing includes the computation of annual construction cost and expected yearly risk associated with floods for selected design schemes. The sum of the annual construction cost and the expected flood-related loss, or risk, is the economic response or expected tangible total costs of the stream crossing to the highway users.

Figure 1 shows the overall logic sequence and analysis procedure for evaluating each design scheme. For each scheme the procedure involves five major steps:

1. Calculate annual construction costs,
2. Perform hydraulic computation,
3. Estimate embankment erosion and scour under bridge,
4. Compute losses associated with structural and property damages, and losses incurred from traffic delay, and
5. Weight losses with flood probabilities to determine risk.

The construction costs are computed for each design scheme by using either a quantity-times-unit-cost method or empirical methods. Structural damage is assumed to be directly related to the extent of embankment erosion caused by flow overtopping, degree of debris clogging at the bridge opening, depth of bridge inundation, scour caused by the excessive velocity under the bridge opening, and the washout of roadway from overtopping. Flood backwater damage to property is derived from a flow- or stage-damage function formulated for each crossing site. Traffic-related losses include the cost of lost time, increased running costs, accident losses on the detour,

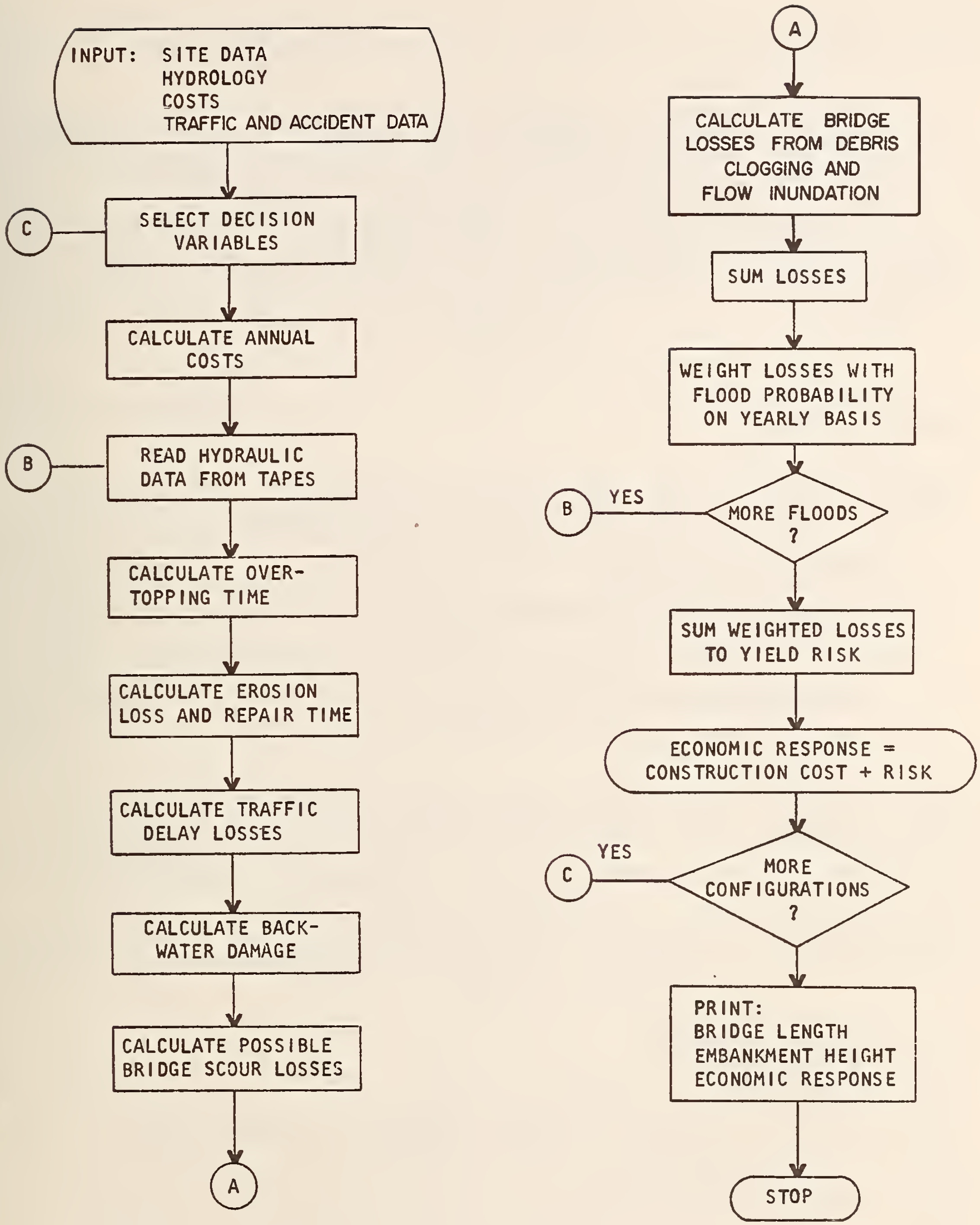


Figure 1. Logic Flow of Risk Analysis

and accident losses due to an unexpected obstacle or barricade placed at the stream crossing site when a failure of the roadway occurs.

The estimated structural damage, flood damage, and traffic-related losses are multiplied by the probability of yearly flood occurrence to obtain the risk for each flood event. Summing the risks over the set of flood events selected for study yields the risk component of the total economic response.

ANNUAL CONSTRUCTION COST

The construction costs for a highway crossing normally consist of:

- Bridge superstructure,
- Bridge substructure and excavation,
- Approach embankments,
- Roadway pavement, and
- Protective measures (spur dikes, riprap).

In general, the total construction costs are governed by the type of bridge, bridge length, bridge width, clearance, span, geology of the river bed, height of the embankment, type of highway (e.g., primary or secondary), and width of the valley at the crossing site. In the model construction costs are calculated as the sum of the following cost components:

(1) Roadway pavement,
(2) Embankment,
(3) Bridge, including the superstructure, substructure and excavation, and
(4) Protective measures.

1. *COST OF ROADWAY PAVEMENT*

An estimate of the cost of this parameter is calculated by multiplying the total length of the roadway between the beginning and end stations of the valley crossing, excluding the bridge length, by the cost per linear foot ($/L-ft) of roadway. It is assumed that (1) the cost factor includes materials and labor, and (2) the cost of roadway pavement over the bridge is included in the bridge cost.

2. *COST OF EMBANKMENT*

Calculation of construction cost for approach embankments is made on a unit volume basis. Given grade and roadway elevation along the highway center line, the embankment top width, and upstream and downstream side slopes, the quantity of earth fill can be readily computed. The total cost is computed by multiplying the quantity of fill volume by the unit cost ($/cu ft). Figure 2 shows the geometry of a typical river crossing.

In the model the volume of the i^{th} element between stations i and i+1 is calculated by

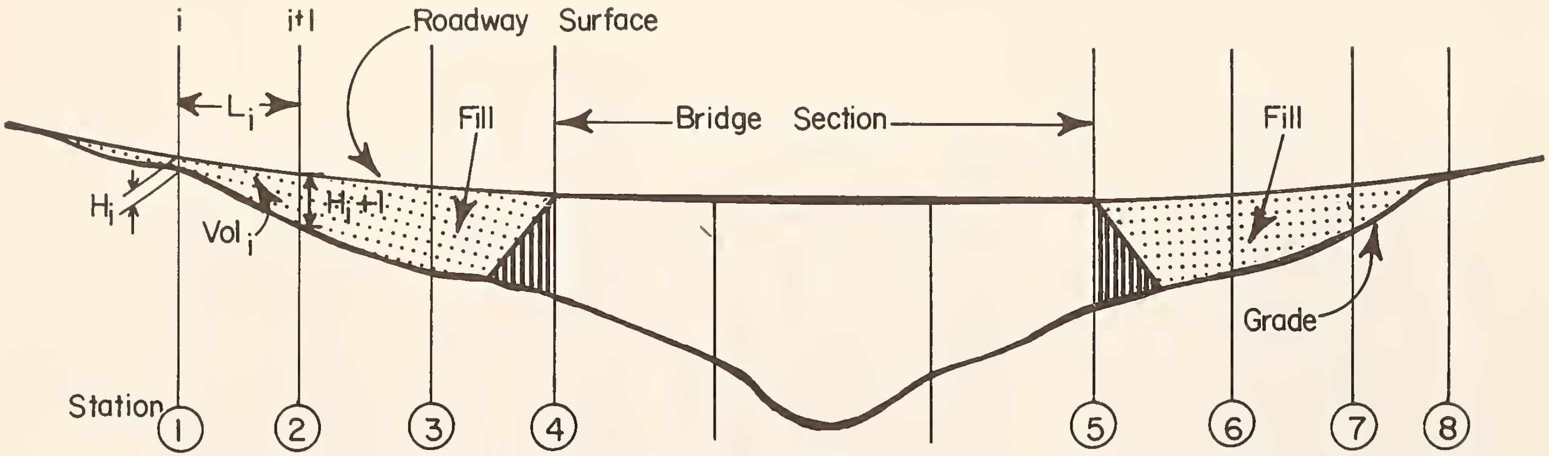
$$Vol_i = RW \frac{H_i + H_{i+1}}{2} L_i + \frac{1}{4} \left(S_1 + S_2\right) \left(H_i^2 + H_{i+1}^2\right) L_i \qquad (1)$$

where H_i, H_{i+1} = fill height at stations i and i+1, respectively,

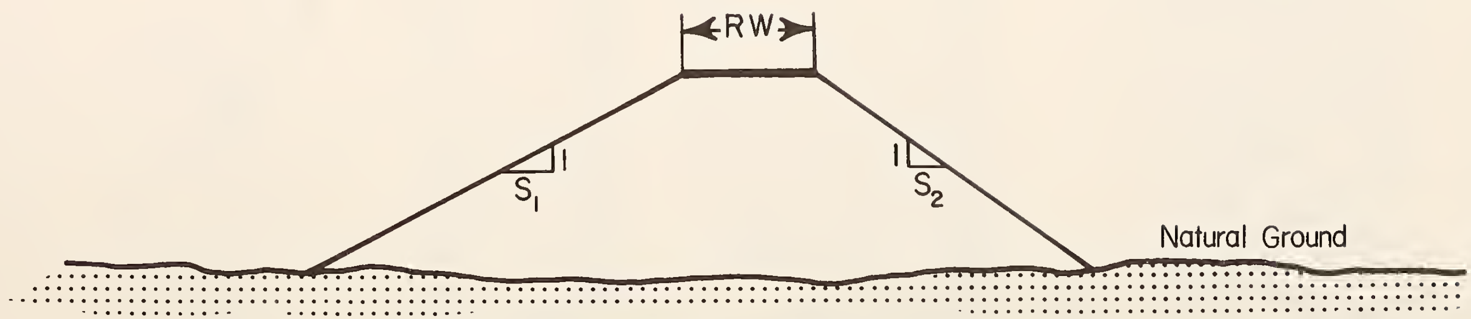
RW = width of roadway,

L_i = element length, and

S_1, S_2 = side slope of fill.



a) STREAM CROSS SECTION



b) EMBANKMENT CROSS SECTION

Figure 2. Geometry of a Typical Highway Stream Crossing

3. BRIDGE COSTS

The calculation of the total Risk associated with a structure requires an accurate evaluation of the cost of construction for the structure. Bridge costs can be divided into the cost of the following major components: bridge deck, piers, abutments, footings and piles. Each of the components can be expressed either as a function of the bridge length, embankment height, expected scour depth, as in the case of piers, or a constant cost. For example, bridge deck cost is related to the length of the span while pier cost can be expressed as a function of expected scour depth. Conceptually, a bridge costing function can take the form:

$$C_b = C_{sup} + C_{sub} = C(L,H) \qquad (2)$$

where

C_b = total costs

C_{sup} = superstructure costs

C_{sub} = substructure costs

L = bridge length

H = fill height

A portion of the substructure costs includes the costs due to the depth piers must be driven in anticipation of expected scour. Presently, the model allows one pier depth to be input for all the model runs using the scour option. If a conservative approach to the analysis is followed this requires this depth and its associated costs to be calculated for the narrowest opening and maximum flow and embankment elevation.

This is suggested for two reasons:

1. Bridges are not purposely designed to fail under any expected conditions and to allow the structure to fail during analysis represents a condition not followed in standard practice.

2. Since only one pier depth is permitted, a conservative approach to the structural design of the bridge requires the piers be designed for the worst case, which is maximum flow, maximum embankment elevation, and minimum opening size.

Ideally a third factor besides embankment height and bridge opening in the analysis would be pier length and its costs. However, this considerably increases the complexity of the problem. Useful information could be obtained by a more detailed study of this problem and can easily be incorporated into the Risk analysis at some future time.

The costing method presently employed allows the user two options. He can either input a cost function for each bridge design or allow the model to use its own internal functions as described in Table 1. Option 1 is formulated below:

$$C_b = f(L) + G*d_1 + K \tag{3}$$

where

$$f(L) = B_1 + B_2 * L$$

and $K = B_3 + B_4$

B_1 = constant coefficient for bridge superstructure cost

B_2 = coefficient of bridge length

B_3 = pier, footing and abutment costs

B_4 = spur dike costs

G = cost/ft of pile (optional)

d_1 = length of pile (optional)

Equation 3 constitutes the basic bridge cost equation for the model. Due to the variation in bridge type and the variation in costs of construction materials and labor from location to location, it is generally difficult to formulate an equation of C_b sufficiently convenient for modeling use. Consequently, the user must provide the coefficients as inputs to the model for determination of bridge cost. It should be noted that Equation 3 also provides the user with the opportunity to input the total bridge cost directly, if such information is available. This may be accomplished by setting the coefficients B_2 through B_4 to zero and inputing B_1 as the known total bridge cost.

A second option is available for those users who are only interested in approximate bridge cost estimation or who are unfamiliar with bridge cost computations. The second option, described below is permanently included in the model. The information provided in the second option was derived based on statistical data of bridge costs throughout the United States collected over a period of 21 years. The bridge cost equation used in the routine was developed during the course of this study based on a regression analysis of costs on bridge lengths. Data were provided by the FHWA (4), which has collected extensive files of cost data through the federal aid highway programs. The bridge cost data contained in the FHWA file (4) for the period 1953-1972 were regressed in the form of

$$C_b = a_o + a_1 x_1 \tag{4}$$

where

a_o = constant

a_1 = coefficient for length (x_1)

x_1 = bridge length

The results are shown in Table 1.

This method of estimating cost is not accurate for bridges of less than 0.1 mile in length since scatter observed in the cost data was too large.

Table 1. Bridge Cost Regressed on Bridge Length[1]

Length (Miles)	a_o	a_4	σ_{yx}	γ
.004 - .009	750.	-1421.	2611.	.12
.01 - .019	1165.	-295.	1295.	.05
.02 - .039	9752.	1593.	687.	.46
.04 - .099	1467.	1722.	665.	.51
.10 - .199	4830.	1547.	163.	.91
>.20	5080.	1608.	184.	.89

where σ_{yx} = standard error, and
γ = correlation coefficient.

[1]Costs are based on 1972 price level. Adjustment for inflation has been considered for the period studied.

4. *PROTECTIVE MEASURES*

Constriction of flood plain by approach embankment invariably induces a lateral movement of flood water from the embankment face toward the bridge opening. As this flow joins the main flow a high flow concentration in the vicinity of the abutment occurs. This high flow concentration may produce violent turbulence as it enters the constriction, thus creating scour at the abutment toe.

An effective means of preventing abutment scour is the installation of spur dikes attached to the abutments. The length of spur dikes is generally governed by the fraction of flow on the flood plain and the velocity of the main flow. A method for determining the length of spur dikes is presented in Reference 5. The height of spur dikes is determined based on water depth in the flood plain.

The side slope of spur dikes is governed by the type of material to be used for spur dike construction. Once the geometry of the dikes is known, the quantity of material and hence the cost can be obtained. This cost is added directly to the construction cost of the bridge under option 1 of calculating bridge cost and is included in the regression equation used in option 2.

At some bridge sites the use of riprap is required to protect the embankments and abutments from erosion. The method of computing the size of riprap materials is given in Reference 6. The cost of the riprap is added to the construction cost of the bridge directly under option 1 of calculating bridge cost and is included in the regression analysis employed under option 2.

The four major construction cost components (roadway pavement, embankment, bridge superstructure, substructure and excavation, and protective measures) are summed to determine the total initial construction cost of the bridge design. The annual construction cost is obtained by multiplying the total initial construction cost by the capital recovery factor for the amortization period (life of the structure) and the appropriate interest rate. The capital recovery factor is expressed as:

$$CRF = \frac{1}{\frac{(1+i)^n - 1}{i}} + i \qquad (5)$$

where

i = appropriate interest rate and

n = amortization period in years.

HYDROLOGY

A detailed description of the hydrologic aspects of highway stream crossing sites is beyond the scope of this study. It is assumed that hydrologic data necessary for risk analysis are available for study sites of interest.

Two types of hydrologic data are essential for risk analysis. The first type is the flood-frequency curve, and the second type is flow hydrographs of each individual flood event. The flood-frequency curve provides data on peak discharges and the associated probability of occurrence needed for computing flood risks.

A waterway constriction controls the flow with an effect similar to that of a reservoir spillway or sluice gate. The stage-discharge relationship is altered once the control structure is in place. Dynamic routing of flows before and after this constriction shows the difference in hydrographic response. However, as dynamic routing is not within the scope of this study, inflow hydrographs and the stage-discharge curve at the bridge site, with bridge in place, are used to estimate the duration of embankment overtopping.

The runoff hydrographs for this study are assumed to be triangular in shape. In order to define these hydrographs, three parameters are required: (1) time to peak, T_p; (2) flood duration, T_b; and (3) the peak flow, Q_p. A general representation of the assumed runoff hydrograph is shown in Figure 3.

Time to peak is estimated using the drainage basin characteristics incorporated in a design method used by the U. S. Bureau of Reclamation (7). Time to peak is approximated by the time of concentration, T_c, defined as the travel time of the runoff from the hydraulically most distant point to the bridge site. The empirical method presented by the Soil

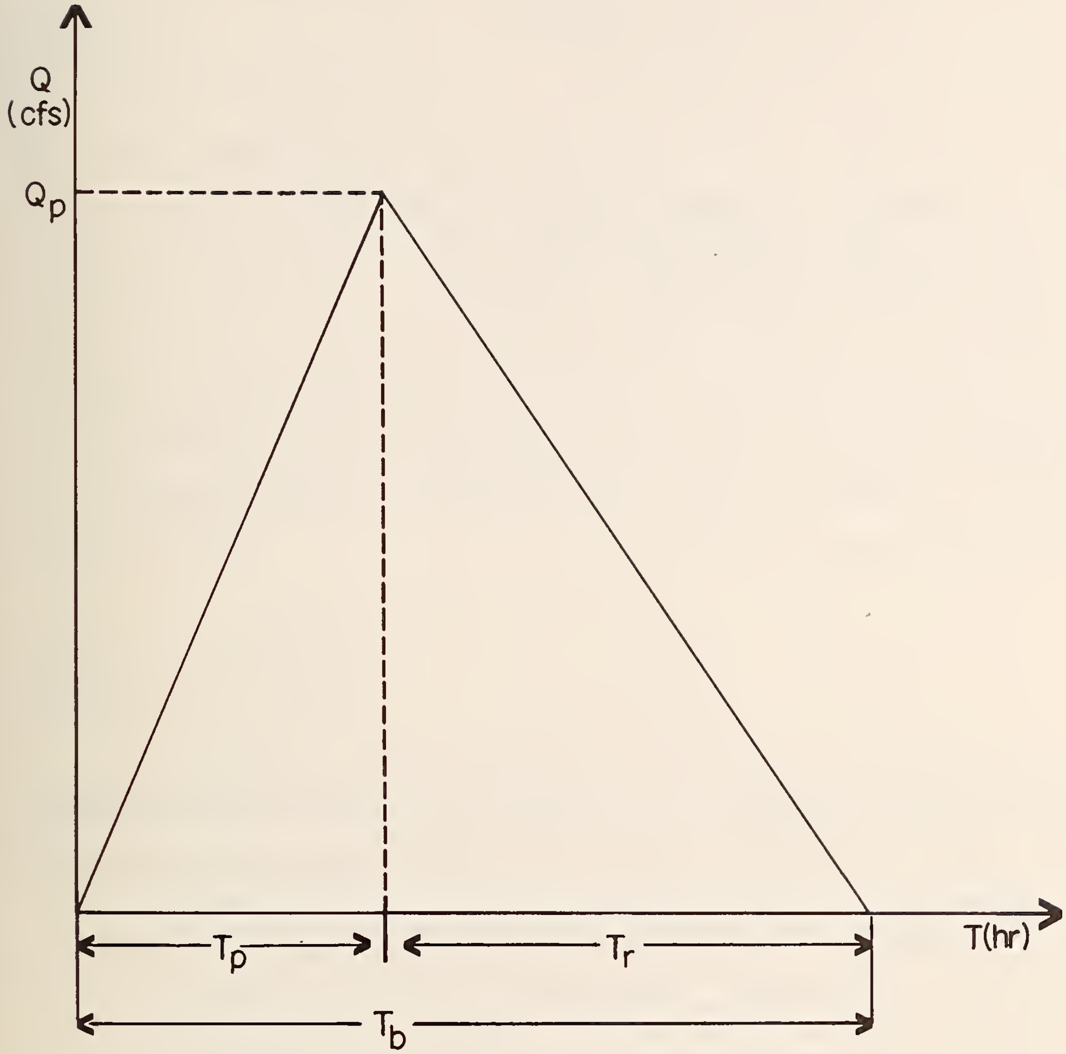


Figure 3. General Shape of Assumed Hydrograph

Conservation Service (8) for determining the time of concentration is

$$T_c = \left(\frac{11.9\ L^3}{H}\right)^{0.385} \tag{6}$$

where

L = length of longest watercourse in miles,
H = elevation difference in feet, and
T_c = time of concentration in hours.

The Bureau of Reclamation method is used to determine the length of time between the peak flow and the end of the hydrograph. This time period is designated T_r in Figure 3. For a given watershed, the relationship between the time to peak (T_p) and T_r is

$$\frac{T_r}{T_p} = K$$

The value of the constant, K, is computed from recorded hydrographs. Analyses by the Soil Conservation Service (8) suggest 1.67 as an average value for this constant for use on ungaged watersheds. This constant substituted into the above equation produces Equation 7, which is used in the RISK module to determine T_r.

$$T_r = 1.67\ T_p \tag{7}$$

In summary, we have the following relationships:

$$T_p = T_c = \left(\frac{11.9\ L^3}{H}\right)^{.385}$$

$$T_r = T_b - T_p = 1.67\ T_p$$

The final parameter required to determine the hydrograph is the peak flow (Q_p). The range of peak flows associated with different recurrence intervals is determined by fitting runoff data at the site to a Gumbel plot. A Gumbel plot is a linearized graph of relative flood peak magnitudes versus the average recurrence interval in years. The axes are divided in such a manner that the storm frequency distributions plot as an approximately straight line. Figure 4 shows a Gumbel plot for the Tallahalla, Mississippi, bridge site. The data for the figure were recorded at Laurel, Mississippi, the nearest station to the Tallahalla bridge site. For demonstration purposes, the data were not corrected for drainage area difference since the station at Laurel is within five miles of the bridge site, with no major tributaries draining into the five-mile reach.

HYDRAULIC COMPUTATIONS

As mentioned previously the construction of bridge approach embankments onto flood plains results in the constriction of flood waterways. This could cause:

1. Increase in water surface elevation over normal stage (i.e., backwater) on flood plains and adjacent lands near the bridge crossing site.
2. Overtopping of approach embankments during flooding.
3. Increase in flow velocity through the bridge opening.

All of the above three cases could produce varying degrees of flood loss. Backwater flood damages are incurred to real properties such as commercial, industrial and residential developments. Embankment overtopping causes losses ranging from traffic delay to structural failure. An excessive increase in velocity through the bridge opening upsets the hydraulic regime, eroding the stream bed and causing local scour

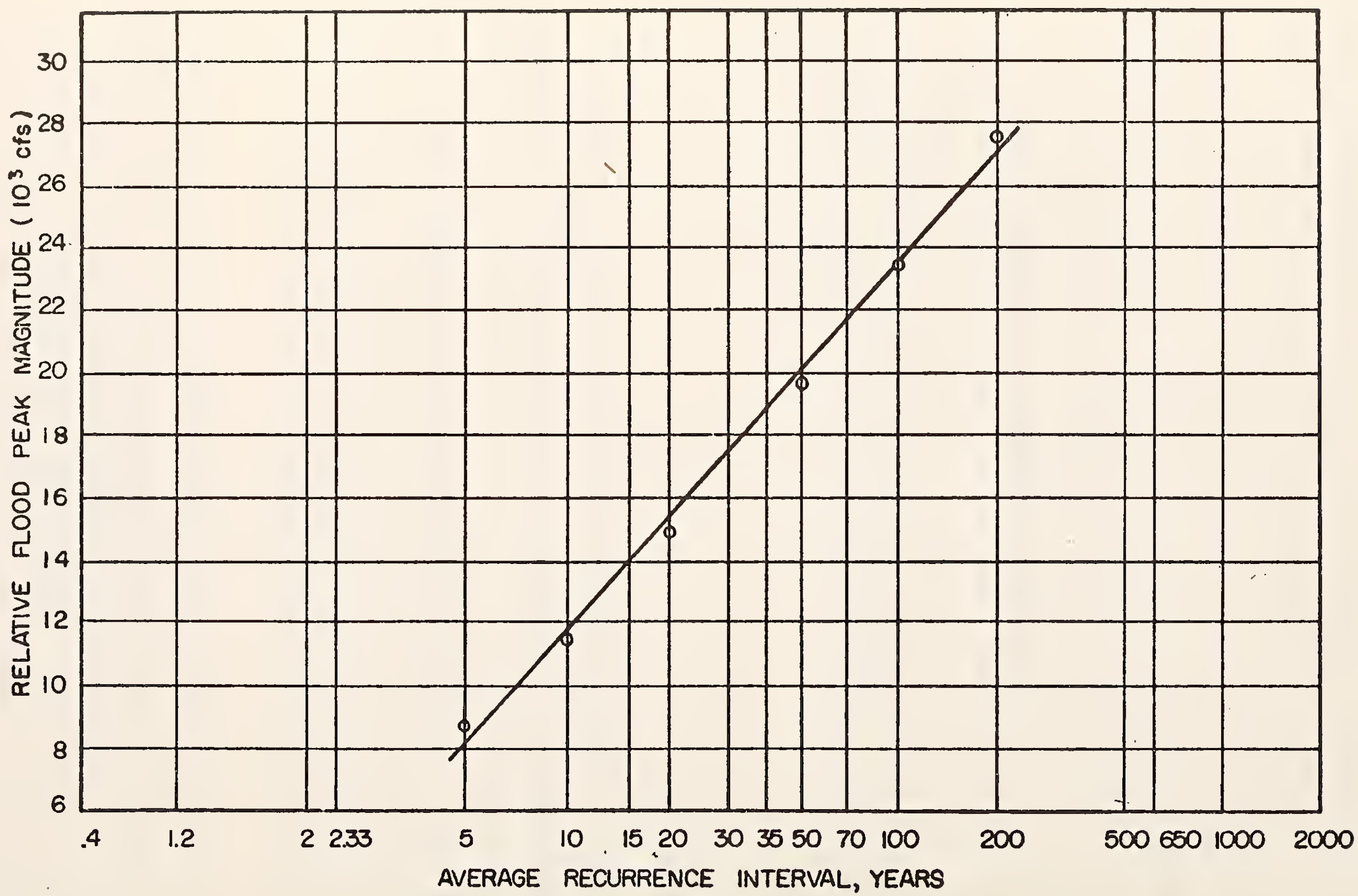


Figure 4. Gumbel Plot for Tallahalla, Mississippi, Bridge Site

around bridge piers. In order to assess the damage that a given flood could produce, the hydraulic information associated with that flood must be properly computed under a preselected set of bridge design schemes.

In the real world flood flow is a dynamic phenomenon. The variation in flood stage and velocity components is both temporal and spatial. Unfortunately, techniques for dynamically routing multi-dimensional flow are still quite limited in both applicability and practicability. In the case of bridge hydraulics the ultimate interest of the designer lies in the peak flow conditions. For this reason the hydraulic computation is necessary for steady state peak flow conditions only.

Data required for the hydraulic computation are:

1. Topography or cross section of stream near bridge site,
2. Aerial photo,
3. Vegetation map,
4. Stage-discharge diagram,
5. Flood-frequency curve, and
6. Bridge configuration--opening size, skewness, eccentricity.

The hydraulic description is obtained by solving the set of governing partial differential equations for the flow region, assuming prescribed boundary conditions. The set of partial differential equations consists of the equations of motion and continuity in a two-dimensional flow region. A numerical technique, the Finite Element Method, is applied to solve the governing flow equations. Throughout this report the hydraulic model is referred to as the Finite Element Model (FEM). The hydraulic output of FEM is:

1. Water surface elevation at various locations throughout the flow regime,
2. Velocity components at various locations along the direction of the stream and the transverse direction,

3. Velocity through the bridge opening, and
4. Flow overtopping, if any, of the approach embankments.

The hydraulic computation is carried out for each flood of interest. The hydraulic data for each flood are stored on hydraulic tapes for the computation of flood risk.

The Finite Element Model is described in detail in Volume III of this series. Chapter VI of that volume describes the results of the hydraulic solution for the Tallahalla Creek bridge site.

CALCULATION OF LOSSES

STRUCTURAL DAMAGES

At a highway stream crossing site, flood-related structural damage results from one or more of the following:

1. Damage to bridge superstructure due to debris and inundation of bridge deck.
2. Embankment erosion due to overtopping.
3. Scour under bridge piers and abutments.

1. Damage to Bridge Superstructure

When the bridge deck is inundated by flood water, the superstructure is subject to two types of force, in addition to its own weight. In the horizontal direction the superstructure is subject to a thrust caused by the dynamic forces of flow acting on the upstream face of the bridge. In the vertical direction the bridge is acted upon by a buoyancy force. Because of the buoyancy the effective weight of a concrete bridge is reduced to about 60 percent of its weight in air. The combination of fluid dynamic forces and buoyancy may push or lift the superstructure from the abutments and piers, causing bridge failure.

There are other factors which may aggravate the bridge failure:

- First, the accumulation of trash at the bridge causing changes in the flow patterns and thus unbalancing the forces acting on the bridge;
- Second, the impact of large floating debris striking the bridge; and
- Third, the entrapment of air under the deck between girders resulting in further reduction of the effective weight of the bridge superstructure.

It is generally difficult to predict the effects of flood forces on bridge superstructure and the extent of bridge damage caused by superstructure inundation, particularly since data on the yield and nature of flood debris are not easy to obtain. Although bridge failures due to flooding of bridge decks have been reported during major floods, this information is insufficient for modeling purposes. Further research is urgently needed in this respect.

While bridge damage from inundation of superstructure is difficult to assess, it is too important to be ignored in assessing flood losses. For lack of information the present model uses the following equation to compute the bridge damage, L_b:

$$L_b = \zeta y \tag{8}$$

where

ζ = a coefficient and

y = submergence of bridge deck.

Values of ζ may be obtained for specific bridge sites from past flood records. If ζ is not specified in the model input, it will be set to zero by the program. This portion of the algorithm may be modified when a more refined method for assessing bridge damage becomes available.

2. *Embankment Erosion*

Embankment erosion caused by flow overtopping has not been studied on a broad scale. This is surprising considering the number of earthfill dams and dikes which have the potential for producing catastrophes if they fail. While the washout of a bridge approach embankment will probably not result in catastrophic damage, it will cause traffic interruption and bridge structural damage. In order to assess these losses, the mechanism of embankment erosion during overtopping must be known. Unfortunately, existing literature can provide only limited information on the subject. A brief description of related work on embankment erosion follows.

- A series of model tests by Posey (9) to study erosion on uniform and graded riprap layers for various flow conditions; the tests were inconclusive.
- Laboratory and field experiments by Tinney and Hsu (10) to demonstrate the feasibility of using a fuse plug in the spillway of a major dam. In this project, a pilot channel, ten feet wide and 11.5 feet high with an invert three feet lower than the crest, starts the washout of the fuse plug. In a 1:2 scale model, the breach time for the pilot channel was one minute 27 seconds. The lateral erosion rate was 5.6 feet per minute for uniform material and 1.4 feet per minute for well graded material. A uniform, cohesive rock material was used at the pilot channel.
- A method developed by Cristofano (11) for computing erosion rate in an earth dam embankment failure, assuming that overflow through a shallow notch of a given width had started. The rate of additional deepening of the notch or erosion of fill material is computed by

$$\frac{Q_{soil}}{Q_{water}} = K\ e^{-x} \tag{9}$$

where

Q_{soil} = volume of soil eroded in each time period,

Q_{water} = volume of water discharged each time period,

K = constant of proportionality, 1 in this case,

e = base of natural logarithmic system, and

$x = b/H \tan \theta$

where b = base length of overflow channel at any given time,

H = hydraulic head at any given time, and

θ = developed angle of friction of soil.

- Application of Equation 9 by Newton and Cripe (12) to analyze the embankment breaching in safety studies of Tennessee Valley Authority (TVA) nuclear power plants.

In the absence of a satisfactory erosion equation, the following empirical equation developed in an earlier WRE study (13) is used in this study:

$$E = \alpha V^{\beta} \tag{10}$$

where

E = erosion in tons/ft/day,

V = velocity in ft/sec, and

α, β = empirical constants.

Estimates of α and β are .25 and 3.8, respectively. These values represent a compromise of the two extremes of a cohesive and cohesionless soil.

Figure 5 illustrates the erosion mechanism assumed, i.e., the eddies of flow turbulence and bed shear on the embankment surface. Once an embankment is overtopped, the head differential between the upstream and downstream sides of the embankment is generally small.

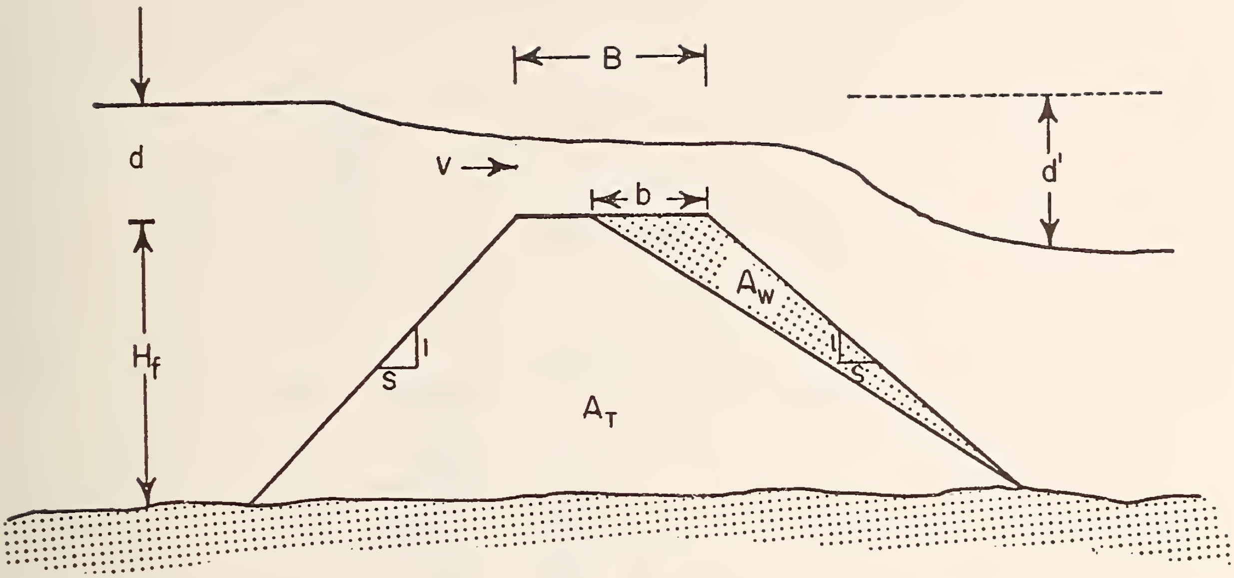
The velocity in Equation 10 is based on the assumption that critical flow exists over the roadway. In view of the small difference in head across the embankment, this assumption may be conservative. The roadway is assumed to act as a broad crested weir in the calculation of the critical velocity. For bridges, V is assumed to be the velocity of the water as it crosses a broad crested weir; this is the critical velocity which corresponds to one-third of the potential energy associated with the depth of the water at the weir. This bridge assumption recognizes the small water surface differences above and below the structure under conditions of complete flooding.

This embankment erosion formulation assumes that after an erosion threshhold velocity (V_e) is reached, embankment erosion can be represented by a triangular approximation, with area A_w. Values for V_e for various soils are given in Figure 6. Given the area eroded, the amount of damage to the roadway can be calculated and a percent of the total embankment erosion can be calculated as follows: Given a section of embankment length L, the total volume of the section is

$$V_t = (B + S \cdot H)\ H\ L \tag{11}$$

where

B = embankment width, and
H = fill height.



$$V = \sqrt{\frac{2}{3} gd}$$

$$E = A_W = \int_0^T \alpha V^\beta \, L \, dt$$

where T = time of overtopping,
L = roadway length, and
d = head above roadway.

Figure 5. Erosion Mechanism

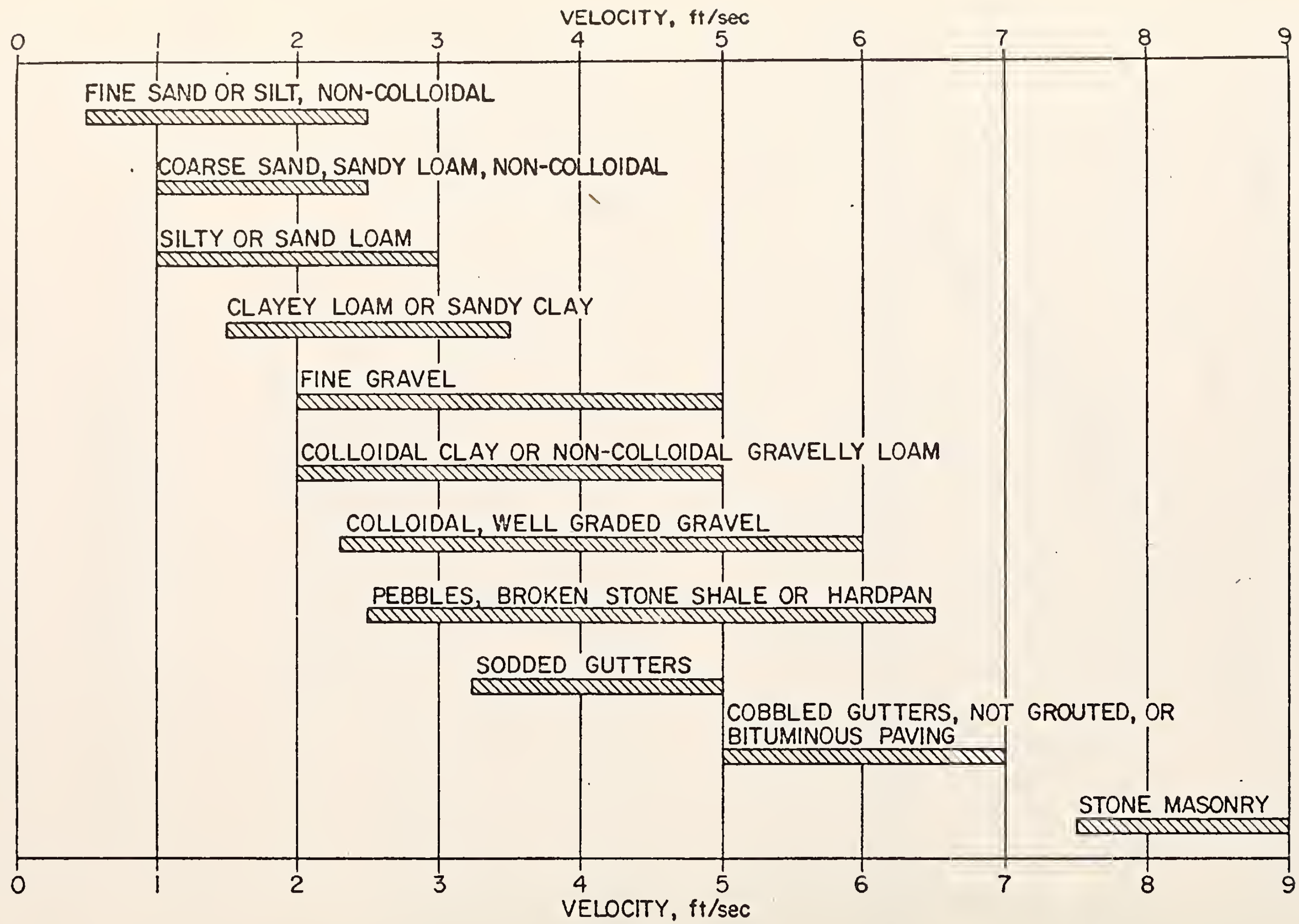


Figure 6. Range of Velocities for Different Soils Above Which Channel Erosion Will Occur (14)

From Equation 10 the total volume of erosion during the overtopping event is calculated as

$$E = \int_T \alpha V^\beta L dt$$

$$= \alpha V^\beta L T = \frac{b}{2} \; H \; L \qquad (12)$$

where T = the time of overtopping, and
b = eroded roadway width.

Thus the percent of embankment erosion is

$$P_1 = \frac{E}{V_t} \times 100 \qquad (13)$$

and the percent of roadway washout is

$$P_2 = \frac{b}{B} \times 100 = \frac{2\ E}{HL} \qquad (14)$$

Reiterating, damage to the approach embankments is of two types:

1. Erosion of the fill, and
2. Damage to the roadway.

Since bridge damage is considered independently of roadway and fill damage, this analysis does not include abutment undermining by erosion and the resultant loss of particular spans. It is assumed that bridges constructed in a flood plain are designed to use approach embankments in much the same way as an overflow spillway is used in dam construction.

The economic loss incurred by damage to the site (L_s) is computed as:

$$L_s = (P_1 C_f + P_2 C_r)\, C_a \qquad (15)$$

where C_f = original cost of fill,
C_r = original cost of roadway, and
C_a = cost adjustment factor.

The cost adjustment factor (C_a) is used to increase the cost of the original construction. This is done to allow for an increase in contracting cost to have a site quickly repaired.

Time of overtopping is determined as follows: Consider a bridge site located at a stream which has a stage-discharge curve, I, as shown in Figure 7. A bridge having an opening size of L_1 is constructed over the stream, resulting in a new stage-discharge curve. Notice that curve II is obtained using the assumption that no overtopping occurs, i.e., $H = \infty$. Now assume a design scheme which has a combination of bridge length L_1 and an embankment height of H_1. Then Q_e is the peak discharge producing a water surface elevation equal to the height of the embankment (point B). Any flood producing a peak flow larger than Q_e will overtop the embankment.

The time of overtopping for each peak flow is determined from the individual hydrograph, e.g. t_2, t_3, t_4 in Figure 7. These values are then used to compute embankment erosion and traffic-related losses.

3. Bridge Pier Scour

In major floods, bridges frequently fail because of scour around piers and abutments. Depth of scour is affected by both hydraulic and geologic conditions, including type of substrata, pier shape, angle of the pier to the flow, protective measures, depth of flow, velocity and turbulent intensity. Among the more random variables is debris clogging, which has been known to increase scour depth significantly and cause unexpected failure.

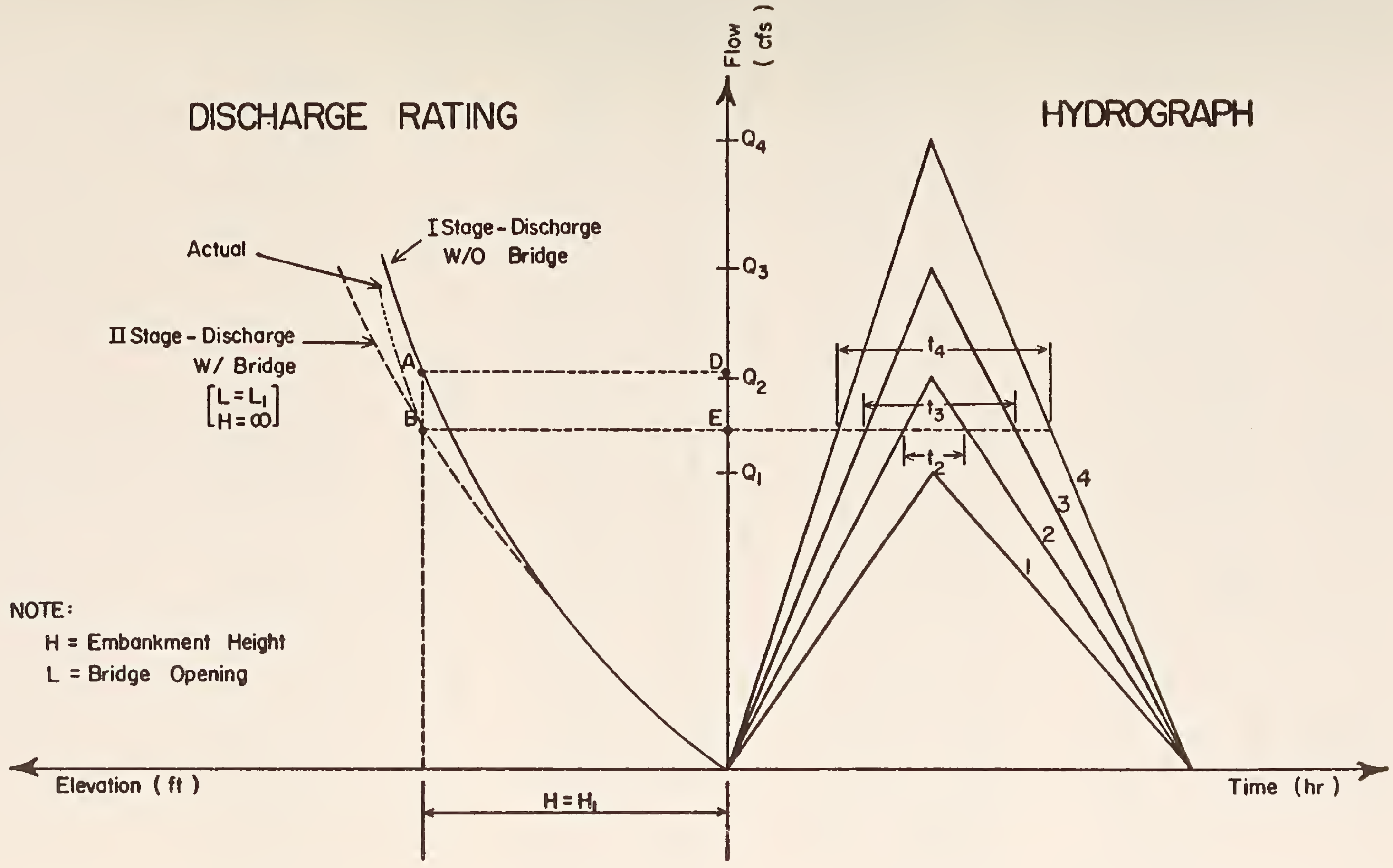


Figure 7. Determination of Embankment Overtopping Time

Methods for computing scour depth are still evolving. The existing formulas are derived primarily from laboratory experiments and while these formulas predict scour depth qualitatively, they do not incorporate the salient time-varying character of scour. Since the laws governing sediment transport have not been adequately defined, model results using presently available equations may not reproduce the prototype behavior. In an approach to this problem, the FHWA is sponsoring a massive field program to collect scour-related data.

For modeling purposes of this study, the empirical equation by Laursen has been adapted for scour computation. The model, however, is sufficiently flexible to accept a more realistic scour formula should one become available. The following simplified assumptions are implemented in the model for scour analysis without compromising accuracy to a significant degree:

1. Pier scour is the same for all shapes of piers, and
2. Velocity across the bridge opening is uniform.

The scour analysis implemented allows the user three different options:

1. Footing is set on solid rock. This implies no scour loss.
2. Piles rest on solid rock. This is taken as a cost added to the initial construction cost.
3. Piers rest on alluvial soil.

The first and second options imply that the scour risk due to flooding is nil. The implementation of the third option makes use of the following empirical depth-of-scour equation presented by Laursen (15).

$$\frac{b_p}{y} = 5.5 \frac{d_s}{y} \left[\left(\frac{1}{11.5} \frac{d_s}{y} + 1 \right)^{1.7} - 1 \right] \qquad (16)$$

where b_p = width of rectangular pier,
y = depth of flow, and
d_s = depth of scour.

This relationship is shown in Figure 8.

If the computed depth of scour exceeds the user supplied maximum depth for option 3, bridge failure occurs. In this case the economic loss is twice the cost of the bridge times the flood recurrence interval since the bridge is lost and a new one must be built in its place.

Scour which does not cause complete bridge failure is assumed to cause some increase in losses determined by multiplying the scour depth by a per unit cost to repair the scour damage. Considering that there is little documentation by the dynamic formation or effects of nondestructive scour, this method provides a reasonable estimate for use by design engineers.

TRAFFIC-RELATED LOSSES

A major portion of the economic loss resulting from damage to a stream crossing structure is the traffic stoppage or the delay caused by an inconvenient detour. The total time that the traffic is not allowed to travel at its normal rate over the crossing is assumed to be equal to the sum of the flood overtopping duration and the additional time required to repair significant damage to the site. The duration of overtopping is computed in the RISK module. The time of repair is estimated from a graph similar to Figure 9 which is developed by the analyst for each case. The distribution and magnitude of the average daily traffic across the

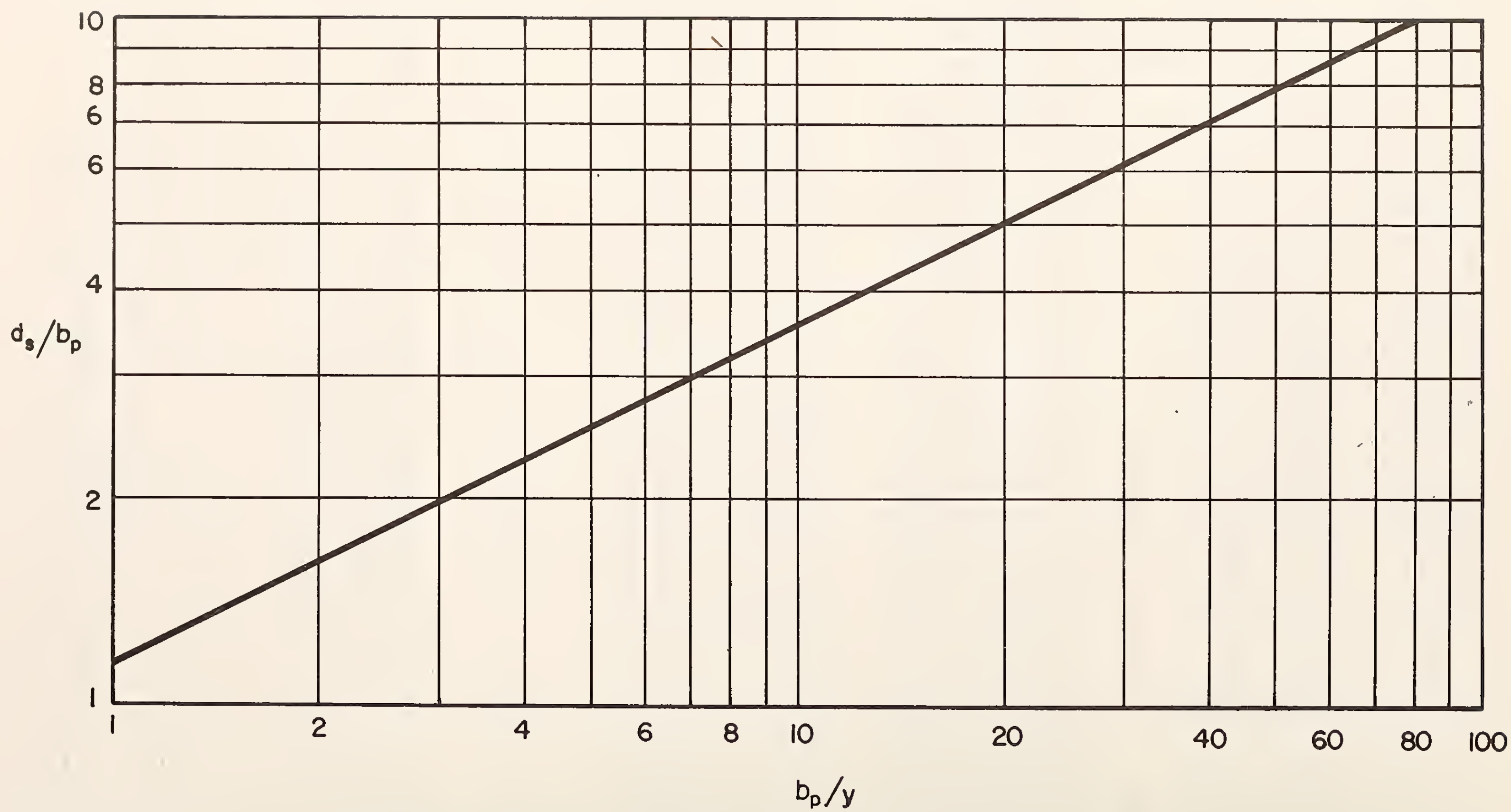


Figure 8. Relationships of Scour Depth to Flow Depth

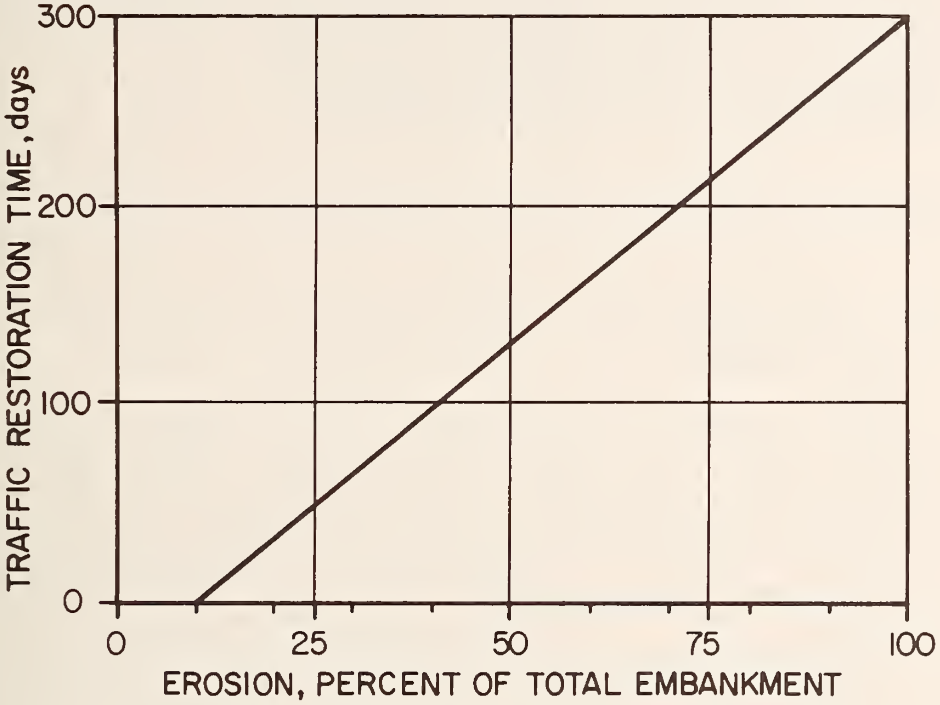


Figure 9. Assumed Traffic Restoration as a Function of Embankment Erosion (13)

bridge is also required for each case. There are four sub-categories of traffic-related losses:

1. Increased running cost due to detour,
2. Lost time of vehicle occupants due to increased time of travel,
3. Accidents on additional detour miles, and
4. Accidents due to the unexpected obstacle.

After barricades are placed around the site, the first three types of losses are incurred on the detour. The fourth type is the cost of the accidents expected at the stream crossing and is postulated to occur as traffic comes upon the failure immediately after the failure occurs.

Increased *running cost* is the difference between running cost on the detour and the normal route. This cost is computed as a function of average daily traffic, travel distance, duration of detour, design speed, and vehicle distribution. Detour duration is the sum of the overtopping duration plus the repair time. Overtopping duration is computed in the flood routing calculations. Five basic classes of vehicles are assumed and actual traffic distributions are fit, as closely as possible, to the five basic classes (13). These are:

1. 0.7-ton passenger cars,
2. 1.25-ton commercial delivery vans,
3. 1.55-ton single unit trucks,
4. 2.2-ton gasoline semitrailer trucks, and
5. 2.75-ton diesel semitrailer trucks.

Running costs are estimated for passenger cars on zero grades and these costs are adjusted to reflect the other classes of vehicles in the five-class distribution. The passenger car running costs as a function of speed are fit to a parabola as a means of facilitating computer applications. The low point of the parabola, or most economical running speed, occurs between 30 and 40 miles per hour.

Time losses are a function of average daily traffic, detour duration, travel distance, vehicle occupancy rate, design speed, and the value placed on an individual's time. The occupancy rate and time values are averages which apply to all individuals in the five classes of vehicles. Only the difference in time between the normal route and the detour is considered.

The death rate is used as the basic unit to compute the increased *accident costs* imposed by the detour (13). For each death, there are a certain number of personal injuries and a certain number of property damage accidents, each of which may or may not be associated with a death. For example, 30 personal injuries for each traffic death and 300 property damage accidents might occur for each death. The *accident losses* are computed by applying the above rates to costs of deaths, personal injuries and property damage. These losses are computed on a vehicle mile basis--the standard for death rate statistics. Accident losses are computed as a function of average daily traffic, length of detour, duration of detour, death rate, ratio of personal injuries to deaths, cost of death, cost of personal injury, and cost of a property damage accident.

The last loss category is the expected accident due to the *unexpected obstacle* at the stream crossing site. The higher death rate is defined as the product of the death rate for normal conditions over one mile of roadway, and a death rate factor for unexpected obstacles (13). This death rate factor is somewhat subjective because of the lack of data on this type of accident. Perhaps a factor of one thousand is appropriate. The engineer can also modify the ratios of personal injuries and property damage accidents to deaths since these ratios may differ from those on the detour.

The parameters necessary to evaluate these losses are:

X_1 = Duration of Detour = Duration of Overtopping + Repair Time (hrs)

X_2 = Average Daily Traffic, ADT (Vehicles/Day)

X_3 = Passenger Cars (Fraction of ADT)

X_4 = Commercial Delivery Vehicles (Fraction of ADT)

X_5 = Single Unit Trucks (Fraction of ADT)

X_6 = Gasoline Service Trailers (Fraction of ADT)

X_7 = Diesel Semi-Trailers (Fraction of ADT)

X_8 = Length of Detour (Miles)

$X_{8.1}$ = Normal Distance (Miles)

X_9 = Speed on Detour (Miles/Hr)

$X_{9.1}$ = Normal Speed (Miles/Hr)

X_{10} = Occupancy Rate (People/Vehicle)

X_{11} = Accident Distribution Ratio - Normal Conditions (Personal Injuries/Death)

X_{12} = Accident Distribution Ratio - Normal Conditions (Property Damage/Death)

X_{13} = Accident Distribution Ratio - Unexpected Obstacle (Personal Injuries/Death)

X_{14} = Accident Distribution Ratio - Unexpected Obstacle (Property Damage/Death)

X_{15} = Death Rate (People/100 Million Miles)

X_{16} = Death Rate Factor for Unexpected Obstacle (Multiplier to X_{15})

C_1 = Cost of Death ($)

C_2 = Cost of Personal Injury ($)

C_3 = Cost of Property Damage ($)

C_4 = Value of Time ($/Hr)

C_5 = Running Cost of a Passenger Car over the Detour Distance ($/100 Vehicles)

C_6 = Running Cost of a Passenger Car over the Normal Distance ($/100 Vehicles)

Parameters X_1 through X_{10} are different for each site considered, but X_{11} through C_3, except X_{16}, represent national statistics. X_{16} is a multiplier applied to the death rate to allow for the increased hazard of an unexpected obstacle. The value of the parameter varies depending on the site conditions. The value of time (C_4) is based on the average income per year of the users of the bridge. The results tabulated below (Table 2) are developed from a study performed by the Stanford Research Institute (16). The results shown in the table are based on the report-adjusted data set with a sample size of 807 using the equation

$$C_4 = 1.803 + 0.461I \qquad (17)$$

where I = income level.

Table 2. Value of Time ($/hr) by Income of Highway User

	I = 1	I = 2	I = 3	I = 4	I = 5	I = 6	I = 7	I = 8
C_4	2.26	2.73	3.19	3.64	4.11	4.57	5.03	5.49

where I = 1 is income level under $4,000/year,
I = 2 is income between $4,000 - 5,999/year,
I = 3 is income between $6,000 - 7,999/year,
I = 4 is income between $8,000 - 9,999/year,
I = 5 is income between $10,000 - 11,999/year,
I - 6 is income between $12,000 - 14,999/year,
I = 7 is income between $15,000 - 20,000/year, and
I = 8 is income over $20,000/year.

The running cost of a passenger car in dollars per 1000 vehicle miles is a function of speed as shown in Figure 10. The appropriate equations for C_5 and C_6 are

$$C_5 = 42.5 - .455X_9 + .0068X_9^2 \tag{18}$$

$$C_6 = 42.5 - .455X_{9.1} + .0068X_{9.1}^2$$

To adjust these passenger car running costs for varying types of vehicle distributions, Equation 18 becomes

$$C_5 = (42.5 - .455X_9 + .0068X_o^2 \cdot (X_3 + 1.2X_4 + 2.0X_5 + 3.2X_6 + 3.1X_7 \tag{19}$$

and

$$C_6 = (42.5 - .455X_9 + .0068X_o^2) \cdot (X_3 + 1.2X_4 + 2.0X_5 + 3.2X_6 + 3.1X_7)$$

To estimate the losses associated with running costs, it is necessary to compute the running cost over the normal route and the detour. The difference in these two cost values represents the additional cost to the user of having to detour due to the failure of the bridge. The equation for computing the running cost ($) is:

$$XL_1 = \frac{X_1\ X_2\ X_8\ C_5}{24,000} - \frac{X_1\ X_2\ X_{8.1}\ C_6}{24,000} \tag{20}$$

The time lost by the vehicle occupants is the delay or the additional time it takes to detour the site. The value of lost time ($) is computed by calculating the difference of the time value of the detour and the original route. The equation used for this calculation is:

$$XL_2 = X_1 \frac{X_8}{X_9} - \frac{X_{8.1}}{X_{9.1}} \frac{X_2}{24} X_{10}\ C_4 \tag{21}$$

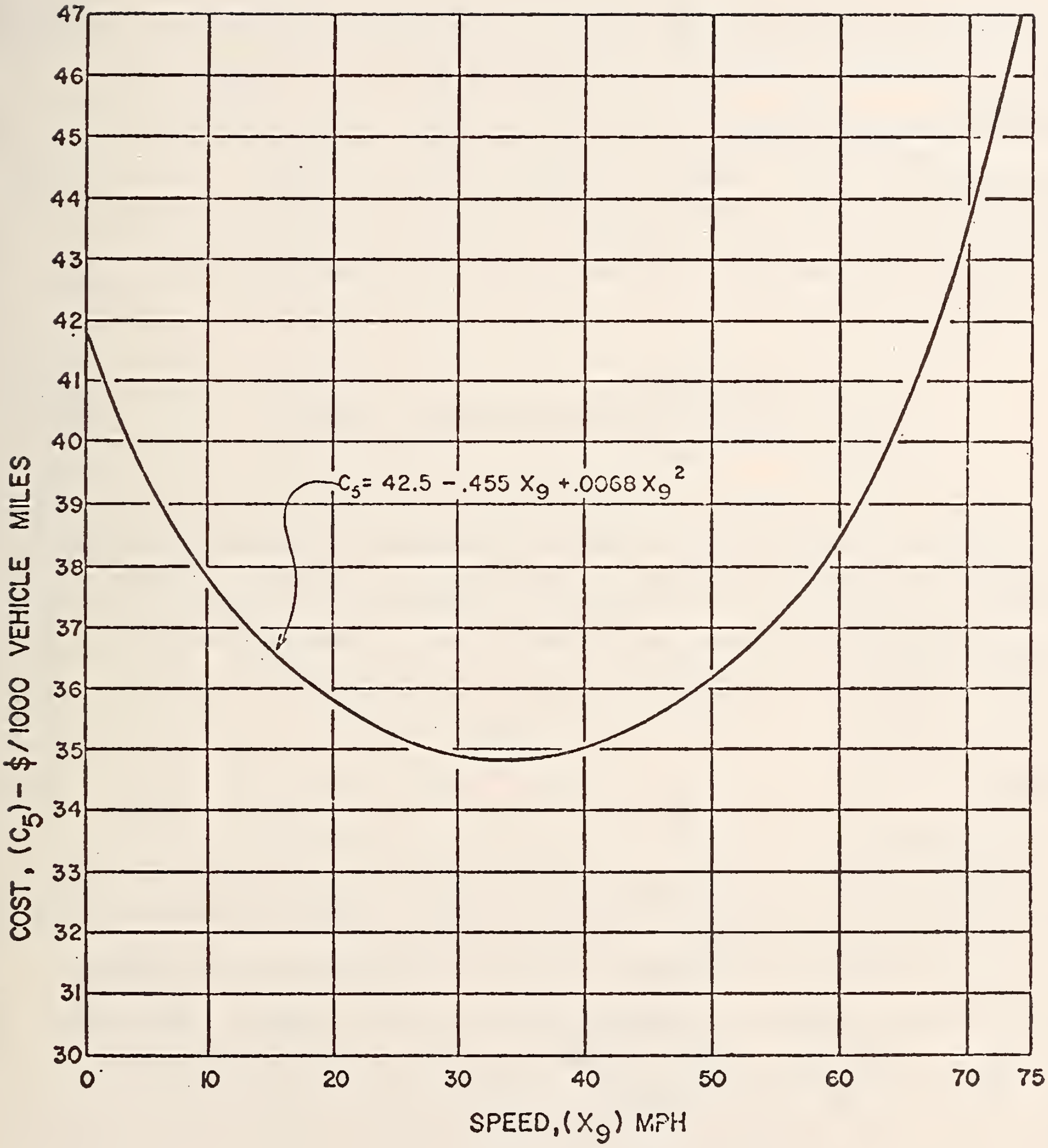


Figure 10. Passenger Car Running Costs (17)

The expected accident cost ($) due to the difference in the dollar value of accidents on the detour and on the original route is calculated by:

$$XL_3 = \frac{X_1 \; X_2 \; (X_8 - X_{8.1}) \; X_{15}}{2.4 \times 10^9} \; (C_1 + X_{11}C_2 + X_{12}C_3) \qquad (22)$$

The expected accident cost due to an unexpected obstacle is computed by assuming one mile of road has a one-hour exposure to a higher death rate defined as the death rate, X_{15}, times a death rate multiplier for unexpected obstacles, X_{16}. Thus, the higher rate is $X_{15}X_{16}$. The accident distribution ratios are X_{13} and X_{14} which may vary from those for the normal death rate, X_{11} and X_{12}. The equation for calculating this loss ($) is:

$$XL_4 = \frac{X_2 \; X_{15} \; X_{16}}{2.4 \times 10^9} \; (C_1 + X_{13}C_2 + X_{14}C_3) \qquad (23)$$

By applying Equations 18 through 23 to a set of data describing a given site, it is possible to compute the total dollar value of the traffic loss due to flooding at the culvert site. Table 3 shows the traffic-related data for two types of highway systems.

FLOOD LOSSES

The constriction of waterways due to approach embankments incurs incremental damage to the adjacent properties when severe flooding occurs. This incremental damage is an amount of loss in addition to the damage that would be caused before the embankments are constructed. The magnitude of the damage depends on the specific land uses and the type of development occurring in the flood plains, for example, woodlands, pasture lands, farm crops, private homes, industries or any combination of these. Different levels of damage are associated with these land uses by flooding. For example, pasture and woodlands may be subject to little damage from water, while a private home or industry may be destroyed by severe flooding.

Table 3. Traffic Loss Data

Variable	Four-Lane Highway	Rural Highway	Units
X_2	16000	466	Vehicles/day
X_3	85	.955	Fraction of ADT
X_4	.01	.043	Fraction of ADT
X_5	.02	0	Fraction of ADT
X_6	.03	.002	Fraction of ADT
X_7	.09	0	Fraction of ADT
$X_8-X_{8.1}$	1.20	1.41	Miles
X_9	55	25	Miles/hr
X_{10}	1.7	2	People/Vehicle
X_{11}^8	30	30	Personal Injury Incidences/Death
X_{12}*	300	300	Property Damage Claims/Death
X_{13}*	15	15	Personal Injury Incidences/Death
X_{14}*	150	150	Property Damage Claims/Death
X_{15}*	5.5	5.5	People/100 Million miles
X_{16}	1000	500	-----
C_1*	50000	50000	$
C_2*	2000	2000	$
C_3*	400	400	$
C_4*	2	2	$/hr

*Accident Facts, National Safety Council, Chicago, 1968.

Flood loss is usually expressed by a stage-damage curve for the area inundated by the flood. A technique for evaluating flood damage at culvert sites was developed by WRE (13). This method relates the flood loss to the ponding of flood water upstream from the culvert site. The computational procedure is similar to the one generally used in reservoir projects. In either case the assumption of horizontal pool level has been made. Thus the stage-area, and hence the stage-damage, curve can easily be developed.

At a bridge site the situation is somewhat different. Instead of having a horizontal water level, the water surface elevation varies with flood magnitudes as well as with location. To develop a single stage-damage curve under such conditions is virtually impossible.

Theoretically a bridge owner should not be held responsible for flood losses incurred under natural flow conditions before a bridge is in place, no matter how large the flood is. It is the bridge owner's liability, however, for the additional portion of flood damage which is caused by the backwater associated with the construction of the stream crossing structures. The stage-damage function developed in this study is based upon this concept.

The first step in the process of deriving the stage-damage curves is defining the steady state hydraulic regime. As discussed previously, water surface elevations in the vicinity of the site (assuming no bridge is in place) are calculated by the two-dimensional computerized program FEM. Figure 11a shows the water surface profiles computed for natural conditions for flows Q_1, Q_2 and Q_3. The next step is to calculate water surface elevations assuming the bridge is in place (Figure 11b). The constriction will cause an increase in water surface elevation in the vicinity of the bridge crossing. Increased water surface elevations

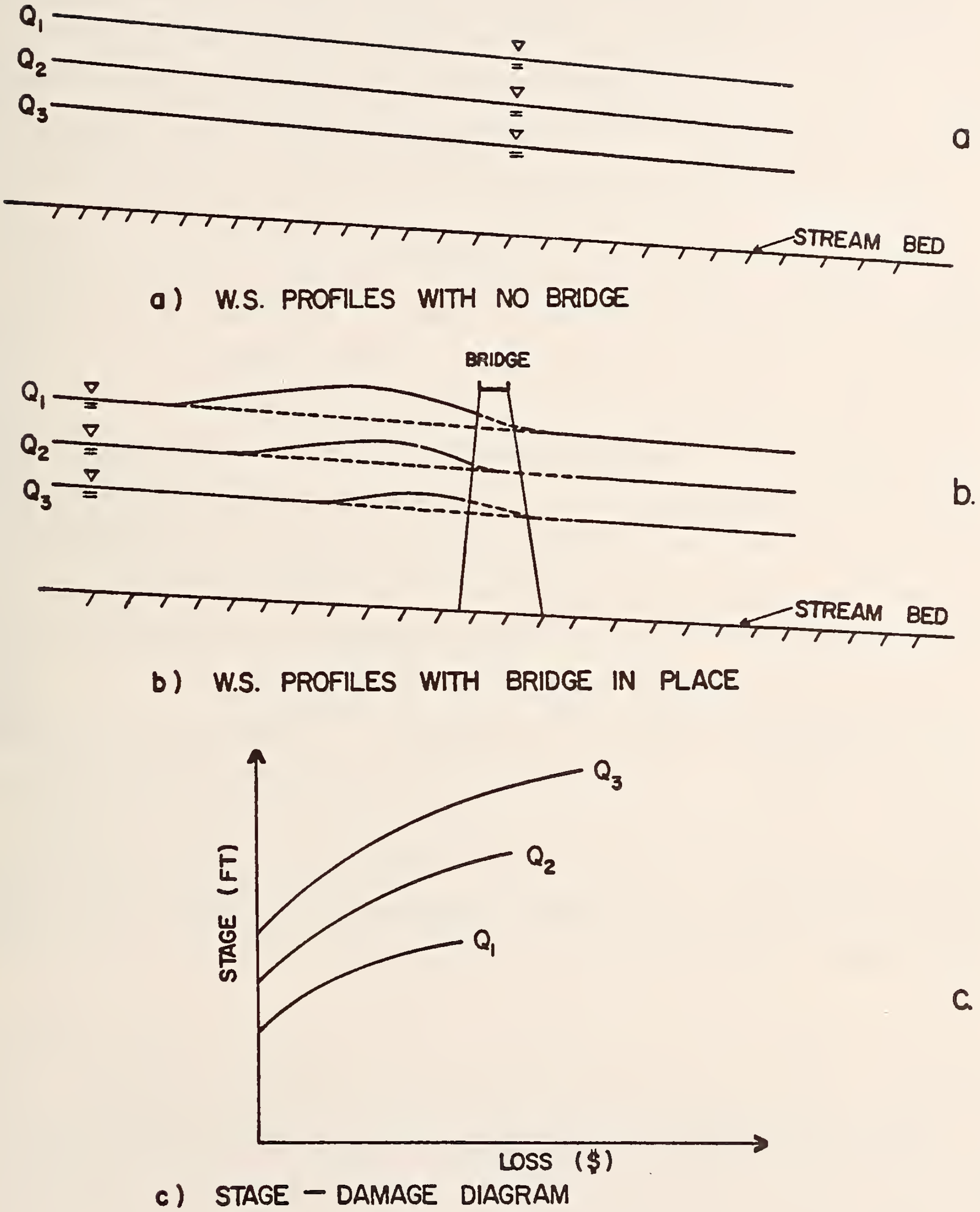


Figure 11. Stage-Damage Curves

result in increased flood-related damages due to the areal spreading of the flood and additional damages at locations affected with no bridge in place. The two sets of surface elevations is the starting point for estimating the economic losses associated with a flood of known magnitude both for the natural conditions and the altered circumstance of having the bridge in place. The difference of these two economic losses defines the economic loss associated with a given bridge design for a specific flood.

For a specific site the two hydraulic regimes (with and without the bridge) are plotted on a USGS contour map of the area. This defines the areal coverage and actual water depth for both regimes.

Once the hydraulic regimes are defined for the cases with and without the bridge, the calculation of the economic losses becomes straightforward. Flood damage tables similar to Table 4 are generated for any field site that is to be analyzed. The details of the development of these tables can be found in Appendix B of Reference 13.

With the required tables, the hydraulic information and a knowledge of the land use pattern in the vicinity of the proposed bridge opening, it is possible to calculate the flood-related losses for the site with and without the bridge. The difference in these values is the flood damage due to the constriction caused by the bridge crossing. Figure 11c shows stage-damage curves derived from Figure 11b.

In this study these calculations for the economic damage caused by the backwater are computed manually using the computer-derived hydraulic information. Data are computed for the complete array of decision parameters considered, various discharges, embankment heights and bridge lengths. The resulting values are part of the input data read into the risk program model and used in determining the total economic loss and resulting risks for all cases of interest.

Table 4. Flood Damage Information

Flow	Flow Rate (cfs)	Return Interval	Bridge Opening	Delta Embankment Ht.	Damage ($)	Stage (ft)
1	16200	.04			5400*	312.36
2	19700	.02			7500*	313.06
3	23500	.01			9400*	313.75
4	27500	.005			11300*	314.42
5	16200	.04	300	0	10000	314.00
6	16200	.04	500	0	8200	313.31
7	16200	.04	500	-5	3400	311.72
8	16200	.04	500	5	8200	313.31
9	16200	.04	1000	0	6500	312.75
10	16200	.04	1000	-5	3000	311.58
11	16200	.04	1000	5	6500	312.72
12	19700	.02	300	0	13300	315.02
13	19700	.02	500	0	10900	314.28
14	19700	.02	500	-5	7200	312.96
15	19700	.02	500	5	10900	314.28
16	19700	.02	1000	0	8900	313.57
17	19700	.02	1000	-5	4300	312.04
18	19700	.02	1000	5	8900	313.57
19	23500	.01	300	0	15200	315.59**

* Damages with no bridge
** Stage and/or damage based on incomplete analysis

Table 4. Flood Damage Information (Cont.)

Flow	Flow Rate (cfs)	Return Interval	Bridge Opening	Delta Embankment Ht.	Damage ($)	Stage (ft)
20	23500	.01	500	0	13700	315.15
21	23500	.01	500	-5	11500	314.48
22	23500	.01	500	5	13900	315.21
23	23500	.01	1000	0	11300	314.39
24	23500	.01	1000	-5	8300	313.37
25	23500	.01	1000	5	11300	314.39
26	27500	.005	300	0	17300	316.24
27	27500	.005	500	0	15600	315.74
28	27500	.005	500	-5	15416	315.37
29	27500	.005	500	5	16900	316.13
30	27500	.005	1000	0	13800	315.14
31	27500	.005	1000	-5	11100	314.34
32	27500	.005	1000	5	13900	315.18

RISK ANALYSIS

Risk analysis is defined as the evaluation of the losses incurred while playing strategy i due to a series of possible states of nature and an assessment of the probability distribution of the states of nature.

We define the risk for strategy i, R_i, for a discrete probability distribution of the states of nature as:

$$R_i = \sum_{j=1}^{n} D_j P_j \tag{24}$$

with $\sum_{j=1}^{n} P_j = 1.0$

where P_j = probability of occurrence of state of nature j, and

D_j = loss incurred by the player due to the occurrence of the j^{th} state of nature.

For a continuous distribution of the state of nature, we define the risk R_i for strategy i as:

$$R_i = \int_0^\infty L(Q) f(Q) dQ \tag{25}$$

with $\int_0^\infty f(Q) dQ = 1, \; \underset{0 \leq Q < \infty}{f(Q) \geq 0}$

where $Q \sim \left[f(Q)\right]$ defines the probability density function of the states of nature Q, and

L(Q) is the continuous loss function.

In the case of applying Risk Analysis to select design schemes, i.e., the combinations of bridge length and height of approach embankment, we make the following analogies to the theory expressed above. The player's strategy i becomes $(\text{design scheme})_i$, which in turn is determined by two design parameters: $(\text{embankment height})_i$, and $(\text{bridge length})_i$. These two design parameters are referred to as decision variable set i. The player corresponds to society in general. The possible states of nature correspond to the possible floods at a bridge site. We note that the distribution of possible floods at the bridge site is a continuous distribution and can be approximated by a double exponential or Gumbel distribution. Therefore we must consider Equation 25 as the governing risk equation which must be evaluated for each design scheme i, to determine that scheme's total economic response.

The RISK Model approximates the integral of Equation 12 by using the five flood events, Q_1, Q_2, Q_3, Q_4 and Q_5 as shown below:

$$R_i = \int_0^{\infty} L(Q)f(Q)dQ = \int_0^{Q_1} L(Q)f(Q)dQ + \int_{Q_1}^{Q_2} L(Q)f(Q)dQ$$

$$+ \int_{Q_2}^{Q_3} L(Q)f(Q)dQ = \int_{Q_3}^{Q_4} L(Q)f(Q)dQ + \int_{Q_4}^{Q_5} L(Q)f(Q)dQ$$

$$+ \int_{Q_5}^{\infty} L(Q)f(Q)dQ \tag{26}$$

Each of the six terms on the right hand side of Equation 26 is then approximated by the following expressions:

$$\int_{0}^{Q_1} L(Q)f(Q)dQ \simeq 0 \quad \text{since it is assumed } L(Q) = 0, \text{ for } 0<Q<Q_1. \tag{27a}$$

$$\int_{Q_1}^{Q_2} L(Q)f(Q)dQ \simeq L_2\int_{Q_1}^{Q_2} f(Q)dQ = L_2\left\{P\left[Q_1 \leq Q \leq Q_2\right]\right\} \tag{27b}$$

$$\int_{Q_2}^{Q_3} L(Q)f(Q)dQ \simeq L_3\int_{Q_2}^{Q_3} f(Q)dQ = L_3\left\{P\left[Q_2 \leq Q \leq Q_3\right]\right\} \tag{27c}$$

$$\int_{Q_3}^{Q_4} L(Q)f(Q)dQ \simeq L_4\int_{Q_3}^{Q_4} f(Q)dQ = L_4\left\{P\left[Q_3 \leq Q \leq Q_4\right]\right\} \tag{27d}$$

$$\int_{Q_4}^{Q_5} L(Q)f(Q)dQ \simeq L_5\int_{Q_4}^{Q_5} f(Q)dQ = L_5\left\{P\left[Q_4 \leq Q \leq Q_5\right]\right\} \tag{27e}$$

$$\int_{Q_5}^{\infty} L(Q)f(Q)dQ \simeq L_5\int_{Q_5}^{\infty} f(Q)dQ = L_5\left\{P\left[Q>Q_5\right]\right\} \tag{27f}$$

since it is assumed $L(Q) = L_5$, for $Q>Q_5$

where L_1, L_2, L_3, L_4 and L_5 are the losses associated with Q_1, Q_2, Q_3, Q_4 and Q_5, respectively for a given design scheme.

Probability, P, in Equations 27a through 27f, weights the flood loss in each flood interval. The application of this concept for risk analysis will be further illustrated in Chapter V, with specific examples.

SELECTION OF MOST ECONOMIC DESIGN

The sum of the estimated construction costs of a design scheme and its calculated flood risks equals the economic response of that design scheme. The design goal of a highway stream crossing is a design which minimizes the economic response. This process involves a great deal of computational effort by using varying decision variables, one at a time. The computation may become more complicated as the number of decision variables increases.

In the design of highway stream crossings the two most important decision variables are the size of the bridge opening and the height of the approach embankments. Other decision variables related to scour around piers and abutments, though important, are not included in the analysis procedure described in this report because these parameters have not yet been adequately defined. These parameters should be incorporated in the present model when better information becomes available. Decision variables regarding protection measures on embankments are also omitted in the analysis. Consideration should also be given to include these variables into the model in future studies.

For illustration purposes, assume that there are an infinite number of design schemes consisting of an infinite number of combinations of the bridge decision variables, embankment height (H) and bridge length (L). Further, assume $L,H > 0$. For each such combination of the decision variables L and H we evaluate the risk according to Equation 25, as $f(L,H)$. We next determine the construction cost for the design scheme corresponding to decision variables embankment height H and bridge length (L) as C(L,H). The total economic response function, TER(L,H), is defined in terms of the decision variable embankment height (H), and bridge length (L) as:

$$TER(L,H) = \overbrace{f(L,H)}^{\text{Risk}} + \overbrace{C(L,H)}^{\text{Construction cost}}, \quad L,H > 0 \tag{28}$$

This response surface is sketched in Figure 12. The optimal design corresponds to that choice of the decision variables L_{opt} and H_{opt} which correspond to the minimum value of TER(L,H); namely $I = TER\ (L_{opt}, H_{opt})$, as shown in Figure 12.

This study considers a finite number of design schemes involving three embankment heights and three bridge lengths. Then the model evaluates the total economic response for each of the seven possible design combinations.

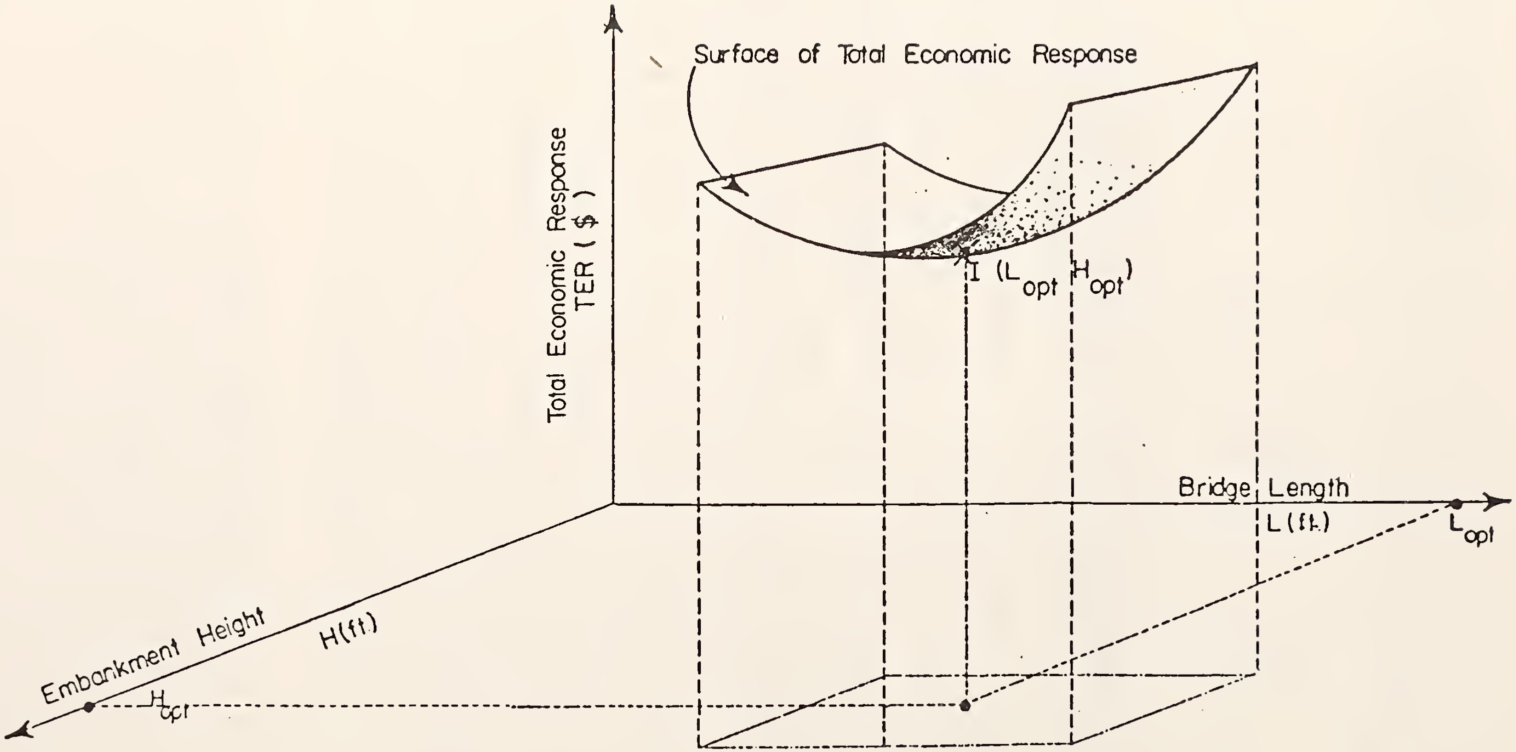


Figure 12. Relationship of Economic Response to Bridge Crossing Decison Variables

IV. APPLICATION OF RISK MODEL TO AN EXAMPLE PROBLEM

SITE INFORMATION

The principles of analysis presented in Chapter III are applied to the Tallahalla Creek bridge site near Waldrup, Mississippi. The flood plain consists of woodlands and parks. At the bridge site the drainage basin of Tallahalla Creek is approximately 33 square miles. The site map is shown in Figure 13. At present there is a 500-foot bridge across Tallahalla Creek near Waldrup. The details are shown in Figure 14.

DESIGN ALTERNATIVES

In the analysis seven alternative bridge design schemes are considered including the present bridge. These design schemes are listed in Table 5.

Table 5 shows that the two major decision variables considered are the bridge length (or bridge opening size) and the height of approach embankments. While these two variables are the primary factors governing the overall economic picture at the crossing site, other factors, such as type of stream crossing (e.g. skewed, eccentric, normal, or any of the combinations), bridge type (e.g. slab, I-beam composite, or steel bridge), and the class of highway (e.g. primary or secondary), also affect the result of economic analysis. The type of crossing governs the amount of backwater and thus property damage and traffic

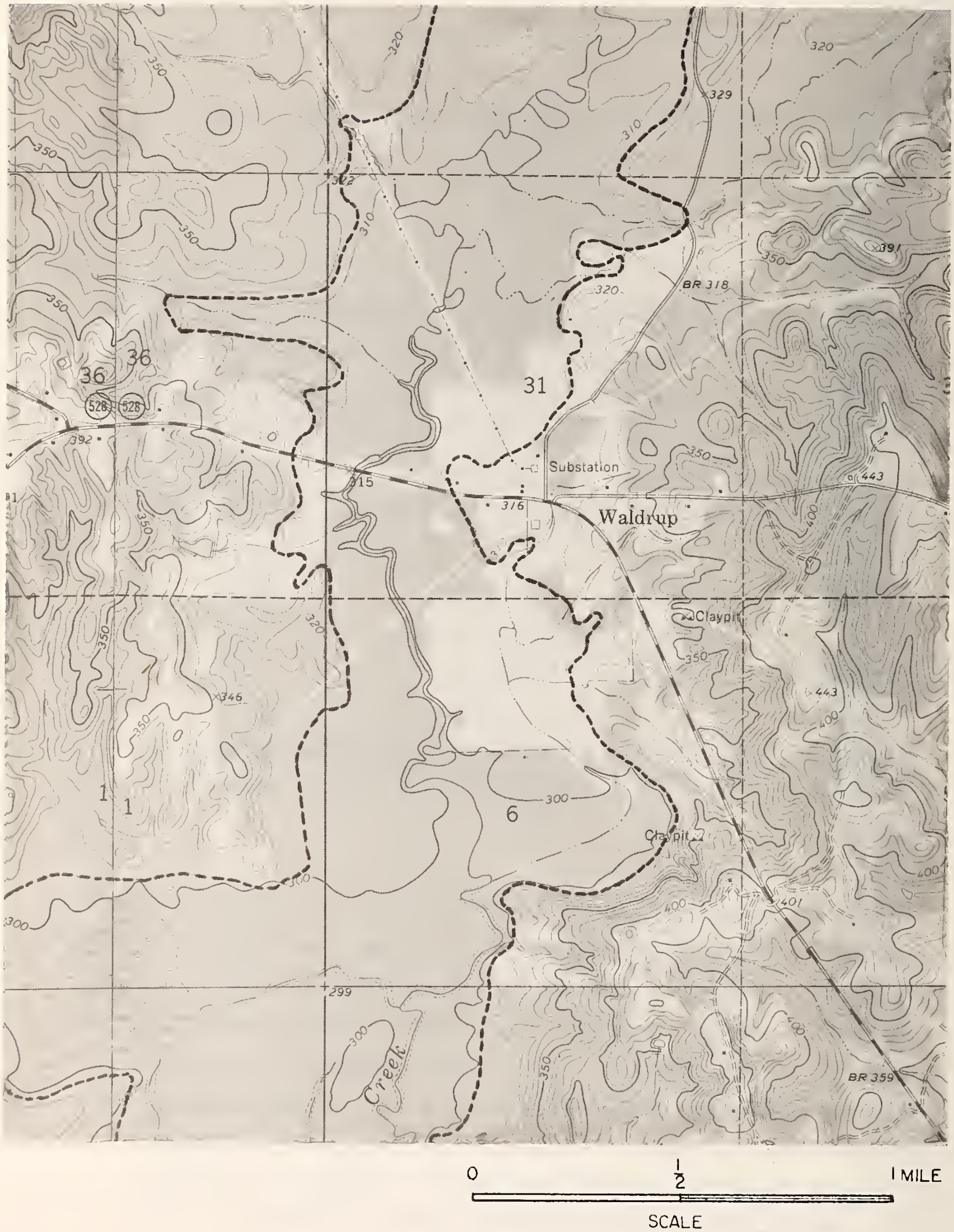


Figure 13. Site Map at Tallahalla Creek, Mississippi

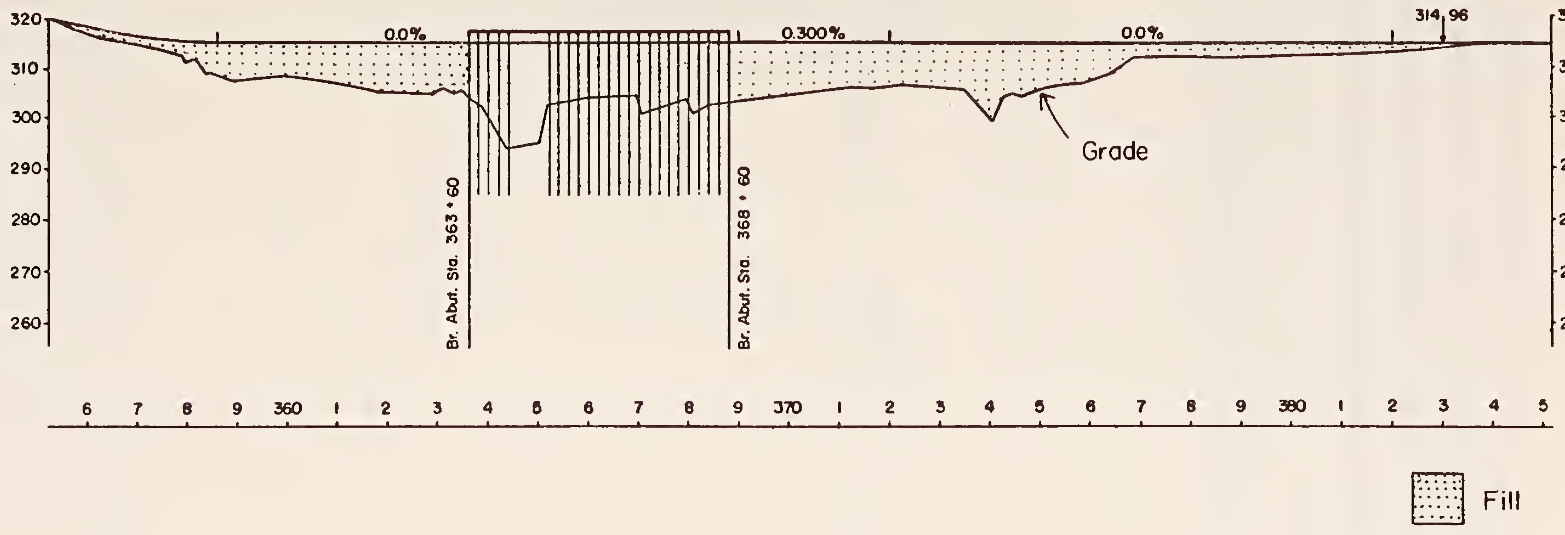


Figure 14. Cross-Section of Bridge Site at Tallahalla Creek, Mississippi

delay. Bridge type determines the unit cost of the bridge, while the class of highway affects the specification of design standards for any given bridge length and embankment height. The extent to which these additional factors would influence the economic analysis depends on each individual bridge site. For the present analysis it is assumed that these additional factors be held constant. That leaves the economic analysis to be focused upon the two degrees of freedom, i.e., the bridge length and the embankment height.

Table 5. List of Design Alternatives

	Decision	Variables
Design Alternative	Bridge Length (ft)	Embankment Elevation (ft)
1	300	315
2*	500	315
3	500	310
4	500	320
5	1000	315
6	1000	310
7	1000	320

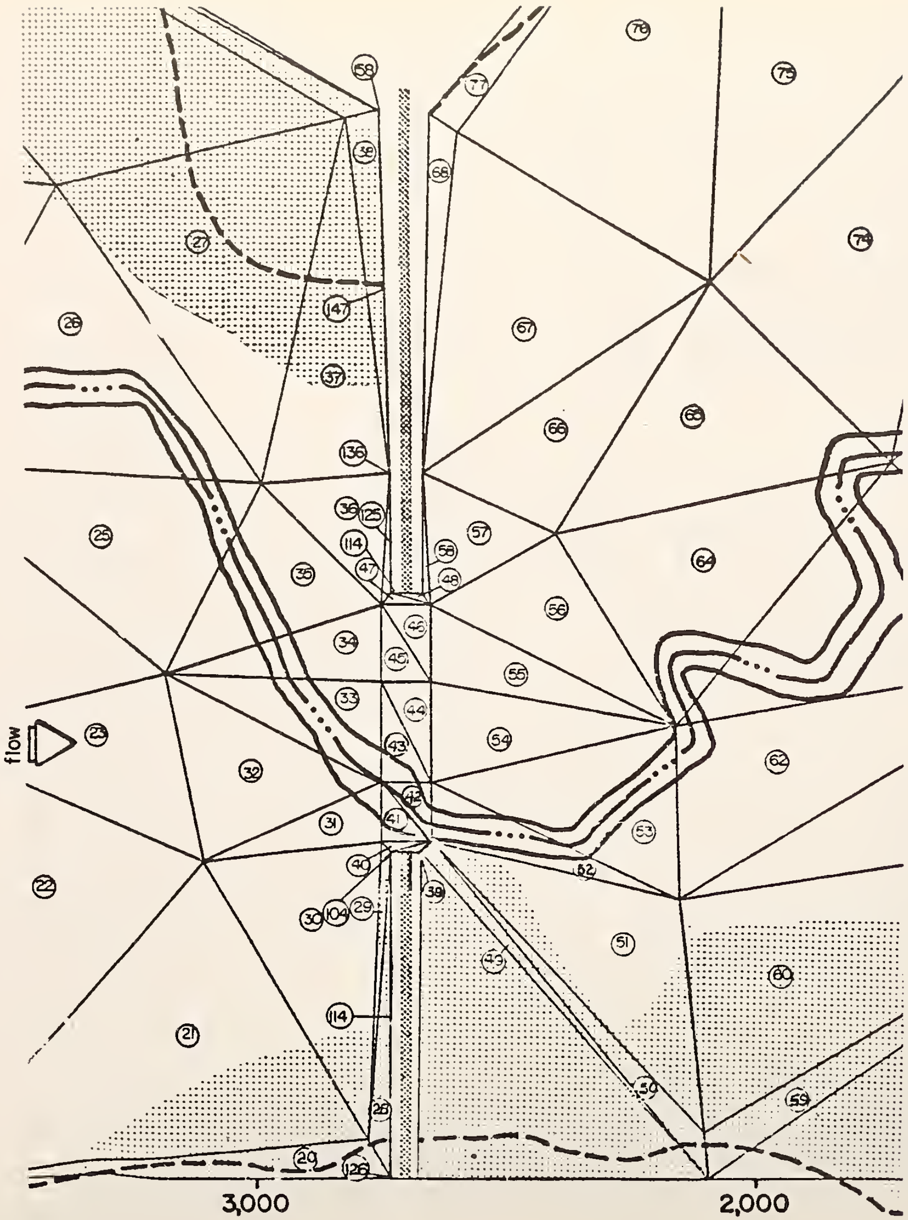
*This scheme is the present design in place

HYDRAULIC COMPUTATIONS

Hydraulic computations for all the design alternatives were performed using the Finite Element Model presented in Volume III of the final report of this project. The network system used to represent the flow region for the 500-foot bridge opening is the same as that used in the example cases of the Tallahalla Creek site in Volume III. Minor modification to the network system across the bridge openings of 300 and 1000 feet was required to reflect the change in opening size. Pertinent data for the opening configuration are shown in Figure 15 and Tables 6 through 8.

Table 6. Embankment Data for Bridge 1
(Bridge Length = 300 ft)

Node	Ground Elevation	Length	Top Elevation
158	309.0	0.0	315.0
147	307.7	365.0	315.0
136	306.5	365.0	315.0
125	305.7	220.0	315.0
114	305.0	220.0	315.0
104	300.0	320.0	315.0
115	304.0	330.0	315.0
126	308.0	330.0	315.0



Embankment Nodes for
300', 500', 1,000'
Bridge Design Categories

158, 147, 136, 125, 114 } Left Embankment

104, 114, 126 } Right Embankment

Key to Tables 6 through 8.

Ground Elev. ≡ Bottom Embankment Elevation at Node Indicated.

Length ≡ Distance Between Node Indicated and Previous Node.

Top Elev. ≡ Top Embankment Elevation at Node Indicated.

Figure 15. Bridge Opening and Embankment Configurations

Table 7. Embankment Data for Bridge 2 (Bridge Length = 500 ft)

Node	Ground Elevation	Length	Top Elevation
158	309.0	0.0	315.0
147	307.7	365.0	315.0
136	306.5	365.0	315.0
125	305.5	120.0	315.0
114	304.6	120.0	315.0
104	300.0	520.0	315.0
115	304.0	330.0	315.0
126	308.0	330.0	315.0

Table 8. Embankment Data for Bridge 3 (Bridge Length = 1,000 ft)

Node	Ground Elevation	Length	Top Elevation
158	309.0	0.0	315.0
147	307.5	265.0	315.0
136	306.0	265.0	315.0
125	306.3	107.5	315.0
114	306.5	107.5	315.0
104	307.0	1020.0	315.0
115	307.5	192.5	315.0
126	308.0	192.5	315.0

HYDROLOGY

The flood frequency curve for the study site is shown in Figure 4 (page 26). For each bridge design, it is necessary to consider a wide range of hydrologic possibilities. Since flow, Q, is considered a continuous random variable, it is improper to speak of the probability associated with one particular flood event. Instead, one must consider the probability that a storm event will lie in the closed interval [a, b] as shown in the equation below.

$$P\ [a \leq Q \leq b] = \int_a^b f(Q)\ dQ \tag{29}$$

where

$f(Q)$ = the probability density function of the random variable, Q.

By referring to Figure 4 one may determine the recurrence interval, r_i, for a given flow, Q_r. The relationship between r_i and Q_r is expressed:

$$P\ (Q \geq Q_r) = \frac{1}{r_i} \tag{30}$$

where

Q = flow,

Q_r = flow associated with recurrence interval, r_i, and

r_i = recurrence interval associated with flow, Q_r.

Thus the flow associated with a storm having a recurrence interval of ten years (e.g., a ten-year storm) is exceeded 10 percent of the years.

For the analysis performed in the RISK module, five storm events are considered as shown in Table 9. It was assumed that storms with a peak discharge below 15,000 cfs caused zero weighted risks and that those above 27,500 cfs did not cause weighted risks above that caused by the 200-year storm event. The situation is shown in Figure 16. Flow Q is a random variable with a probability density function, f(Q).

Table 9. Storm Events

Flood Event	Probability that flow will be equaled or exceeded in any one year	Recurrence Interval (yrs)	Flow (cfs) $i = 1 \ldots 5$	$P\left[Q_{R_i} \leq Q \leq Q_{R_{(i+1)}}\right]$* $i = 1,\ldots 4$
Q_{R1}	.05	20	15000	
				.01
Q_{R2}	.04	25	16200	
				.02
Q_{R3}	.02	50	19700	
				.01
Q_{R4}	.01	100	23500	
				.005
Q_{R5}	.005	200	27500	

$$^{*}P\left[Q_{R_i} \leq Q \leq Q_{R_{(i+1)}}\right] = \frac{1}{R_i} - \frac{1}{R_{i+1}}$$

LOSS FUNCTION AND RISK

A loss function L(Q) is associated with the random variable Q. It is assumed that L(Q) = 0 for all flows below the 20-year flood, Q_{20}, and that $L(Q) = L_{max}$ for all flows above the 200-year flood, Q_{200}.

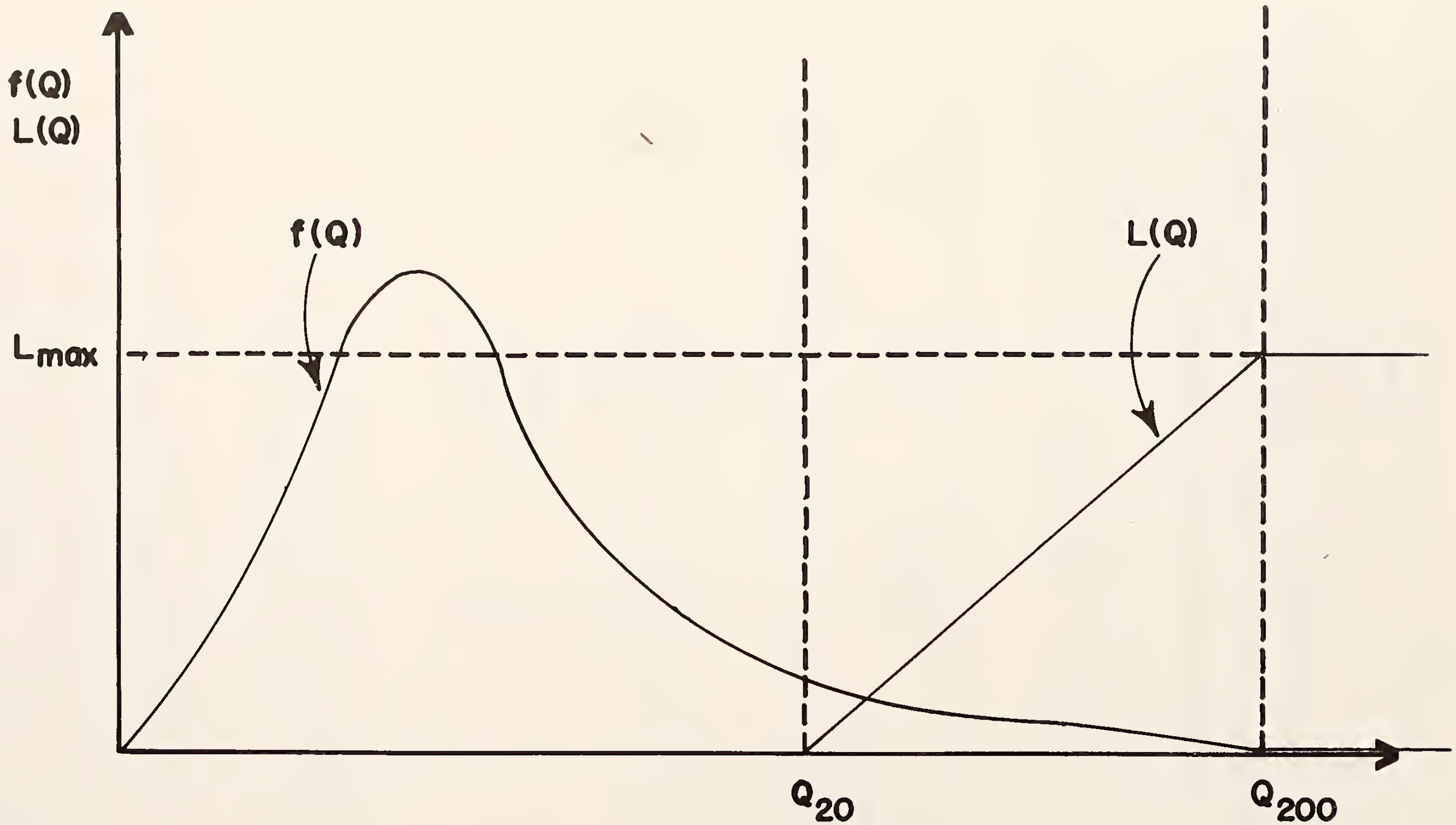


Figure 16. Probability Density Function and Loss Function

The Risk, R, is defined as:

$$R = \int_0^\infty f(Q)L(Q)dQ = \underbrace{\int_0^{Q_{20}} f(Q)L(Q)dQ}_{R_I} + \underbrace{\int_{Q_{20}}^{Q_{200}} f(Q)L(Q)dQ}_{R_{II}} + \underbrace{\int_{Q_{200}}^\infty f(Q)L(Q)dQ}_{R_{III}} \quad (31)$$

The first term, R_I, on the right hand side of Equation 31 above is zero since $L(Q) = 0$ for every Q contained in $(0, Q_{20})$; i.e., $R_I = 0$.

The third term, R_{III}, of (31) above, $\int_{Q_{200}}^\infty f(Q)L(Q)dQ = L_{max} \int_{Q_{200}}^\infty f(Q)dQ = f_{200}L_{max}$

since for $Q \geq Q_{200}$, $L(Q) = L_{max}$, and $\int_{Q_{200}}^\infty f(Q)dQ = f_{200}$.

The evaluation of the middle term, R_{II}, is the main issue. In the RISK module, the following approximation is made for R_{II}:

$$R_{II} \approx P\left[Q_{R1} \leq Q \leq Q_{R2}\right] LQ_{R2} + P\left[Q_{R2} \leq Q \leq Q_{R3}\right] LQ_{R3}$$

$$+ P\left[Q_{R3} \leq Q \leq Q_{R4}\right] LQ_{R4} + P\left[Q_{R4} \leq Q \leq Q_{R5}\right] LQ_{R5} \quad (32)$$

From Table 9: Q_{R1} = 15,000 cfs, Q_{R2} = 16,200 cfs, Q_{R3} = 19,700 cfs, Q_{R4} = 23,500, and Q_{R5} = 27,500 cfs. LQ_{R2}, LQ_{R3}, LQ_{R4} and LQ_{R5} are the losses associated with flows Q_{R2}, Q_{R3}, Q_{R4} and Q_{R5} respectively. Since $Q_{R5} = Q_{200}$ = 27,500 cfs, $LQ_{R5} = L_{max}$.

Equation 32 above is approximated as follows:

$$R \simeq P\left[Q_{R1} \leq Q \leq Q_{R2}\right] L Q_{R2} + P\left[Q_{R2} \leq Q \leq Q_{R3}\right] L Q_{R3}$$

$$+ \; P\left[Q_{R3} \leq Q \leq Q_{R4}\right] L Q_{R4} + \left\{P\left[Q_{R4} \leq Q \leq Q_{R5}\right] + f_{200}\right\} L_{max} \qquad (33)$$

Referring to Table 9 and Figure 16:

$$P\left[Q_{R1} \leq Q \leq Q_{R2}\right] = .01 \qquad P\left[Q_{R3} \leq Q \leq Q_{R4}\right] = .01$$

$$P\left[Q_{R2} \leq Q \leq Q_{R3}\right] = .02 \qquad P\left[Q_{R4} \leq Q \leq Q_{R5}\right] = .005$$

$$f_{200} = .005$$

Equation 33 reduces to:

$$R \simeq .01L_{16,200} + .02L_{19,700} + .01L_{23,500} + .01L_{27,500}$$

In the RISK module the losses for the 16,200 cfs, 19,700 cfs, 23,500 cfs, and 27,500 cfs storm events are evaluated and weighted as shown in Equation 33 above to determine the risk associated with a particular bridge design.

LOSS ESTIMATES

The total loss resulting from each of the above flood events consists of the following four losses:

1. Backwater damages,
2. Erosion damage to approach embankments,
3. Scour damage, and
4. Traffic delay and accident losses.

BACKWATER DAMAGES

Backwater damages are due to inundation of areas of the flood plain which would normally not be under water were the given bridge configuration not in place.

To develop a method to evaluate the adjacent property loss due to flooding, it is necessary to obtain information that relates damage to the type of land development in the upstream flood plain. Information is shown in Tables 10 through 15 relating losses in terms of 1974 dollars to the following land uses:

1. Agricultural,
2. Manufacturing,
3. Single Family Residences,
4. Retail Businesses,
5. Selected Services, and
6. Wholesale Businesses.

The development of these tables is described in Appendix B of Reference 13.

There are several notable characteristics of these data. First, flood losses do not always increase for depths exceeding four feet. For agriculture, the unit flood loss is not expected to significantly exceed the unit loss at a depth of three feet on the basis that most crops do not grow taller than this height. A similar trend of limited unit losses is expected for single family residences and selected services. Unit losses for manufacturing, on the other hand, can be expected to increase for depths greater than four feet because stock piles of raw materials and plant assets are commonly in excess of heights of four feet. Similarly, increasing unit losses are expected for retail and wholesale businesses. For these latter land uses, extrapolating available data to depths of six or seven feet appears justifiable.

Table 10. Estimated Flood Loss Data for Agriculture in Mississippi[1]

	Direct and Indirect Damages in 1974[2] In Dollars Per Acre at Water Depths of:			
	0.5'	1'	2'	3' +
Mississippi	$28	$36	$50	$61
Jasper County	9	12	15	18

[1]U. S. Department of Commerce, Bureau of the Census, 1969 United States Census of Agriculture, Vol. 1, Section 1, Summary Data, pp. VII, 5 & 6.
Ibid., Section 2, County Data, pp. 249.
U. S. Department of Agriculture, Soil Conservation Service, Economics Guide for Watershed and Flood Prevention, March 1964.
James, L. D., A Time-Dependent Planning Process for Combining Structural Measures, Land Use, and Flood Proofing to Minimize The Economic Cost of Floods, Stanford University, August 1964.

[2]Monetary data is converted to a 1974 base by applying average annual compound interest rates earned on long-term U. S. Government Securities to the basic data.

Table 11. Estimated Flood Loss Data for Manufacturing Industries in Mississippi[1]

Industries	Value Added by Manufacturing Per Production Worker, 1972	Direct and Indirect Flood Damage in 1974[2] In Dollars Per Dollar of Value Added By Manufacturing at Outside Water Depths of:			
		1'	2'	3'	4' +
1. Food and Kindred Products	$18,520	0.036	0.046	0.127	0.148
2. Textile Mill Products	12,091	0.038	0.046	0.127	0.148
3. Apparel and Related Products	7,977	0.035	0.046	0.127	0.148
4. Lumber and Wood Products	16,188	0.036	0.046	0.127	0.148
5. Furniture and Fixtures	14,178	0.036	0.046	0.127	0.148
6. Paper and Allied Products	29,825	0.036	0.046	0.127	0.148
7. Printing and Publishing	4,612	0.036	0.046	0.128	0.149
8. Chemicals and Allied Products	58,447	0.036	0.046	0.127	0.148
9. Petroleum and Coal Products	92,667	0.036	0.046	0.127	0.148
10. Rubber and Plastic Products	18,580	0.036	0.046	0.128	0.149
11. Leather and Leather Products	-	-	-	-	-
12. Stone, Clay and Glass Products	21,185	0.036	0.046	0.127	0.148
13. Primary Metal Industries	19,952	0.036	0.046	0.127	0.148
14. Fabricated Metal Products	23,012	0.036	0.046	0.127	0.148
15. Machinery, Except Electrical	23,232	0.036	0.046	0.127	0.148
16. Electrical Equipment and Supplies	18,262	0.036	0.046	0.127	0.148
17. Transportation Equipment	13,942	0.036	0.046	0.127	0.148
18. Instruments and Related Products	16,278	0.036	0.046	0.127	0.146
19. Miscellaneous Manufacturing Industries	20,700	0.036	0.046	0.127	0.148
20. Administrative and Auxiliary	-	-	-	-	-
Jasper County	$18,857	0.036	0.046	0.127	0.148

[1]U. S. Department of Commerce, Bureau of the Census, 1972 Census of Manufacturers (Preliminary Report)-Mississippi
U. S. Department of Commerce, Bureau of the Census, 1972 Census of Governments, Taxable Property Values and Assessment - Sales Price Ratios, Volume 2, Part 1.
Stanford Research Institute, A Study of Procedure in Estimating Flood Damage to Residential, Commercial, and Industrial Properties in California, 1960.

[2]Monetary data is converted to a 1974 base by applying an average annual compound rate of interest on long-term U. S. Government securities to the basic data.

Table 12. Estimated Flood Loss Data for Single Family Residences In Jasper County, Mississippi[1]

Estimated Market Value of Property	Direct and Indirect Damages in 1974 to Structure and Contents for Inside Water Depths of:[2]			
	1'	2'	3'	4' +
Less than $5,000	$ 681.5	$1,039.3	$1,367.2	$1,724.1
$5,000 to $9,999	1,247.8	1,909.5	2,518.2	3,176.7
$10,000 to $14,999	2,018.4	3,101.2	4,095.5	5,178.0
$15,000 to $19,999	2,720.4	4,205.2	5,568.7	7,053.3
$20,000 to $24,999	3,408.1	5,289.5	6,969.7	8,900.4
$25,000 to $34,999	4,246.2	6,662.4	8,885.6	11,307.9
$35,000 or more	5,303.9	8,414.6	11,281.6	14,405.5

[1]U. S. Department of Commerce, Bureau of the Census, United States Census of Housing, 1970, Mississippi, State and Small Areas.
Stanford Research Institute, A Study of Procedure in Estimating Flood Damage to Residential, Commercial and Industrial Properties in California, January 1960.

[2]Value classification for 1970 expanded to 1974 classifications on basis of average annual compound interest rates earned on long-term U.S. Government Securities. These classifications do not include land values.

Table 13. Estimated Flood Loss Data for Retail Business in Mississippi[1]

Retail Trade	Annual Sales Per Employee 1967	Direct and Indirect Flood Damage in 1974[2] In Dollars Per $1000 of Annual Sales Per Establishment at Water Depths of:			
		1'	2'	3'	4' +
1. Building Materials, Hardware, and Farm Equipment Dealers	$42,500	$10	$20	$43	$52
2. General Merchandise Group Stores	26,700	8	17	36	43
3. Food Stores	55,400	6	11	24	29
4. Automotive Dealers	52,100	8	16	33	41
5. Gasoline Service Stations	38,200	6	11	23	28
6. Apparel and Accessory Stores	24,600	10	19	41	50
7. Furniture, Home Furnishings, and Equipment Stores	31,100	10	19	35	49
8. Eating and Drinking Places	10,200	5	10	19	26
9. Miscellaneous Retail Stores	38,000	8	15	33	40
10. All others	28,700	7	14	30	36
Jasper	$42,300	$ 3	$ 7	$15	$18

[1] U. S. Department of Commerce, Bureau of the Census, 1967 Census of Business, Retail Trade, Mississippi.
U. S. Department of Commerce, Bureau of the Census, Annual Sales and Purchases, Year End Inventories, and Accounts Receivable of Retail Stores, By Kind of Business for 1972.
U. S. Department of Commerce, Bureau fo the Census, 1972 Census of Governments, Taxable Property Values and Assessment - Sales Price Ratios, Volume 2, Part 1.
Stanford Research Institute, A Study of Procedure in Estimating Flood Damage to Residential, Commercial, and Industrial Properties in California, 1960.

[2] Monetary data is converted to a 1974 base by applying an average annual compound rate of interest earned on long-term U. S. Government securities to the basic data.

Table 14. Estimated Flood Loss Data for Selected Services in Mississippi[1]

Service Specialty	Annual Revenue Per Employee 1967	Direct and Indirect Flood Damage in 1974[2] Per $1000 of Annual Revenues Per Establishment at Water Depths of:			
		1'	2'	3'	4' +
1. Hotels, Motels, Tourist Courts and Camps	$ 8,743	$3	$5	$11	$16
2. Personal Services (Laundries, Beauty Shops, Barber Shops, etc.)	9,779	3	5	11	16
3. Miscellaneous Business Services	13,956	3	5	11	16
4. Automobile Repair and Services	18,861	3	5	11	16
5. Miscellaneous Repair Services	22,193	3	5	11	16
6. Motion Pictures	10,988	3	5	12	16
7. Amusement and Recreation Services (Except Motion Pictures)	15,948	3	5	12	16
Jasper	$10,912	$2	$4	$11	$15

[1]U. S. Department of Commerce, Bureau of the Census, 1967 Census of Business, Selected Services, Mississippi.
U. S. Department of Commerce, Bureau of the Census, 1972 Census of Governments, Taxable Property Values and Assessment - Sales Price Ratios, Vol. 2, Part 1.
Stanford Research Institute, A Study of Procedure in Estimating Flood Damage to Residential, Commercial, and Industrial Properties in California, Basic Report, January 1960.

[2]Monetary data is converted to a 1974 base by applying average annual compound interest rates earned on long-term U. S. Government Securities to the basic data.

Table 15. Estimated Flood Loss Data for Wholesale Businesses in Mississippi[1]

Wholesale Business	Annual Revenue Per Paid Employee 1967	Direct and Indirect Flood Damage in 1974[2] Per $1000 of Annual Revenues Per Establishment at Water Depths of:			
		1'	2'	3'	4' +
1. Motor Vehicles and Automotive Equipment	$ 62,400	$11	$14	$40	$46
2. Piece Goods, Notions and Apparel	125,100	10	13	37	43
3. Groceries and Related Products	87,700	8	11	30	35
4. Farm Products - Raw Materials	382,000	9	11	31	36
5. Electrical Goods	89,200	11	13	39	45
6. Hardware, Plumbing, Heating Equipment and Supplies	39,200	13	16	46	54
7. Machinery, Equipment and Supplies	67,500	13	16	46	54
8. Petroleum and Petroleum Products	152,100	8	10	28	32
9. Tobacco and its Products	100,500	9	11	31	36
10. Lumber and Construction Materials	97,800	8	10	28	33
11. Farm Supplies	168,900	9	11	32	38
12. All Others	66,300	10	12	35	41
Jasper	$ 41,300	$ 9	$12	$34	$39

[1]U. S. Department of Commerce, Bureau of the Census, 1967 Census of Business, Wholesale Trade, Mississippi.
U. S. Department of Commerce, Bureau of the Census, 1972 Census of Governments, Taxable Property Values and Assessment - Sales Price Ratios, Vol. 2, Part 1.
Stanford Research Institute, A Study of Procedure in Estimating Flood Damage to Residential, Commercial, and Industrial Property in California, January 1960.

[2]Monetary data is converted to a 1974 base by applying an average annual compound rate of interest earned on long-term U. S. Government securities to the basic data.

Another characteristic of the flood data that should be noted is related to geographical application. The flood loss data for agriculture (Table 10) is developed for Jasper County and for the State of Mississippi, whereas flood loss data on single family residences (Table 12) are developed specifically for Jasper County. The flood loss data for the remaining categories, namely manufacturing (Table 11), retail business (Table 13), selected services (Table 14), and wholesale business (Table 15), are applicable to the State of Mississippi.

Tables 10 to 15 are used in conjunction with an inventory of the land use in the upstream flood plain to develop a stage flood loss function. The approach is to compute losses for land area covered by varying degrees of depth of flood waters. Because the flood plain at the bridge site consists of only woodlands and pasture, an approximate stage-damage curve was developed to determine the backwater damages. For a more varied land use pattern in the flood plain, the approach outlined above is recommended to determine backwater losses. The approximate stage-damage curve developed for the study site is shown in Figure 17 and the flood damage information for the flows considered in the risk analysis is shown in Table 4.

EROSION DAMAGES

Approach embankments may be eroded during the flood events considered. The amount of erosion is determined by the time of overtopping and the overtopping head. In order to calculate overtopping time, the duration of the storm hydrograph must be determined. The pertinent hydrograph data is shown in Table 16. A cost adjustment factor is used to multiply the repair cost to indicate that emergency repair is more costly than normal repair. In addition, an inspection time of two hours is assumed to inspect the roadway if any overtopping results before opening the roadway to traffic again. The erosion information is shown in the bottom section of Table 16.

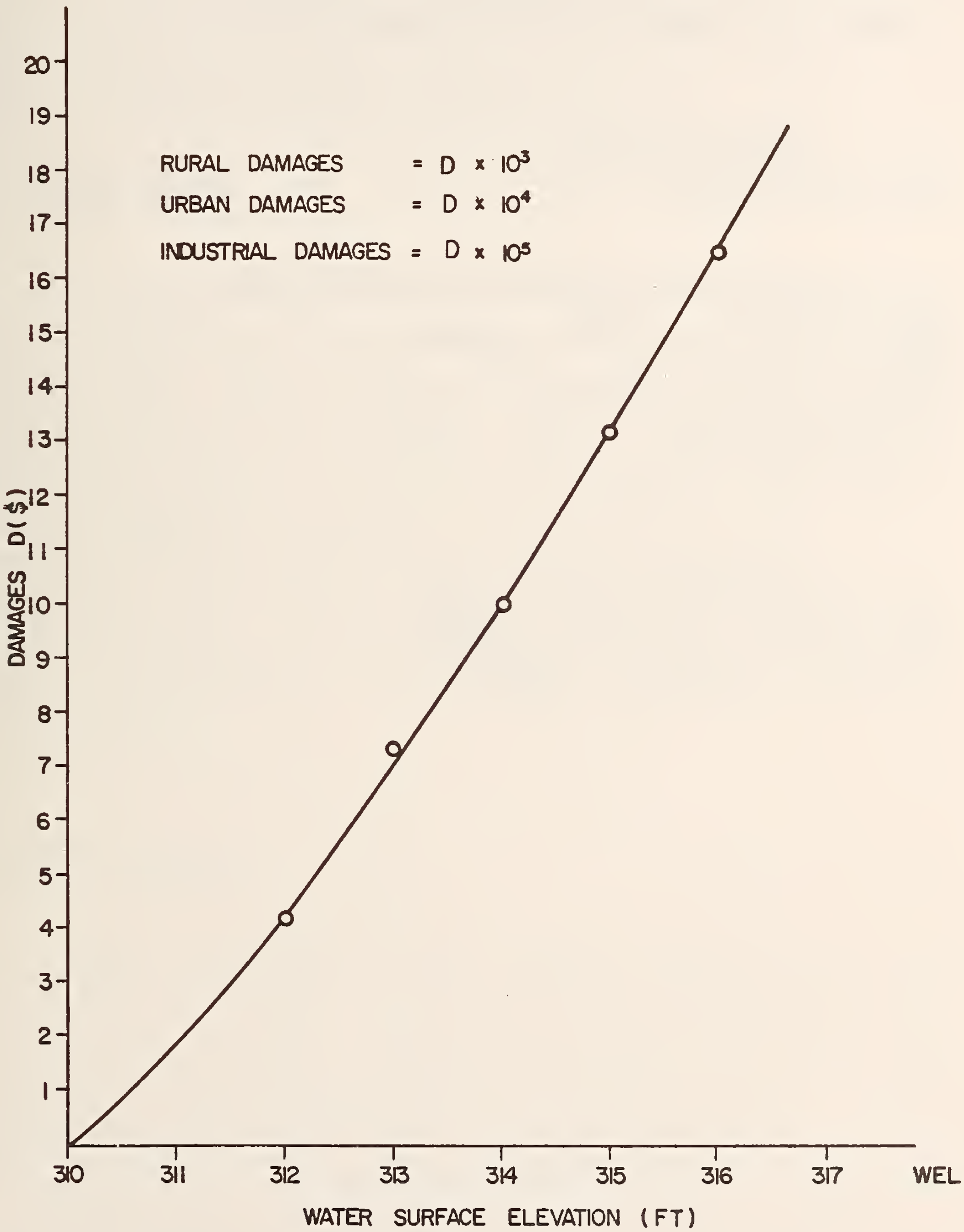


Figure 17. Stage-Damage Curve

Table 16. Hydrologic, Scour and Erosion Data

```
          HYDROLOGIC DATA
LENGTH OF LONGEST WATERCOURSE                         17.000  MILES
ELEVATION DIFFERENCE                                  53.000  FEET


          SCOUR INFORMATION (ALL LENGTHS IN FEET)
CHANNEL TYPE IS        1.000
COST PER FOOT OF SCOUR IS      -0.000
MAXIMUM SCOUR DEPTH IS     -0.000
VELOCITY NODE FOR SCOUR IS        -0
RECTANGULAR WIDTH OF PIER IS    -0.000
NUMBER OF PILES IS         -0
PILE DEPTH IS      -0.000


          EROSION INFORMATION
INCIPIENT VEL.(FT/SEC) IS    3.5000
WEIGHT (LBS/FT3) OF SOIL IS  128.0000
COST ADJUSTMENT FACTOR IS    2.0000
INSPECTION TIME(HR) IS    2.0000
```

SCOUR DAMAGE

In the example problem it is assumed that the pieces of the bridge rest on bedrock so that there is no scour damage. The variables which would be used to calculate scour are set to zero. The scour information is shown in the middle portion of Table 16.

TRAFFIC DELAY LOSSES

During the course of the storm the bridge may become impassable due to overtopping during which embankment erosion may occur. The sum of overtopping time, inspection time, and embankment repair time constitutes the total delay time to motorists. A traffic distribution is assumed as shown in Table 17 along with a detour distance and travel speed which is compared to the normal route distance and speed. The results are used to calculate the lost time of the motorist which is converted to an economic loss by use of the value of time parameter shown in the economic section of Table 17. Additional losses are accident and obstacle related damages. Accident rate and cost data are also shown in Table 17.

TOTAL ECONOMIC RESPONSE

In order to determine the total economic response for each bridge design, the total construction cost of each bridge design must be added to the total weighted losses. The total construction cost is calculated as an equivalent annual cost based on a given project life and interest rate using the capital recovery factor. The total construction cost of the bridge is made up of the cost of the bridge, the cost of embankments, and the roadway costs. The bridge cost function and the pertinent embankment and roadway cost information is shown in Table 18.

Table 17. Economic and Traffic Information

PROJECT LIFE (YRS) =	100.000
INTEREST RATE(PER CENT) =	7.000
AVE. VALUE OF TIME ($/HR)	2.730

AVERAGE DAILY TRAFFIC LEVEL	16000.000
PASSENGER CAR TRAFFIC LEVEL	.850
COMMERCIAL DELIVERY VEHICLE LEVEL	.010
SINGLE UNIT TRUCK LEVEL	.020
GASOLINE TRUCK LEVEL	.030
DIESEL SEMI TRAILER LEVEL	.090
NORMAL TRAVEL DISTANCE	4.500
NORMAL TRAVEL SPEED	55.000
DETOUR TRAVEL DISTANCE	18.000
DETOUR TRAVEL SPEED (M/HR)	40.000
AVE. VEH. OCCUPANCY RATE	1.700
ACCIDENT RATE DATA	
DEATH RATE/100 MILLION MILES (NORMAL)	5.500
PERSONAL INJURIES (NO./DEATH) (NORMAL)	30.000
PROPERTY DAMAGE (NO./DEATH) (NORMAL)	300.000
PERSONAL INJURY RATE OBSTACLE	150.000
PROPERTY DAMAGE RATE OBSTACLE	15.000
DEATH RATE FOR OBSTACLES	1000.000
ACCIDENT RELATED COST DATA	
COST PER DEATH	50000.000
COST OF PERSONAL INJURY	2000.000
PROPERTY DAMAGE	400.000

Table 18. Cost Data

```
HYDRAULIC INFORMATION IS ON TAPE      7

BRIDGE COST FUNCTION
BRIDGE COST =     .483E+04 +   -0.          * AREA +   -0.        *PIERS +  -0.
                   *CLEAR. +    .155E+04 * LNGTH +   -0.        * RDWY WIDTH

EMBANKMENT INFORMATION

FILL COST ($/CY)                        2.000
UPSTREAM SLOPE (PERCENT)               67.000
DOWNSTREAM SLOPE (PERCENT)             67.000
BRIDGE WIDTH (FT)                     108.000
ROADWAY COST ($/FT)                    58.000

BRIDGE INFORMATION FOLLOWS
ON THE NEXT THREE PAGES
```

The total economic response is then computed and the results of the risk analysis for each of the bridge designs is shown in Table 19. The 300-foot bridge with a 315-foot embankment height has a lower total economic response than the present bridge design, the 500-foot bridge with a 315-foot embankment height. This is due to the fact that the savings in bridge cost of the 300-foot bridge over the 500-foot bridge is greater than the increase in risk. This can be readily seen by examining the risk and bridge construction cost columns. For a 300-foot bridge with an embankment of 315 feet, the risk component of the total economic response is approximately $535 greater than the risk component for the present bridge configuration. On the other hand, a savings of over $20,000 per year in construction cost is realized by building the 300-foot bridge rather than the present bridge design. The data used in this example problem is representative and not exact for the given Tallahalla Creek bridge site and therefore we are not stating specifically that the 300-foot bridge length design is better than the present design although this would appear to be the case based on the representative data set.

The plot option of the RISK module was used to generate three plots of the information shown in Table 19. In the first plot (Figure 18) the total economic response times 10^{-3} (TER * 10^{-3}) for the 500-foot bridge category is plotted versus embankment height. The 315-foot embankment height gives a lower response than the 310-foot and 320-foot embankment heights for a 500-foot bridge. The economic response of the 315-foot embankment height is lower than that of the 310-foot because the savings in construction cost of the 310-foot embankment height over the 315-foot configuration ($5,400) fails to offset the larger risk component of the 310-foot embankment height configuration ($27,000). The 315-foot embankment height economic response is lower than that of the 320-foot because increase in construction cost of the 320-foot configuration over the 315-foot configuration ($6,000) is larger than the savings of the 320-foot configuration risk over the risk of the

Table 19. Results of Economic Analysis

RISK FACTOR ANALYSIS RESULTS

BRIDGE CONFIGURATION (FT)		ECONOMIC RESPONSE COMPONENTS (DOLLARS)		
LENGTH	EMBNT. HT.	CONSTRUCTION COST	RISK	TOTAL ECONOMIC RESPONSE
300.000	315.000	52172.305	1483.047	53655.352
500.000	315.000	72715.814	948.478	73664.292
500.000	310.000	67312.107	33251.00*	100563.107
500.000	320.000	78750.984	608.000	79358.984
1000.000	315.000	122919.755	658.443	123578.197
1000.000	310.000	119293.935	28491.836	147785.771
1000.000	320.000	126983.337	495.000	127478.337

RISK BASED ON FLOOD EVENTS

FLOW	VOLUME(CFS)	RECURRENCE INTERVAL
1	16200.000	.010
2	19700.000	.020
3	23500.000	.010
4	27500.000	.010

CONSTRUCTION COST CALCULATED AS EQUIVALENT ANNUAL COST
BASED ON PROJECT LIFE 100.000YEARS INTEREST RATE 7.000 PERCENT

TOTAL ECONOMIC RESPONSE EQUALS SUM OF
CONSTRUCTION COST AND RISK

*Calculation based on incomplete information

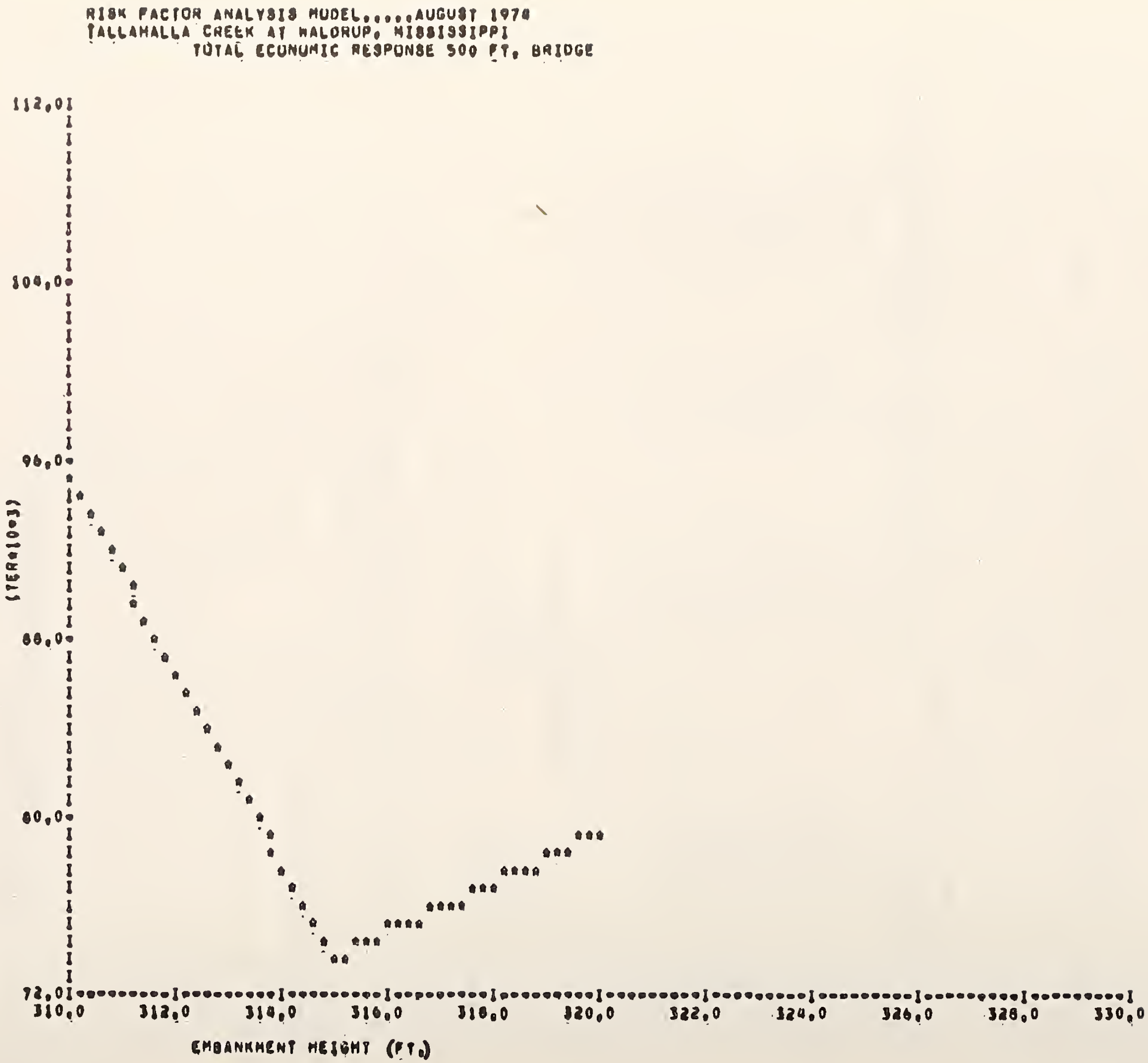


Figure 18. Total Economic Response for 500-Foot Bridge

315-foot configuration ($340). In the second plot (Figure 19) the total economic response time 10^{-3} (TER * 10^{-3}) for the 1000-foot bridge category is plotted versus embankment height. The results are similar to those discussed for the 500-foot bridge category. In the third plot (Figure 20) the total economic response times 10^{-3} (TER * 10^{-3}) is plotted versus bridge length for all bridge configurations having an embankment height of 315 feet. The increase in total economic response with increasing bridge length at the 315-foot embankment height is linear. This is due to the fact that the construction cost components of the total economic response dominate the risk components for all configurations plotted, and the construction cost is linearly monotonic, increasing with bridge length for a fixed embankment height.

In this example, the dominance of the construction cost components over the risk components for all bridge designs considered is due to the bridge site location in a rural area where the backwater damages are minor. In the following chapter on Sensitivity Analysis, a site will be considered where the backwater damage is great and the risk component of the economic response is comparable to the bridge construction cost.

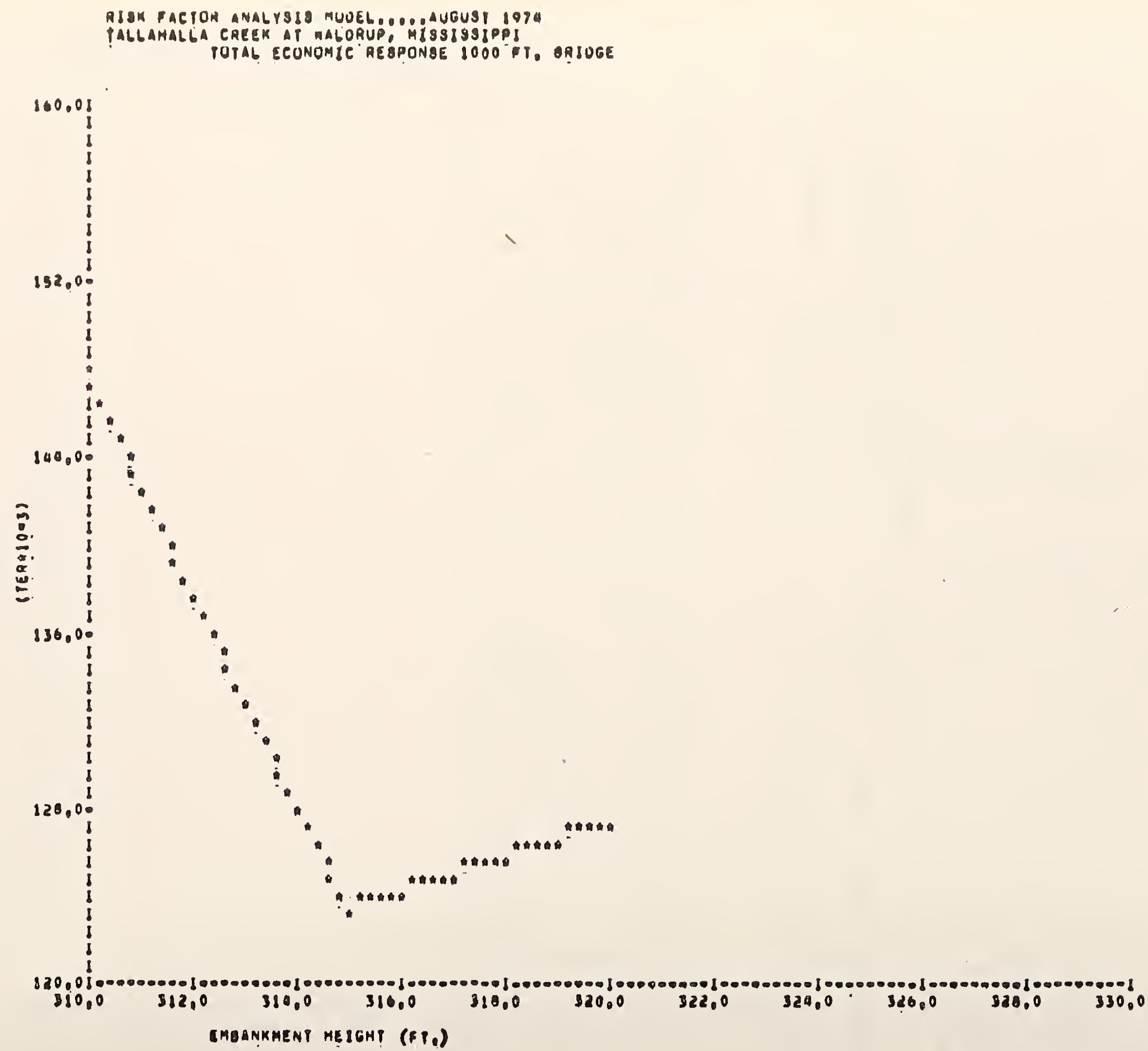


Figure 19. Total Economic Response for 1,000-Foot Bridge

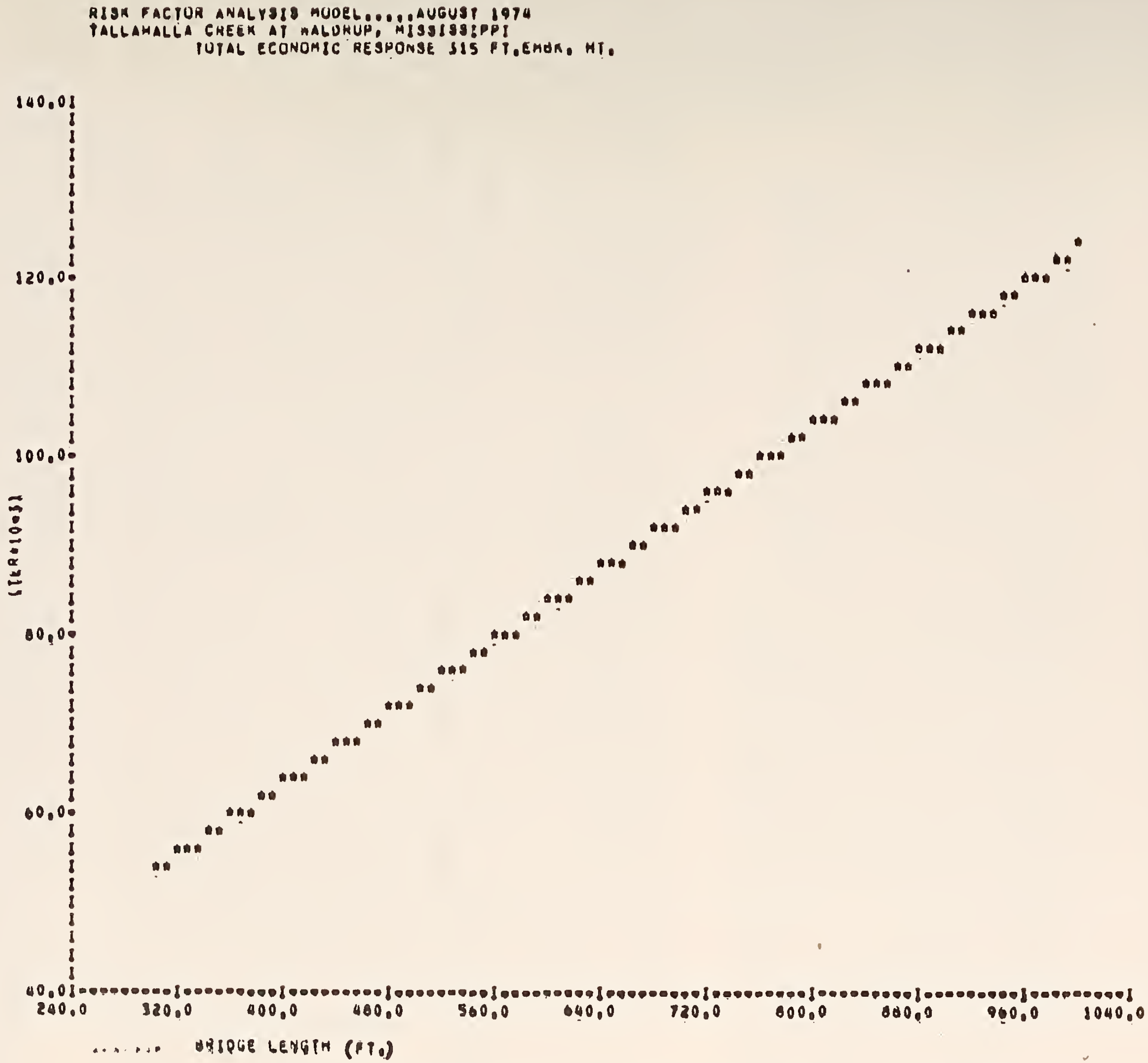


Figure 20. Total Economic Response for 315-Foot Embankment Height

V. SENSITIVITY ANALYSIS

In the development of the methodology for performing risk analysis of highway stream crossings, assumptions were made for several physical processes. For example, estimates were made from available information for such design parameters as traffic level and characteristics, and hydrologic data. These assumptions and estimates are subject to errors. Hence the use of this information in calculating the total economic response at a bridge site may induce solution errors, which in turn may affect the decision-making process.

The number of parameters involved in the risk analysis is large and the governing hydrologic and hydraulic processes are complex. Moreover, the economic data used for the analysis varies from site to site and also with time. The uncertainties associated with the risk analysis need not discourage the use of the method as long as the limitations inherent in the method of analysis are identified. Sensitivity analysis is the means by which these limitations may be assessed. The results of sensitivity analysis permit the designer to deal with the uncertainty presented in the method of analysis. Sensitivity analysis identifies critical variables and factors for the purpose of singling them out for careful consideration in the design process to reduce uncertainty. It also serves the purpose of establishing research priorities and resolves estimating problems associated with sensitive design factors.

Virtually every parameter and measurement associated with bridge design is subject to some degree of estimation. Basically there are three major groups of parameters governing the total cost for a crossing site.

These are: (1) hydrologic - hydraulic, (2) engineering, and (3) economic variables. In a previous study by WRE (13) for 22 culvert sites, it was found that six of the factors in the three groups appear to be relatively significant in the economic response. These factors are:

- interest rate,
- unit cost,
- stage-damage curve,
- flow hydrographs, and
- embankment erosion.

This list is the basis for the selection of factors in the present sensitivity analysis. The major parameters subject to analysis are:

- interest rate,
- bridge cost,
- stage-damage curve (backwater damages), and
- hydrology, i.e., flood-frequency curve.

Minor parameters analyzed include (1) cost of time, and (2) average daily traffic (ADT). The results of the sensitivity computer runs are shown in Table 20. Run 1 represents the baseline values (or the optimal design) used in the example problem of Chapter IV. Runs 2 through 13 comprise the sensitivity analysis runs made in this study. The optimal solution remained the 300-foot bridge with a 315-foot embankment height for all the sensitivity analysis runs. The effect of changes in the sensitivity analysis parameters on the total economic response of this optimal bridge design is presented in Figure 21. The relative effect of each parameter varied in the sensitivity analysis on the total economic response of the optimal bridge design is evaluated in Table 21. In Table 22 the sensitivity analysis parameters are ranked by order of impact on the total economic response of the optimal bridge design.

Table 20. Sensitivity Analysis Results

Run	Bridge Cost Parameters B(1) $*10^3$	B(6) $*10^3$	RWCST	CY	Interest Rate%	Cost of Time ($/hr)	Abe. Daily Traffic Level (veh/day)	Backwater Damages	Flow Frequency (weights)	Optimal Design[1]	TER ($)
1	4.83	1.547	58.0	2.0	7	2.73	16000	Baseline	.01 .02 .01 .01	BL=300 ft EH=315 ft	53655
2					5						38991
3					9						68497
4					7	3.64					53687
5						4.57					53720
6						2.73	12000				53490
7							20000				53820
8							16000		.02 .03 .022 .028		55271
9									.006 .0087 .0033 .002		52692
10	6.038	1.934	73.0	3.0					.01 .02 .01 .001		69467
11	3.622	1.16	3.0	1.0							37844
12	4.83	1.547	58.0	2.0				Baseline*10			59875
13								Baseline*100			122064

[1]BL = Bridge Length, EH = Embankment Height

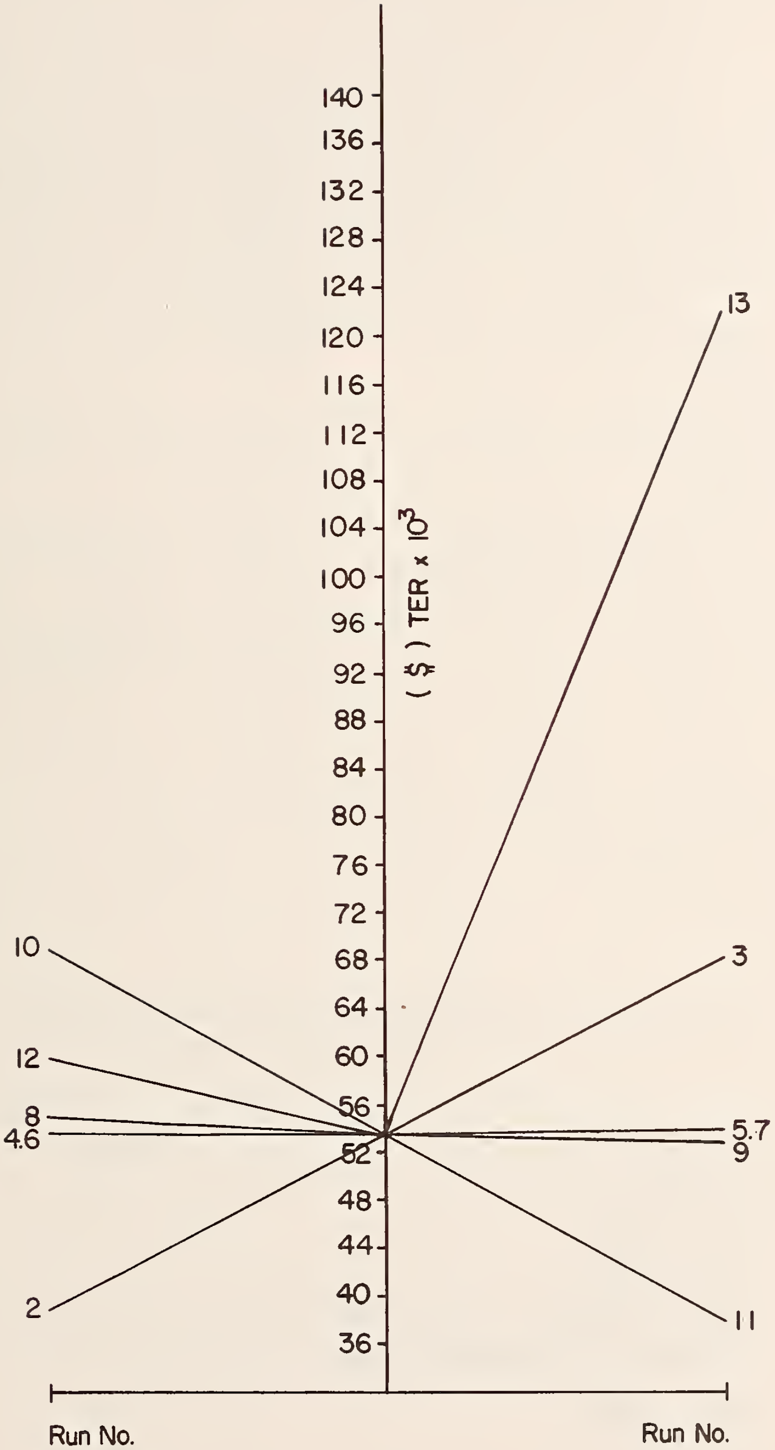


Figure 21. Sensitivity Analysis Results

Table 21. Effect of Parameter Changes on Total Economic Response

Run	Parameter	$\Delta TER/TER \; \Delta P/P$ [1]	Avg. Relative Effect on Response
2	Interest Rate 5%	0.987	0.987
3	Interest Rate 9%	0.987	
4	Cost of Time ($3.64/hr)	0.00089	0.0013
5	Cost of Time ($4.57/hr)	0.0018	
6	Average Daily Traffic Level (12000 veh/day)	0.0127	0.0127
7	Average Daily Traffic Level (20000 veh/day)	0.0127	
8	+25% Flow for Given Frequency	0.1205	0.096
9	-25% Flow for Given Frequency	0.072	
10	+25% Bridge Cost	1.178	1.178
11	-25% Bridge Cost	1.178	
12	Baseline Backwater Damages X 10	0.0115	0.0121
13	Baseline Backwater Damages X 100	0.0127	

[1]Relative Effect on Response

Table 22. Ranking of the Parameters of the Sensitivity Analysis by Impact on Total Economic Response

Parameter	Rank
Bridge Cost	1
Interest Rate	2
Flow Frequency Curve (Gumbel Plot)	3
Average Daily Traffic Level	4
Flood Losses	5
Cost of Time	6

Bridge cost has the largest impact on the total economic response of the optimal crossing design. To produce the ±25 percent changes in bridge cost, the bridge regression coefficients B(1) and B(6), the cost of roadway per foot (RWCST), and the embankment fill cost (CY) are all increased and decreased by 25 percent. The cost of roadway per foot and the embankment fill cost are also used in determining erosion losses and thus have an effect on the risk component of the total economic response. A one percent change in B(1), B(6), RWCST and CY produces a 1.178 percent change in the total economic response of the optimal solution.

The interest rate used in determining the equivalent annual bridge construction cost is the next most critical parameter. The equivalent annual cost is determined by multiplying the bridge cost by the capital recovery factor. The total economic response is the sum of the equivalent annual cost of the bridge and the risk. A one percent change in interest rate produces a 0.987 percent change in the total economic response of the optimal solution.

The nature of the flow frequency curve has a significant impact on the total economic response of the optimal bridge design. The flow frequency curves used in the sensitivity analysis are presented as the Gumbel plots shown in Figure 22. For a given recurrence interval the flow is increased and decreased by 25 percent in order to develop the plus and minus 25 percent straight lines shown in Figure 22. The return weights used to develop the risk component of the total economic response are determined from the Gumbel plot of the flood frequency information. The evaluation of the return weights is also based on the flood events considered in the risk analysis and is shown in Table 23. A one percent change in the Gumbel plot of Figure 22 produces a 1.096 percent change in the total economic response of the optimal bridge design.

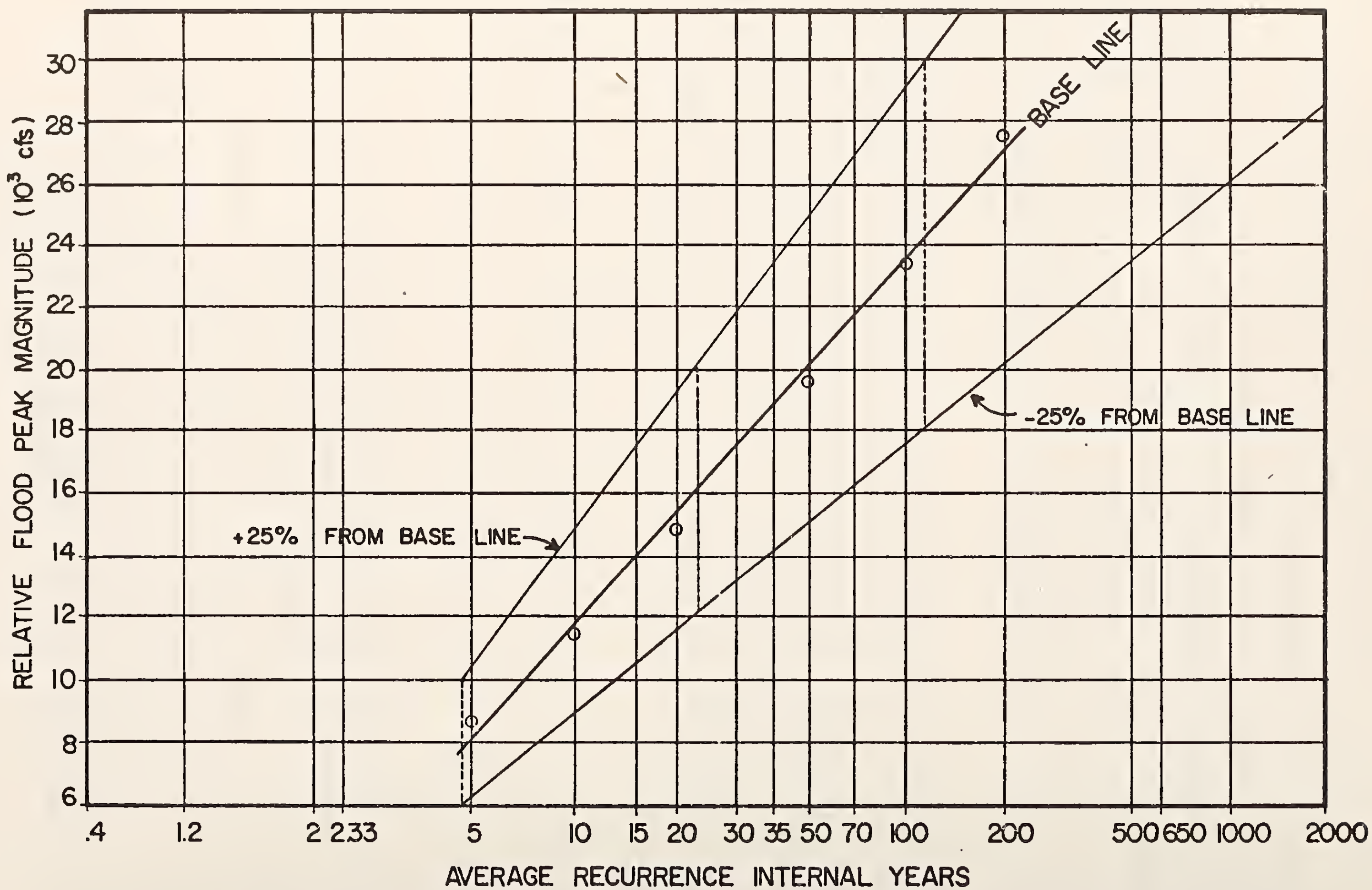


Figure 22. Flow Frequency Curves

Table 23. Evaluation of Return Weights for Flood-Frequency Sensitivity Analysis

	Q Flow (cfs)	Loss for Flow Q ($)	Return Interval (yr)	$i=1,..5$ $P[Q>Q_i]$	$i=1,..4$ $P[Q_i<Q<Q_{i+1}]$	Return Weight
	15000	L_{15000}	20	0.05		-
					0.01	
	16200	L_{16200}	25	0.04		0.01
					0.02	
Baseline	14700	L_{14700}	50	0.02		0.02
					0.01	
	23500	L_{23500}	100	0.01		0.01
					0.005	
	27500	L_{27500}	200	0.005		0.01
					$P[Q>Q_i] = 0.005$	

$$\text{Risk} = 0.01\,L_{16200} + 0.02\,L_{14700} + 0.01\,L_{23500} + 0.01\,L_{27500}$$

$$\text{Baseline Return Weight Set} = \begin{bmatrix} 0.01 \\ 0.02 \\ 0.01 \\ 0.01 \end{bmatrix}$$

Table 23. Evaluation of Return Weights for Flood-Frequency Sensitivity Analysis (Cont.)

	Q Flow (cfs)	Loss for Flow Q ($)	Return Interval (yr)	i=1,..5 $P[Q>Q_i]$	i=1,..4 $P[Q_i<Q<Q_{i+1}]$	Return Weight
+25 Percent	15000	L_{15000}	10	0.1		-
					0.02	
	16200	L_{16200}	12.5	0.08		0.02
					0.03	
	19700	L_{19700}	20	0.05		0.03
					0.022	
	23500	L_{23500}	35	0.028		0.022
					0.014	
	27500	L_{27500}	70	0.014	$P[Q>Q_5] = 0.014$	0.028

$$\text{Risk} = 0.02\ L_{16200} + 0.03\ L_{19700} + 0.022\ L_{23500} + 0.028\ L_{27500}$$

+25% Return Weight Set $\begin{bmatrix} 0.02 \\ 0.03 \\ 0.022 \\ 0.028 \end{bmatrix}$

Table 23. Evaluation of Return Weights for Flood-Frequency Sensitivity Analysis (Cont.)

-25 Percent

Q Flow (cfs)	Loss for Flow Q ($)	Return Interval (yr)	i=1,..5 $P[Q>Q_i]$	i=1,..4 $P[Q_i<Q<Q_{i+1}]$	Return Weight
15000	L_{15000}	50	0.02	0.006	-
16200	L_{16200}	70	0.014	0.0087	0.006
19700	L_{19700}	190	0.0053	0.0033	0.0087
23500	L_{23500}	500	0.002	0.0014	0.0033
27500	L_{27500}	1700	0.0006	$P[Q>Q_5] = 0.0006$	0.002

$$\text{Risk} = 0.006\ L_{16200} + 0.03\ L_{19700} + 0.022\ L_{23500} + 0.028\ L_{27500}$$

$$\text{-25\% Return Weight Set} = \begin{bmatrix} 0.006 \\ 0.0087 \\ 0.0033 \\ 0.002 \end{bmatrix}$$

The average daily traffic level in vehicles per day is used to determine the total dollar amount of traffic-related losses caused by inundation of candidate bridge designs. The total dollar amount of traffic-related losses forms one component of the total risk which directly affects the total economic response. A one percent change in average daily traffic level is small at 0.0127 percent.

The losses due to backwater created by flow constriction of the bridge are a component of the total risk. The baseline backwater damages are in the order of 10^3 dollars in magnitude and are those associated with a real site such as Tallahalla Creek. In the sensitivity analysis these backwater damages are first multiplied by a factor of 10 to represent an urban flood plain damage pattern and then by a factor of 100 to represent industrial flood plain damage. The total economic response of the optimal bridge design is quite insensitive to changes in backwater damages even in the case of industrial flood plain development for which the risk components of the total economic response are on the same order of magnitude as the bridge construction cost. For a one percent change in backwater damages a change of 0.0121 percent in the total economic response of the optimal solution is observed.

The cost of time in dollars per hour, like the average daily traffic level, is used in determining the total dollar amount of traffic delay losses incurred by overtopping of the bridge embankments and subsequent embankment erosion. The total dollar amount of traffic delay losses comprises one component of the total risk which in turn is used to evaluate the total economic response. The input of a one percent change in the cost of time in dollars per hour on the total economic response of the optimal bridge design is quite small at 0.0013 percent.

In conclusion, the optimal bridge design for the Tallahalla site is the 300-foot bridge, 315-foot embankment height configuration for all changes in the sensitivity analysis parameters. Interest rate and bridge cost have a major influence on the total economic response of the optimal bridge design. Changes in the flood frequency curve significantly impact the total economic response of the optimal solution, while changes in average daily traffic level, backwater damages, and cost of time produce only minor changes in the total economic response.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

An engineering systems analysis technique has been developed to facilitate the economic risk analysis for highway stream crossings. The technique is based on a probabilistic approach, incorporating hydrologic, hydraulic and economic factors in the engineering analysis of bridge waterways. It relates the initial construction costs, flood-related highway losses and damage to properties from backwater to crossing design and flood frequency.

The basic concept of the risk analysis of highway stream crossing is a method to determine the economic measurement of various crossing designs at a bridge site. The economic measurement used in this study is the total economic response, defined as the sum of project construction cost and risk, on an annual basis. A design scheme giving the least total economic response is the optimal design.

The annual project construction cost is derived from the cost of bridge, approach embankments and the pavement, amortized over the project life at a given interest rate. Such a cost is generally governed by the type of bridge, bridge length, bridge width, clearance, span, geology or underlying river bed, height of the approach embankments, type of highway, and width of the valley at the crossing site. Risk is the sum of the products of the weighted probability of flood occurrence and flood-related economic losses. The determination of risk requires hydrologic, hydraulic and economic data at and near the highway crossing site. Tangible losses to be considered include structure damages, traffic-related (e.g., traffic stoppage or delay) losses, and flood losses.

Hydrologic data are obtained from the U. S. Geological Survey stream gaging records. Flood data are plotted on Gumbel probability paper to define the flood-frequency curve at the crossing site. Hydraulic data such as the water surface elevations and the velocities at and near the bridge site are computed by a two-dimensional Finite Element Model.

The decision variables considered for various design alternatives in this study are limited to the bridge length and embankment height. Other minor variables such as bridge type and crossing type may be incorporated in the analysis when situations warrant. The complexity of the decision matrix increases as the number of decision variables increases.

The method of risk analysis is implemented by a model in the form of a computer program using FORTRAN program language. Details of the model description and its input specifications are presented in Appendix B.

CONCLUSIONS

The following conclusions have been drawn from the present study:

1. The study has illustrated that the application of systems analysis techniques to provide the means for design engineer's decision-making process in highway stream crossings is feasible and practical. This report has successfully demonstrated a methodology to deal with a complex problem by a systematic simplification of the analysis.

2. Results of sensitivity analysis for the parameters tested reveal that the relative importance in design parameters affecting the total economic response for the example site is in the following: bridge cost, interest rate, flow frequency curve, ADT, flood losses and the cost of time. For bridges subject to inundation, results of sensitivity analysis may vary.

3. Because the example site is located in a rural area, the results show that the bridge cost outweighs the risk. Such an observation may not be true for bridge sites located in urban areas.

4. With the limited data available at the Tallahalla Creek site, the results of the example problem have indicated that the present method gives a more economic design than the conventional method. This is consistent with the results arrived at in the previous study for box culverts (13).

RECOMMENDATIONS

The research effort described herein encountered numerous problems, the solution to which should be pursued simultaneously on a twofold front. The estimation of such important variables as pier, abutment, and channel scour, embankment erosion, and bridge failure mechanisms, require work on both simplistic empirical formulations and basic research to develop methodology that is generally applicable to the wide range of conditions normally encountered. Of course, this should not delay the application of current technology to solving present day problems. It is only in this way that the needed data-base can be assembled from which new techniques can be established and tested. In most cases the methodology employed in this report is not generally applicable to all cases but must be calibrated by a trial and error process to the bridge site under study. Ideally, as more information is gained, the difficulty in estimating important parameters will be alleviated by a compilation of a set of "Handbook" values applicable to a wide range of situations. Specific recommendations in this regard follow:

1. A more phenomenologically oriented method for calculating embankment erosion is needed. The method used here is a log-linear relationship developed as a function of velocity. Additional study is required to either improve this empirical relationship or to develop alternative approaches.

2. Presently, only pier scour is included in the Risk analysis. Abutment and channel scour should also be included in the analysis. An approach such as proposed by Laursen (15) would be a useful addition to the analysis.

3. Bridge damage, caused by inundation, is handled in only a superficial manner. However, the method accurately quantifies the amount of information presently available describing this problem. This presents an area where basic research and evaluation of data is urgently needed.

4. In order to move the model from a research tool to a field implementable one, it is recommended that additional sites be analyzed with the present techniques. This will provide a basis for the improvement of present methods and will allow valuable input by field engineers into the structure of the model.

5. The hydraulic model should be simplified in order to reduce the cost of analysis. Such a simplification could be made by compiling hydraulic data covering a wide range of field design conditions by the use of the Finite Element Model developed under this contract.

LIST OF REFERENCES

1. Chang, F. M., "Statistical Summary of the Cause and Cost of Bridge Failures," Report Prepared for the Office of Research, Federal Highway Administration, Department of Transportation, September 1973.

2. Personal communication with staff of Pennsylvania Department of Transportation.

3. Personal communication with staff of Virginia Department of Highways.

4. U. S. Department of Transportation, Federal Highway Administration, Offices of Physical Services Computer Files, "New Federal-Aid Highway Bridges," 1953 through 1973; "Bridges over Water," as of December 31, 1973.

5. Bradley, J. N., *Hydraulics of Bridge Waterways,* Hydraulic Design Series No. 1, Hydraulic Branch, Bridge Division, Office of Engineering, FHWA, 2nd Edition, September 1973.

6. U.S. Department of Transportation, Federal Highway Administration, *Use of Riprap for Bank Protection*, Hydraulic Engineering Circular No. 11, April 1970.

7. U.S. Bureau of Reclamation, *Design of Small Dams*, Washington, D.C., 1965.

8. U.S. Department of Agriculture, Soil Conservation Service, *National Engineering Handbook - Hydrology,* 1960.

9. Posey, C. J., "Flood-Erosion Protection for Highway Fills," Transactions ASCE, Paper No. 2871, Vol. 122, 1957, pp. 531-555.

10. Tinney, E. R., and H. Y. Hsu, "Mechanics of Washout of an Erodible Fuse Plug," Transactions, ASCE, Paper No. 3283, Vol. 127, Part I, 1962, pp. 31-59.

11. Cristofano, E. A., "Method of Computing Erosion Rate for Failure of Earthfill Dams," Engineering and Research Center, Bureau of Reclamation, Department of the Interior, Denver, Colorado, April 1965.

12. Newton, D. W., and M. W. Cripe, "Flood Studies for Safety of TVA Nuclear Plants, Hydrologic and Embankment Breaching Analysis," Tennessee Valley Authority, Knoxville, Tennessee, 1974.

13. Young, G. K., R. S. Taylor and L. S. Costello, *Evaluation of the Flood Risk Factor in the Design of Box Culverts,* Vol. I, Final Report, Prepared for the Federal Highway Administration, Department of Transportation, by Water Resources Engineers, September 1970.

14. Seelye, E. E., *Data Book for Engineers,* Vol. I, 3rd Edition, May 1966.

15. Laursen, E. M., "Scour at Bridge Crossings," *J. Hyd. Div., ASCE,* Vol. 86, HY2, February 1960, pp. 39-53.

16. Stanford Research Institute, *The Value of Time Saved by Trip Purpose,* Prepared for the Bureau of Public Roads, Contract FH-11-6881, October 1970.

17. Winfrey, R., *Economic Analysis for Highways,* International Textbook Company, Scranton, Pennsylvania, 1969.

GLOSSARY OF MATHEMATICAL TERMS

a_o = Constant

a_1 = Coefficient for area (x_1)

a_2 = Coefficient for area (x_2)

a_3 = Coefficient for area (x_3)

a_4 = Coefficient for area (x_4)

a_5 = Coefficient for area (x_5)

A_o = Intercept coefficient

A_1 = Slope coefficient

b = Eroded roadway width

b_p = Width of retangular pier

B = Embankment width

B_3 = Abutment, footing and pier costs

B_4 = Protective measure costs (spur dikes and riprap)

C_a = Cost adjustment factor

C_f = Original cost of fill

C_r = Original cost of roadway

C_s = Cost of bridge superstructure

CRF = Capital recovery factor

D_j = Loss incurred due to occurrence of state of nature j

d = Flood head above roadway

d_f = Pile length required for nominal scour depth

d_s = Depth of scour

E = Embankment erosion (tons/ft/day)

G = Cost per unit pile length

H = Fill height

H_i = Fill height at station i

i = Interest rate

L = Bridge length

L_i = Length of bridge embankment element i

L_b = Bridge damage

P_j = Probability of occurrence of state of nature j

Q = Flow

Q_p = Peak flow

r_i = Recurrence interval associated with given flow Q_r

R_i = Risk for strategy i

RW = Roadway length

R = Risk

S_1, S_2 = Side slope of embankment fill

T = Time of overtopping

T_b = Flood duration

T_c = Time of concentration

T_p = Time to peak

T_r = Time between peak flow and end of hydrograph

TER = Total economic response function

V = Velocity in ft/sec

V_e = Erosion threshold velocity

y = Submergence of bridge deck

α = Empirical constant for embankment erosion for cohesive soil

β = Empirical constant for embankment erosion for cohesionless soil

γ = Correlation coefficient

ζ = Coefficient for bridge damage due to inundation

σ_{yx} = Standard error for bridge cost regression

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

FEDERAL-AID HIGHWAY PROGRAM MANUAL

VOLUME	6	ENGINEERING AND TRAFFIC OPERATIONS
CHAPTER	7	BRIDGE, STRUCTURES AND HYDRAULICS
SECTION	3	HYDRAULICS, EROSION CONTROL AND WATER QUALITY

Subsection 2 HYDRAULIC DESIGN OF HIGHWAY ENCROACHMENTS ON FLOOD PLAINS

Transmittal 30
May 29, 1974
HNG-31

1. PURPOSE

The purpose of this directive is to prescribe policies and procedures for hydraulic designs for highway projects constructed with Federal-aid funds and projects under the direct supervision of the Federal Highway Administration.

2. AUTHORITY

This is issued under authority of 23 U.S.C. 109(a), 315, 23 CFR 1.32, 49 CFR 1.48(b)(8) and implements Executive Order 11296 (August 10, 1966, 3 CFR, Part II).

3. POLICY

a. *Pursuant to Executive Order 11296, it is the policy of the Federal Highway Administration to encourage a broad and unified effort to prevent uneconomic, hazardous or unnecessary use and development of the Nation's flood plains, and in particular to lessen the risk of flood losses in connection with Federally-financed or supported improvements; and to comply with the "Flood Hazard Evaluation Guidelines for Federal Executive Agencies," May 1972, published by the Water Resources Council.* (See Attachment 1)

b. *It is the policy of the Federal Highway Administration that, where practicable, highway locations shall avoid areas subject to flooding.*

4. DEFINITIONS

a. *The term "basic flood" shall mean the 100-year flood.*

b. *The term "conveyance of the basic flood" shall mean the ability to accommodate passage of the 100-year flood.*

(1) *Conveyance may be through structures or both through structures and over the highway.*

(2) *Conveyance along a highway may include inundation of the highway.*

c. *The term "design flood" shall mean the peak discharge, volume (if appropriate), and stage or wave crest elevation of the flood associated with the recurrency interval selected for the design of a highway encroachment on a flood plain. By definition, the highway will not be subjected to inundation from the stage of the design flood.*

d. *The term "flood plain" shall mean (1) the valley area adjacent to a stream or river subject to overflow, (2) an area adjacent to a lake, an estuary, an ocean, or similar body of water subject to high tides, surges, tsunamis, or any combination of these; or (3) an area where the path of the next flood flow is unpredictable, as in a debris cone, an alluvial cone or fan, a debris slope, or a talus.*

e. *The term "encroachment" shall mean a highway and/or appurtenant feature within the limits of a flood plain.*

5. DESIGN STANDARDS

a. *Where encroachment on a flood plain is necessary, an evaluation, using the basic flood, shall be made of the flood hazard to the highway, and the effect of the proposed highway on the flood hazard to other property, stream stability, and the stream and flood plain environment.* (See Attachment 2)

b. The design flood selected for each encroachment and the design for conveyance of the basic flood should be supported by the following, where applicable: an incremental analysis of estimated construction costs; probable property damage including damage to the highway; the cost of traffic delays; the availability of alternate routes, emergency supply and evacuation routes; and with consideration of the potential for loss of life and of budgetary constraints.

k. *Buildings, waste treatment facilities and other high cost installations or potential major source of pollution for highway rest areas shall be located outside the flood plain or flood proofed against damage from the basic flood.*

l. *Where highway fills are to be used to form dams or levees, appropriate permits, with regard to water rights, impoundments, and diversions shall be obtained. Prior to authorization by the Division Engineer, the hydrologic, hydraulic, and structural design of the fill and appurtenant spillways, shall have the approval of the State or Federal agency responsible for the safety of dams or like structures within the State.*

6. STUDIES AND REPORTS

a. *Reports shall be prepared by the State highway department or its agent showing (1) hydrologic and hydraulic data and design computations, (2) the analysis of the highway effect on stream stability, and (3) the favorable or adverse effects on the stream environment.*

b. *The reports and design computations shall be retained in the highway agency's permanent design files for the project, and upon request made available to the Federal Highway Administration for review. Copies of these reports shall accompany preliminary plans which require regional or Washington office approval.*

c. *The reports shall be commensurate with the importance of the structure and the risk to life and property. Less comprehensive reports are appropriate for encroachments on minor streams and at locations where the risk of property damage or loss of the highway is small.*

7. FEDERAL PARTICIPATION IN CONSTRUCTION COSTS

a. *Federal-aid participation in cooperative projects using the highway fill to provide for flood control or water resource development will be limited to the pro rata share of the estimated cost to construct the highway only.*

c. *All highways that encroach on flood plains, bodies of water or streams shall be designed to permit conveyance of the basic flood without causing significant damage to the highway, the stream, body of water, or other property.*

d. *At each location where the highway will encroach upon a flood plain, project plans shall show (1) the magnitude, frequency, and water surface elevations for the design flood and the basic flood, if different from the design flood, and (2) the magnitude, water surface elevations and date of occurrence of the flood of record, if greater than the basic flood.*

e. *The effects of existing flood control channels, levees, and reservoirs shall be considered in estimating the peak discharge and stage for all floods considered in the design.*

f. *All highways on the Interstate System that encroach on flood plains shall be designed to avoid inundation of the highway from floods at least as great as the 50-year flood.*

g. Encroachments on flood plains by ramps for traffic interchange with Interstate highways may be designed to permit inundation of the ramp from floods smaller than the 50-year flood where traffic service would not be unduly reduced and where the highest standards of service are not warranted for the crossroad.

h. Encroachments on flood plains by Interstate highway service roads or frontage roads should be designed to permit inundation of the road from floods smaller than the 50-year flood except at locations where lower design standards for the service road would interfere with the performance of hydraulic structures for the Interstate roadway or where higher standards can be shown to be warranted.

i. Highways, other than those on the Interstate System, which encroach on flood plains, may be designed to permit inundation by floods smaller than the 50-year flood, where lower standards are warranted.

j. Ramps, parking and picnic areas for rest areas may be designed to be inundated by overbank flow in the flood plain, dependent upon the expected duration of flooding, expected cleanup and repair costs and the hazard to users. Precautions should be taken to insure that benches, tables, trash barrels and other furnishings do not become waterborne debris during floods.

The following extracts from "Flood Hazard Evaluation Guidelines for Federal Executive Agencies," United States Water Resources Council, May, 1972, are applicable to the location, design and construction of Federal and Federal-aid highways. The WRC publication has been distributed by various sources. Additional copies are available from FHWA on request.

"(1) Determine first, ..., whether there is any need to evaluate the flood hazard at the site or structure location being considered."

"(3) Use the following to identify and evaluate the flood hazard:"

"(3A) The 100-year flood as the basic flood:"

"(3B) The flood hazard zone, defined as the area inundated by the basic flood:"

"(3C 2) In the Case Approach, a procedure to assure that any encroachment on the flood plain will permit conveyance of the basic flood without increasing flood heights or velocities to an extent which would cause significant upstream or downstream damage to existing or reasonably anticipated future development:"

"(3D) Floods greater or less than the basic flood as appropriate."

"(4) Determine whether there are existing laws or statutes of the Federal Government, rules or regulations of other Federal agencies, or laws, statutes, ordinances, etc., of State or local governments that provide standards for regulation of the floodplain under study. In cases where those standards are either more stringent than those based on these guidelines, or are applicable to situations or conditions not covered by these guidelines, they should be considered for the evaluation of flood hazard in that area."

"(5) Decide on the conditions under which an evaluation must be made to determine the impacts of including or excluding the use of site in a floodplain. Such evaluation must demonstrate clearly that the use of the site is to the advantage of society as well as to the user of such site."

"(6) Select the floods to be used in a flood hazard evaluation to fit conditions of the area being investigated."

"(10) Determine the effects of proposed highway construction in the floodplain and its vicinity, and of proposed upstream or local flood prevention or control measures, if any, on the elevations of the evaluation floods."

"(12) Adopt the policy of discouraging the construction of those roads, utilities, and other public facilities (except those crossing streams) within the most hazardous portions of the floodplain that aggravate flooding and encourage undesirable developments in that zone."

"(14) Delineate, or ensure the delineation of, on Federally owned properties, the elevation of the 100-year flood, and the elevations and dates of occurrence of floods of record whose magnitudes should be known by the public."

"(15) Encourage State and local agencies to keep a permanent record of information on each floodplain evaluated, the flood hazard evaluation procedure and decisions, the flood prevention or control measures proposed for upstream or local construction, the flood elevation delineations..."

Checklist for Drainage Studies and Reports

(This is a checklist of items to be considered for inclusion in hydraulic studies and reports. Numbers in parenthesis indicate references cited at the end of the checklist).

1. Preliminary drainage surveys[1]

    a. Investigate potential problems

        (1) Flood hazard - land use and development in flood plain, flood hazard studies[2]

        (2) Channel stability - bank stability, bends and meanders, aggradation, degradation, necessity for channel change.

        (3) Effects on the environment, fish and other wildlife, domestic water supplies, recreational resources, etc.

        (4) Debris and ice

        (5) Skew of crossing

    b. Coordination with other agencies

        (1) Permits required

        (2) Existing and proposed water resource projects (PPM 50-4.2 (Volume 6, Chapter 1, Section 1, Subsection 4, of the Federal-Aid Highway Program Manual))

        (3) Possibility of cooperative projects

2. Design

    a. Site data

        (1) Vicinity map

            (a) Purpose - to show proposed highway alinement and reach of river, bends and stream meanders, general flow directions

            (b) Type

                1. USGS quadrangle sheet or map of equal detail

2. Aerial photo

(2) Site map:

(a) Purpose - for use in estimating flood flow distribution; to locate cross sections of stream; to show location of proposed encroachment and structure(s), alinement of piers, skew of crossing, stream controls, existing encroachments, existing highway structures

(b) Type

1. Specially prepared map showing 1- or 2-foot contours, vegetation and manmade improvements

2. In some cases, cross sections normal to floodflow are acceptable in lieu of map. A minimum of three sections are desirable including cross sections upstream, at crossing, and downstream

(3) Existing structures (including relief or overflow structures):

(a) Locate existing structures with respect to proposed crossing or encroachment

(b) Describe each fully, giving-

1. Type, including span lengths and number of spans, bent design, pier orientation, culvert size, number of cells

2. Foundation type (spread footing, piling) founding depth

3. Scour history at abutments and bents, culvert outlets; head cutting; stream aggradation, degradation

4. Cross section beneath structures, noting clearance to superstructure and skew with direction of current during extreme floods

5. Flood history, highwater marks (dates and elevation), nature of flooding (including overtopping), damages and sources of information

6. Damage from abrasion, corrosion, wingwall failure, culvert end failure

(4) Locate and determine elevations of highwater marks along stream, giving dates of occurrence

(a) Describe or list critical flood elevations of interest in evaluating possible damage (record datum used)

(b) Refer to flood hazard studies for area(2)

(5) Comment on drift, ice, nature of streambed, bank stability, bends, meanders, vegetative cover, land use

(6) Photographs showing existing structures, past floods, main channel and flood plain to help in evaluating a location and documenting conditions existing prior to construction

(7) List factors affecting water stages

(a) Highwater from other streams

(b) Reservoirs - existing or proposed and approximate date of construction

(c) Flood control projects (give status)

(d) Tides

(e) Other controls

b. Hydrologic analysis (site inspection should be made by engineer making hydrologic and hydraulic analysis)(3)(7)

(1) List available flood records

(2) Determine drainage area above proposed construction(3)

(3) Evaluate potential for changes in watershed characteristics which would change magnitude of flood peaks; e.g., urbanization, channelization

(4) Plot flood-frequency curve

(5) Plot stage-discharge-frequency curve

(6) Determine distribution of flow and velocities for several discharges or stages in natural channel for existing conditions

c. Hydraulic analysis

(1) Design of bridge waterways[5]

(a) Determine permissible upstream water surface elevations

(b) Compute backwater for various trial bridge lengths and discharges

(c) Select design flood and waterway design (Paragraph 4.c.)

(d) Provide for conveyance of 100-year flood

(e) Estimate scour depth at piers and abutments[6]

(f) Design riprap for bank protection and scour attenuation devices, if required.

(g) Investigate need for spur dikes

(h) Show final layout in plan and profile

<u>1</u>. Show design discharge, elevations, and frequency

<u>2</u>. Show discharge and elevations of 100-year flood

(i) Comment on:

<u>1</u>. Selection of design flood

<u>2</u>. Conveyance of 100-year flood

<u>3</u>. Channel change (if provided)

4. Effects of construction

5. Need for stream controls to protect highway

(2) Design of culverts

(a) Determine allowable headwater elevation

(b) Compute and plot performance curves for trial culvert sizes[4]

(c) Evaluate abrasion and corrosion potential

(d) Select design flood and culvert design (Paragraph 4.c.)

(e) Provide for conveyance of 100-year flood

(f) Evaluate need for debris control

(g) Evaluate need for outlet protection

(h) Investigate need for protection against buoyancy and/or failure by separation at joints[9]

(i) Show final layout in plan and profile

1. Show design discharge, elevations, and frequency

2. Show discharge and elevations of 100-year flood

(j) Comment on:

1. Selection of design flood

2. Conveyance of 100-year flood

3. Channel change (if provided)

4. Effects on stream stability

5. Provision for fish passage

(3) Design of longitudinal encroachments

(a) Determine the effect of proposed encroachment on water-surface profile using various roadway design alternatives

(b) Select design flood and roadway design (Paragraph 4.c.)

(c) Provide for conveyance of 100-year flood

(d) Evaluate effects on scour and deposition in channel

(e) Design embankment, bank and channel protection needed

(f) Show final layout in plan and profile

1. Show design discharge, elevations, and frequency

2. Show discharge and elevations of 100-year flood

(g) Comment on:

1. Selection of design flood

2. Conveyance of 100-year flood

3. Channel change (if provided)

4. Effects on stream stability

5. Effects on stream biology

REFERENCES

1. Guidelines for Hydraulic Considerations in Highway Planning and Location, Volume 1, Highway Drainage Guidelines, AASHTO, 1973.

2. For information regarding flood plain delineation studies, write to: Department of Housing and Urban Development, Federal Insurance Administration, Assistant Administrator for Flood Insurance, 451 Seventh Street, SW, Washington, D.C. 20410.

3. Guidelines for Hydrology, Volume II, Highway Drainage Guidelines, AASHTO, 1973.

4. a. Herr, Lester A. and Bossy, Herbert G., Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular No. 5, Federal Highway Administration, U.S. Government Printing Office, Washington, D.C., 1965, 54 p.

   b. Herr, Lester A. and Bossy, Herbert G., Capacity Charts for the Hydraulic Design of Highway Culverts, Hydraulic Engineering Circular No. 10, Federal Highway Administration, U.S. Government Printing Office, Washington, D.C., 1965, 90 p.

   c. Harrison, L. J., Morris, J. L., Normann, J. M., and Johnson, F. L., Hydraulic Design of Improved Inlets for Culverts, Hydraulic Engineering Circular No. 13, Federal Highway Administration, Washington, D.C., August 1972, 150 p.

5. Bradley, J. N., 1970, Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, Federal Highway Administration, U.S. Government Printing Office, Washington, D.C., 1970, 111 p.

6. Highway Research Board, 1970, Scour at Bridge Waterways, National Cooperative Highway Research Program Synthesis 5, Highway Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418.

7. Flood-frequency analysis, such as those of U.S. Geological Survey or other water-resources agencies, for the region in which the structure is located.

8. Searcy, J. K., Design of Roadside Drainage Channels, Federal Highway Administration, Hydraulic Design Series No. 4, U.S. Government Printing Office, Washington, D.C.

9. Circular Memorandum, G. M. Williams, July 21, 1966, Plans for Pipe Culvert Inlet and Outlet Structures, Federal Highway Administration.

APPENDIX B

RISK MODULE USER'S MANUAL

INTRODUCTION

A computer program called RISK has been developed using FORTRAN programming language to facilitate the computation for the risk analysis described in this volume. The information flow to the RISK module and the logic flow of the module with subroutine flowcharts and descriptions are discussed in the General Description Section. A detailed description of the necessary user-supplied input data along with a sample input data set are included with a definition of variables and a program listing.

GENERAL DESCRIPTION

The RISK module accesses two types of information. The first is information supplied by the FEM hydraulic solution by means of the hydraulic tape and the second is the necessary user-supplied data for the RISK analysis. The information flow of the RISK module is shown in Figure 23.

The RISK module consists of one main calling program, four function routines, and eight subroutines as indicated in Table 24. The detailed logic of the RISK program is shown in Figure 24.

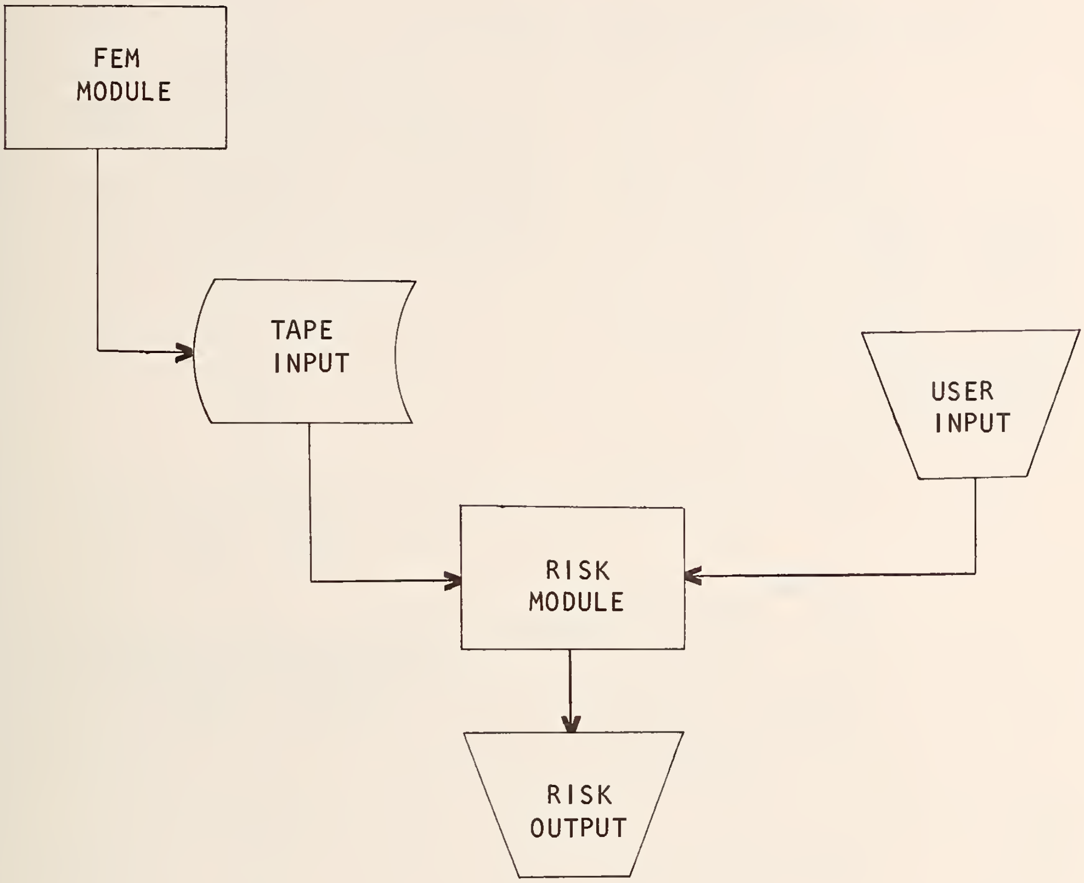


Figure 23 RISK Module Information Flow

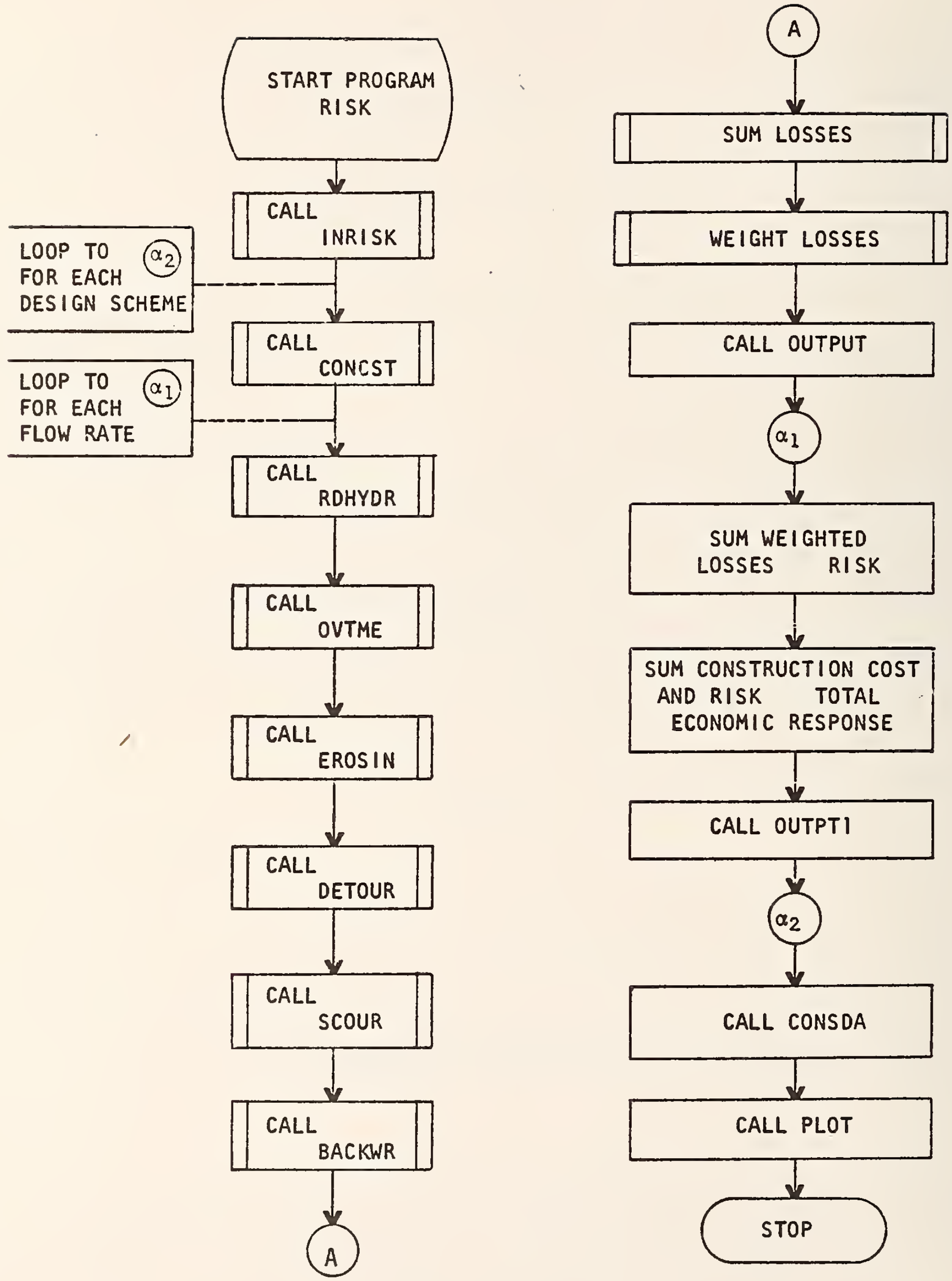


Figure 24 Main Program RISK

Table 24 Program RISK

Main	Functions	Subroutines
RISK	DETOUR	INRISK
	CONCST	RHYDR
	BACKWR	OVTME
	SCOUR	EROSIN
		OUTPUT
		OUTPT1
		CONSDA
		PLOT

Upon entrance to the RISK program the INRISK subroutine is called to read the user-supplied input data. The program flow enters the α_2 loop and the CONCST routine is called to determine the cost of the given bridge configuration being considered. The program then enters the α_1 loop in which a set of flows is considered to evaluate the associated risk components. For each flow considered, the RDHYDR routine is called to read the hydraulic solution provided by the FEM module. Next, the OVTME routine is called to calculate the overtopping time for each embankment section following which the erosion losses and the necessary repair time are determined in the EROSIN routine. Traffic delay losses are then calculated in the DETOUR routine. Following the DETOUR routine, the SCOUR routine is called to determine the scour losses for the given flow with the backwater property damage determined in the BACKWR routine. All of the above losses are then summed and weighted and the OUTPUT routine is called to print the results for each flow. After all flows have been considered the program exits the α_1 loop. All weighted losses are then summed to give the total risk for the considered bridge configuration. The resulting total risk is printed in the OUTPUT1 routine. After all bridge configurations have been considered, the α_2 loop is exited and a consolidated summary of results for all bridge designs is printed in the CONSDA routine. The user has the option to plot the summary results in the PLOT routine. Upon completion of the PLOT routine the program is terminated.

SUBROUTINE INRISK

INRISK is a subroutine called by the main program RISK. This subroutine reads and echoes all user input. The necessary user input is shown in the flowchart in Figure 25. The detailed input card formats are discussed in subsequent sections.

FUNCTION CONCST

This function evaluates the total cost of the particular bridge superstructure and substructure by means of a regression equation or a user specified function. The embankment fill volume is calculated for each embankment section. The fill volumes are then added to obtain a total embankment fill volume. This total fill volume is then converted to a dollar value on the basis of a per unit fill volume cost for embankment fill. The length of roadway is calculated for both embankments and over the bridge. The roadway cost is determined by multiplying the roadway length by a per unit length cost factor. The bridge costs, the embankment fill costs, and the roadway costs are summed and converted to an equivalent annual cost using a specified project life and interest rate by the capital recovery factor. If the bridge has piles which are driven to bedrock to prevent scour damage (TYP=0), this additional cost is added to the bridge construction cost computed above. The flowchart for this function is shown in Figure 26.

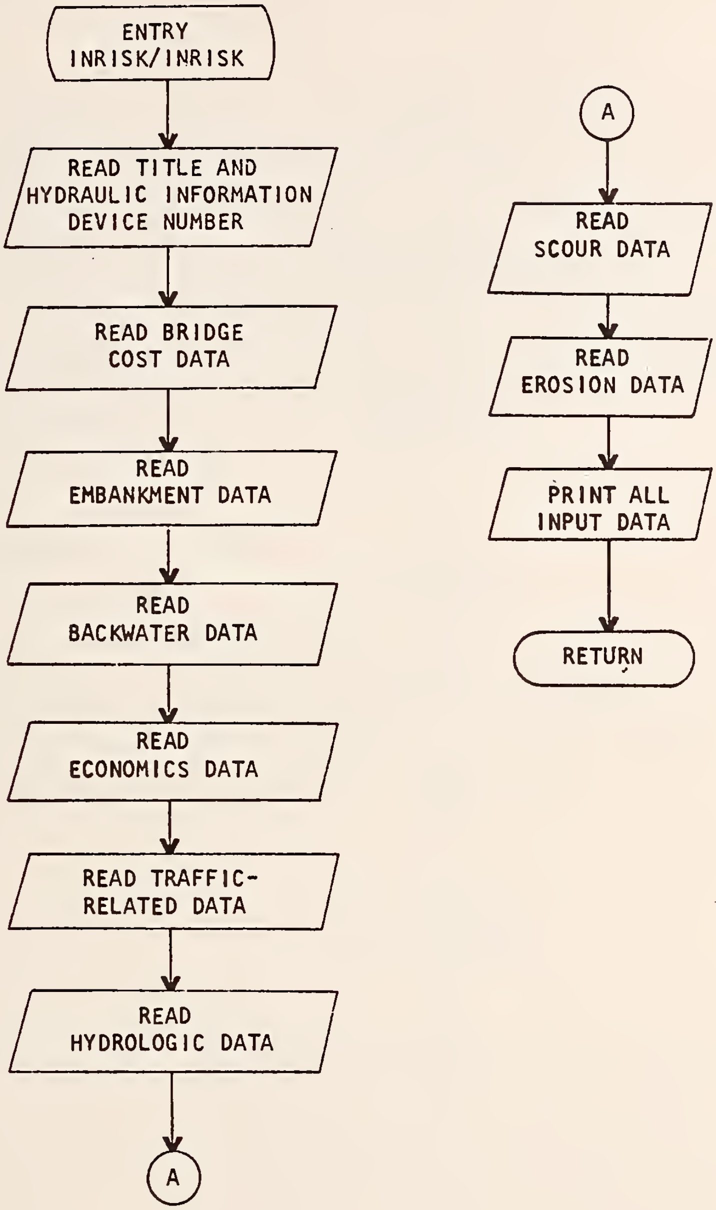


Figure 25. Subroutine INRISK Flowchart

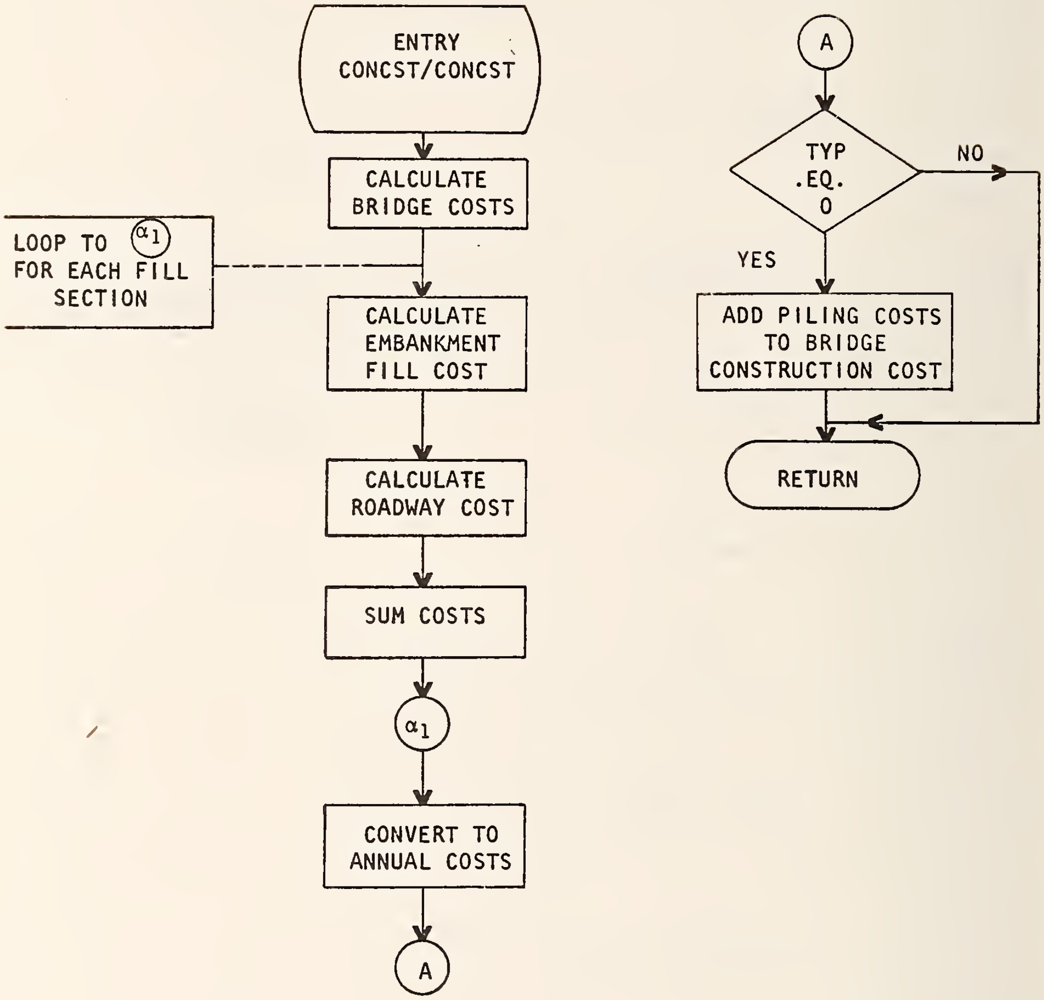


Figure 26. Construction Cost Subroutine

SUBROUTINE RDHYDR

This subroutine accesses the hydraulic tape for each flow-embankment opening combination. An indicator (ICK) to represent whether overtopping of the embankments has occurred is read along with the number of possible overtopping nodes, NP. The x and z velocity components of flow, water surface depth, and water surface elevation are then read from the hydraulic tape for each overtopping node in the particular configuration. The flowchart for this subroutine is shown in Figure 27.

SUBROUTINE OVTME

Subroutine OVTME calculates the amount of time an embankment section was overtopped. It then examines the overtopping time for each embankment section and the bridge itself to determine the maximum overtopping time. The flowchart is shown in Figure 28 .

SUBROUTINE EROSIN

The EROSIN subroutine calculates the amount of erosion by embankment section. It also calculates the roadway loss in each section of the embankment. It determines a total percentage of fill volume lost by erosion and uses this percentage to determine the time to repair the embankments. The losses due to erosion, namely, fill volume losses and roadway losses, are summed and multiplied by a weighting factor to determine the erosion risk component. The flowchart for this subroutine is shown in Figure 29 .

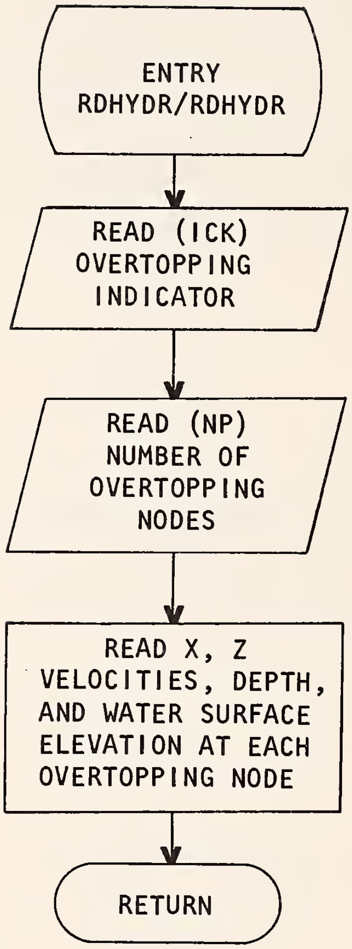


Figure 27. Subroutine RDHYDR Flowchart

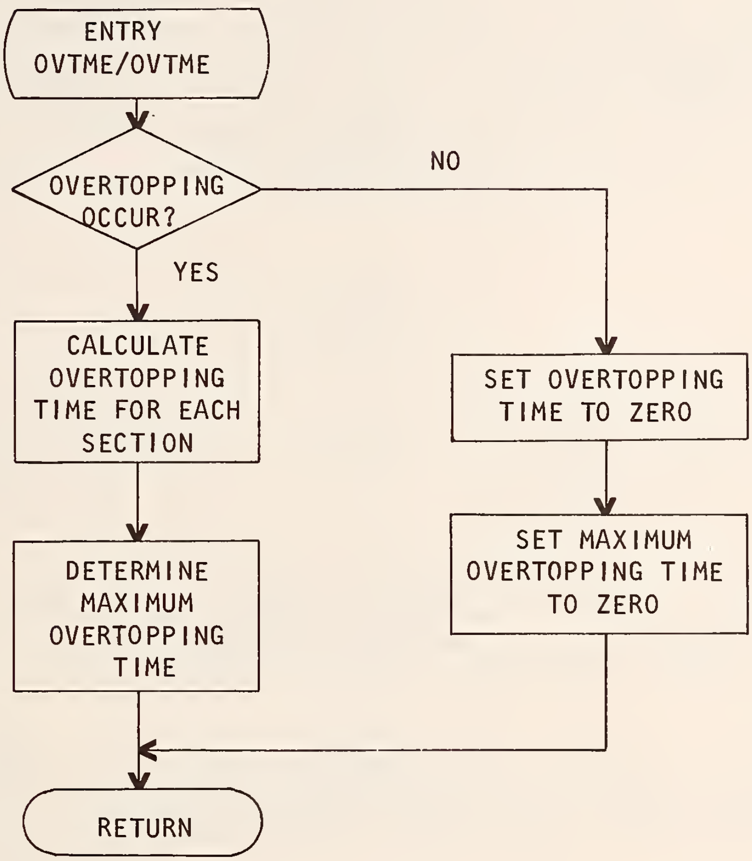


Figure 28. Subroutine OVTME Flowchart

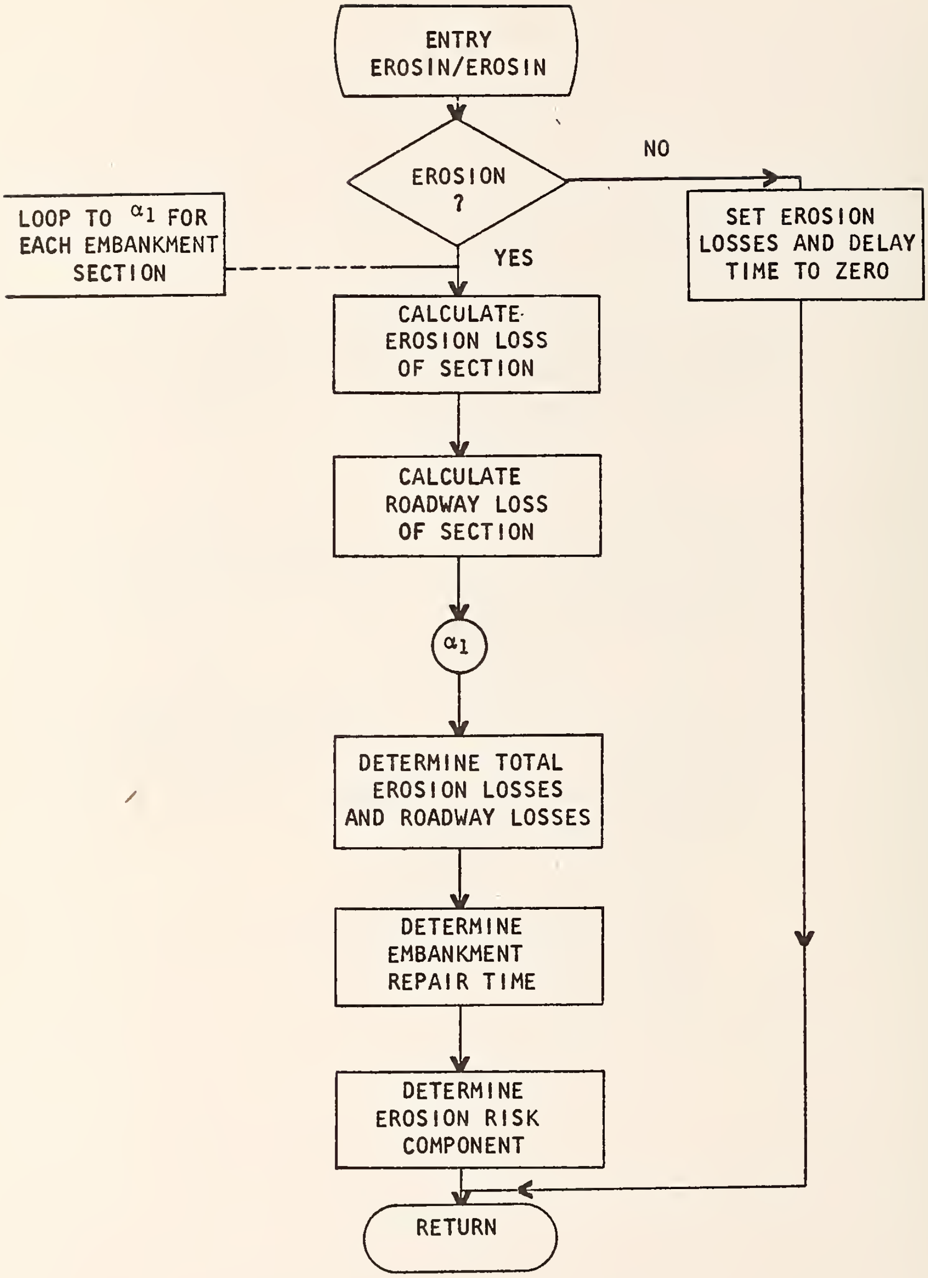


Figure 29 . Subroutine EROSIN Flowchart

FUNCTION DETOUR

The function DETOUR calculates the cost of traffic delay caused by embankment overtopping. Traffic-related losses are divided into four categories: 1) detour travel cost, 2) detour accident costs, 3) unexpected obstacle cost, and 4) cost of time delay. All four traffic-related losses are summed and multiplied by a weighting factor to determine the DETOUR risk component. The flowchart for this function is shown in Figure 30.

FUNCTION SCOUR

This function computes the pier scour damage caused by flooding of each bridge and embankment configuration. Three types of bridge foundations are considered:

1. Piles are driven to bedrock and no scour damage is assumed to occur. The data input refers to this type as Type "0". The cost of piles should be added to the bridge construction cost.

2. The second type has either the footing on bedrock or countermeasures being taken to prevent pier scour. Again pier scour damages are assumed negligible. Data input refers to this type as Type "1".

3. The third type considers piles driven into alluvial soil where the possibility of scour is a certainty. Data input refers to this type as Type "2". Maximum scour, taken from input data, is compared with the pier scour depth calculated by the function SCOUR. This calculation is derived from Laursens "Scour at Bridge Crossings",(15).

If the scour depth is greater than the maximum scour depth the bridge is assumed lost, if not a scour repair cost is determined. All scour costs incurred are multiplied by a weighting factor to determine the scour risk component. The flowchart of the routes is shown in Figure 31 This function also estimates bridge damage due to submergence and includes it as a component of the initial scour damage.

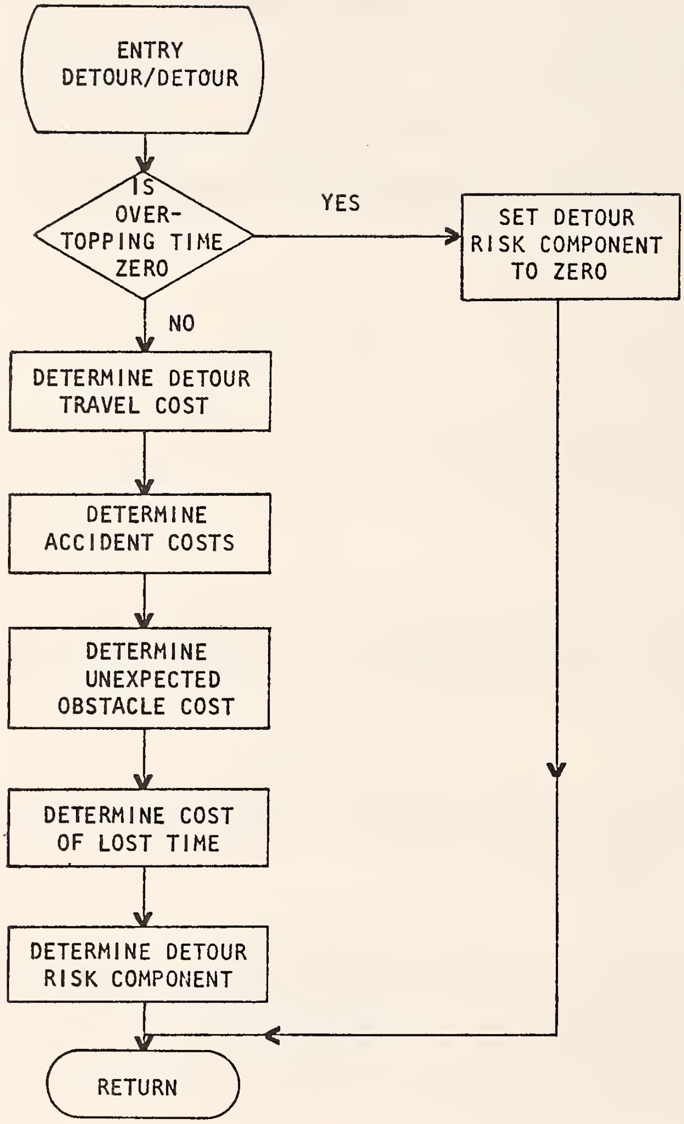


Figure 30. Function DETOUR Flowchart

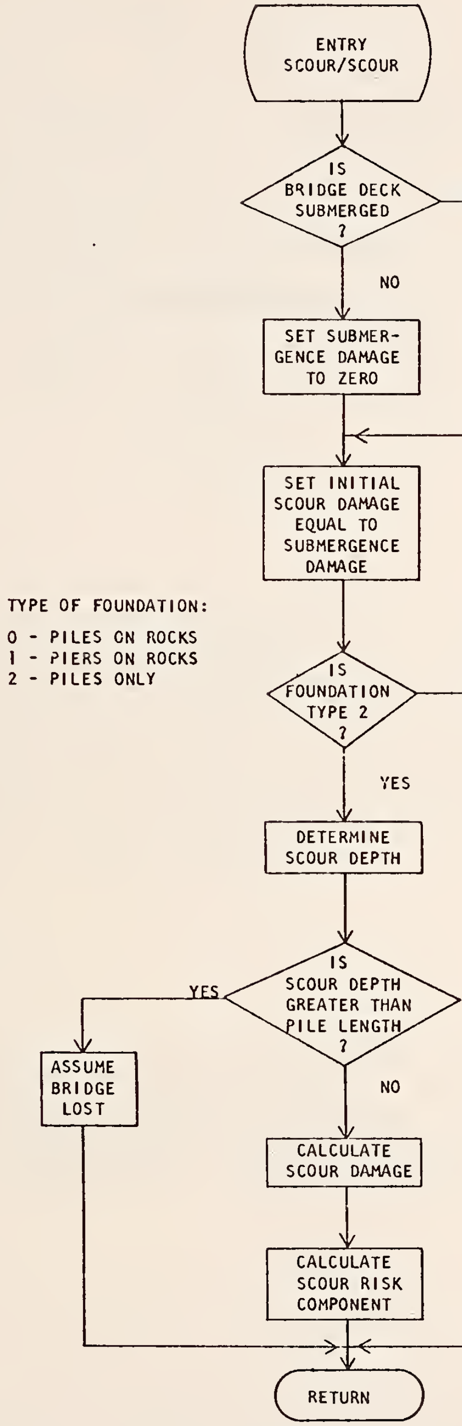


Figure 31. Function SCOUR Flowchart

FUNCTION BACKWR

This function returns the backwater damage due to a particular flood event for a particular bridge configuration. The actual backwater damage calculations are performed manually by the analyst using the normal runs of the FEM model and consulting the corresponding runs for each particular bridge configuration. The results of these manual calculations are input to subroutine INRISK which passes the information to BACKWR. BACKWR selects the appropriate backwater damage and multiplies the damage by a weighting factor and returns the result to the main RISK program as the backwater risk component. The flowchart is shown in Figure 32 .

SUBROUTINE OUTPUT

This subroutine prints for the given bridge configuration the overtopping time and the time duration of the resulting delay for the given storm event. The detour, scour, erosion, and backwater risk components and the total risk component associated with the storm are then printed. The flowchart for this subroutine is shown in Figure 33 .

SUBROUTINE OUTPUT1

This subroutine prints for the given bridge configuration the results of the risk analysis. The total economic response, the construction costs and the total risk are printed. The flowchart is shown in Figure 34.

SUBROUTINE CONSDA

This subroutine prints a consolidated table of the risk analysis results for each bridge configuration. The decision variables, the total economic response, construction cost and total risk are output for each bridge design. The flow and return frequency for all storms used in the

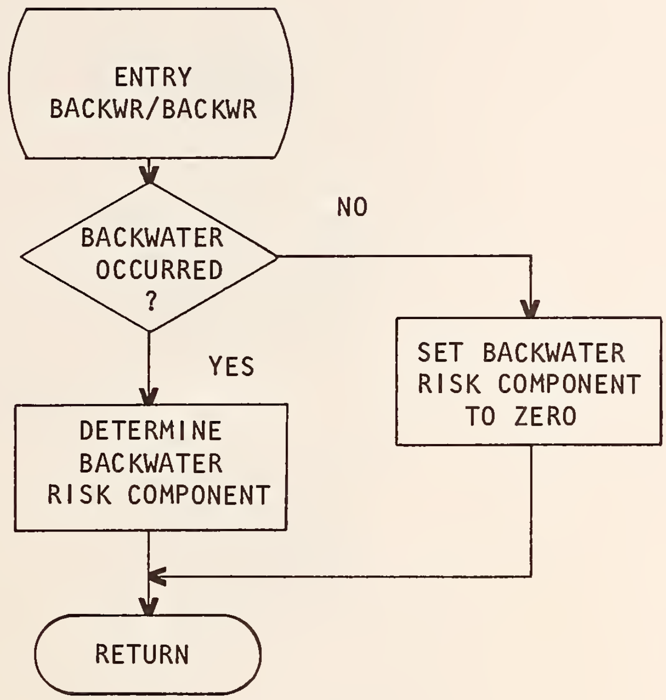


Figure 32. Function BACKWR Flowchart

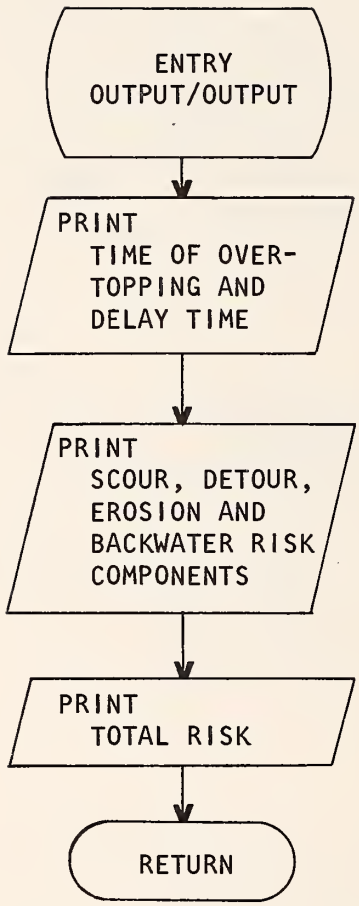


Figure 33 . Subroutine OUTPUT Flowchart

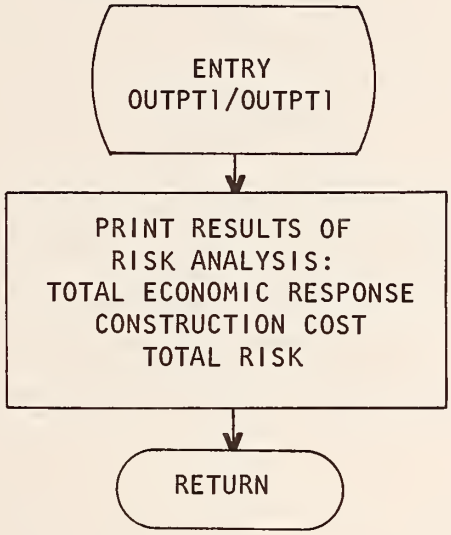


Figure 34. Subroutine OUTPT1 Flowchart

risk analysis are then printed. The project life and interest rate for calculating the equivalent annual cost of the bridge are output next. This subroutine is shown in the flowchart in Figure 35 .

SUBROUTINE PLOT

The PLOT subroutine provides the model users with the option to obtain plots of total economic response versus embankment height for a fixed bridge length, and total economic response versus bridge length for a fixed embankment height. The user may bypass the plot option if desired. The flowchart for this subroutine is shown in Figure 36 .

USER INPUT DATA DESCRIPTION

The following description indicates the exact FORTRAN card format to be used by the RISK module. All user-supplied input is accessed on logical unit 5. In the preparation of card input data all integer variables should be right justified in the card columns indicated.

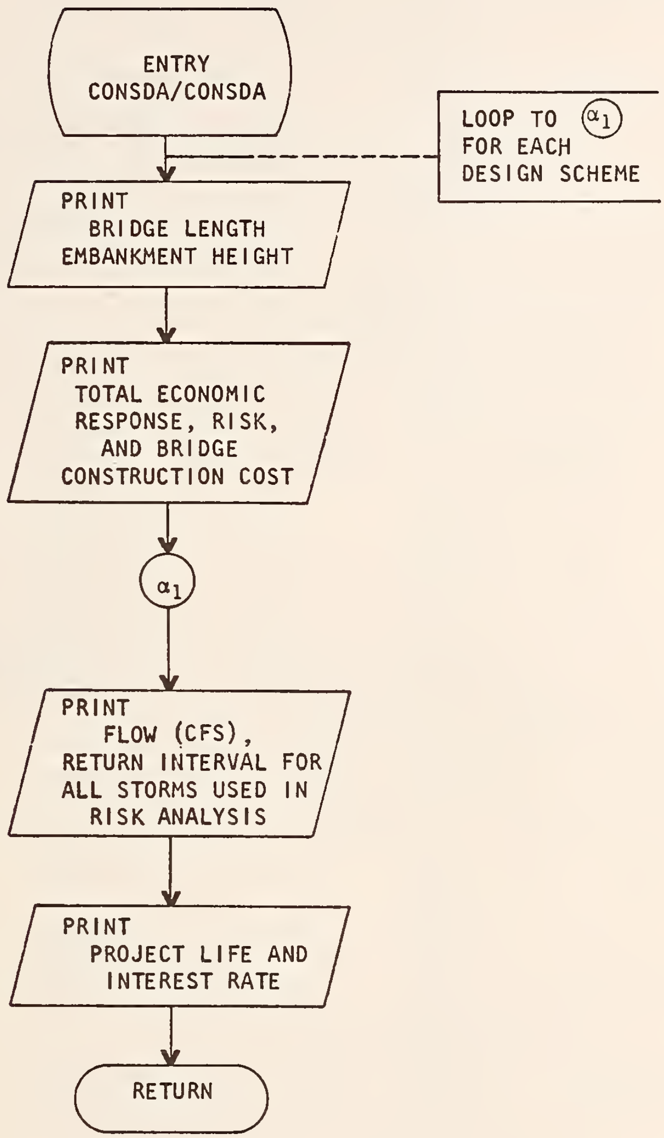


Figure 35. Subroutine CONSDA Flowchart

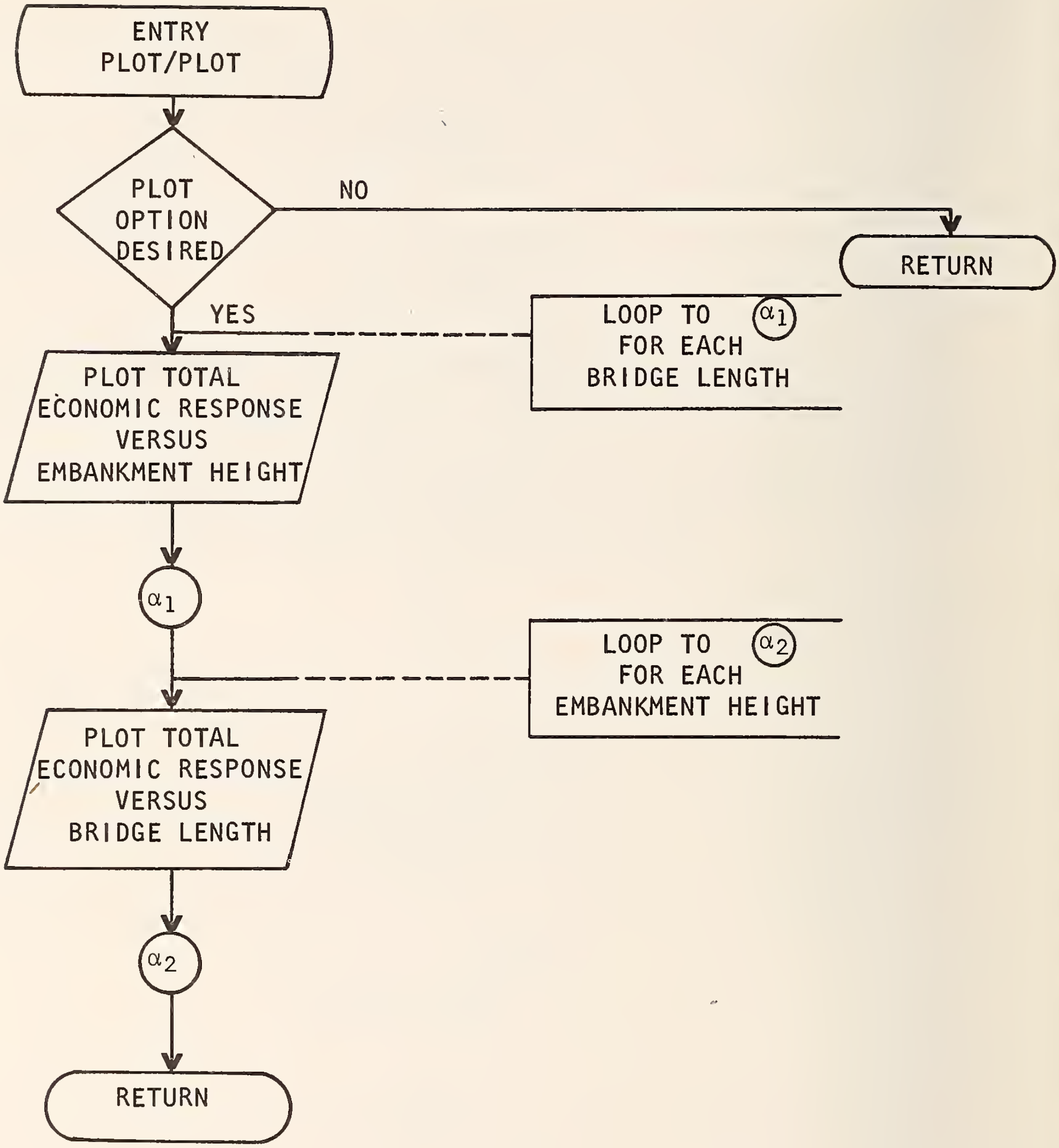


Figure 36. Subroutine PLOT Flowchart

Card Sequence: Number of Cards	Card Columns	FORTRAN Name	Format Type	Description of Input Value
1:1	5-80	TITLE(1,20)	A	Header Information
1:2	5-80	TITLE(2,20)	A	Header Information
2:1	21-25	ITYPE	I	Input Tape File
2:1	26-30	IBC	I	Bridge Cost Function: 1--User Supplied Bridge Cost Function 0--Model Supplied Bridge Cost Function
3:1	1-10	NLEN	I	Number of Bridge Lengths
3:2	1-10	FLEN(1)	F	Bridge Length 1
3:2	11-20	FLEN(2)	F	Bridge Length 2
3:2	21-30	FLEN(3)	F	Bridge Length 3
3:2	31-40	FLEN(4)	F	Bridge Length 4
3:2	41-50	FLEN(5)	F	Bridge Length 5
4:1*	11-20	B(1,I)	E	Coefficient for Bridge Superstructure Cost
4:2	11-20	B(2,I)	E	Coefficient 2 for Bridge Superstructure Cost
4:3	11-20	B(3,I)	E	Pier, Footing and Abutment Costs
4:4	11-20	B(4,I)	E	Spur Dike Cost
5:1	11-20	RWCST	F	Dollar Cost/Foot for Paved Roadway
5:1	21-30	CY	F	Dollar Cost/Yard^3 of Fill
5:1	31-40	VSLP	F	Upstream Embankment Slope in %
5:1	41-50	VSLP	F	Downstream Embankment Slope in %
5:1	51-60	BWID	F	Average Bridge Width (ft)
6:1	1-10	NFLFR	I	Number of Flows
6:2	1-10	FLFR(1,1)	F	Flow 1
6:2	11-20	FLFR(1,2)	F	Weight 1

*Repeated for each candidate bridge design for IBC=1. Ignore card group 3 if IBC=0.

Card Sequence: Number of Cards	Card Columns	FORTRAN Name	Format Type	Description of Input Values
6:2	21-30	FLFR(2,1)	F	Flow 2
6:2	31-40	FLFR(2,2)	F	Weight 2
6:2	41-50	FLFR(3,1)	F	Flow 3
6:2	51-60	FLFR(3,2)	F	Weight 3
6:2	61-70	FLFR(4,1)	F	Flow 4
6:2	71-80	FLFR(4,2)	F	Weight 4
6:3	1-10	FLFR(5,1)	F	Flow 5
6:3	11-20	FLFR(5,2)	F	Weight 5
6:3	21-30	FLFR(6,1)	F	Flow 6
6:3	31-40	FLFR(6,2)	F	Weight 6
7:1*	1-5	NMB(4)	I	Number of Different Embankments
8:1*	11-20	EMB(4,1)	F	Delta Embankment Height 1
8:2	21-30	EMB(4,2)	F	Delta Embankment Height 2
8:3	31-40	EMB(4,3)	F	Delta Embankment Height 3
9:1*	1-5	NC(4)	I	Bridge Clearance
9:1*	6-15	CEN(4)	F	Number of Nodes to Center of Bridge
10:1*	1-5	NNDS(4)	I	Number of Overtopping Nodes
11:1*	5-10	NVP(4,40)	I	Overtopping Nodes
11:1	11-20	BTEL(4,40)	F	Bottom Embankment Elevations
11:1	21-30	BTL(4,40)	F	Distance Between Embankment Nodes
11:1	31-40	WELEV(4,40)	F	Top Embankment Elevations

*Card Groups 7 through 11 are repeated for each bridge length.

Card Sequence: Number of Cards	Card Columns	FORTRAN Name	Format Type	Description of Input Values
$12{:}60_{max}$	21-40	DAM(60)	E	Backwater Damages

Note: Expected order is by bridge opening, embankment height and flow.

Opening	Embankment Ht	Flow
1	1	1
1	1	2
1	2	1
1	2	2
2	1	1
2	1	2
2	2	1
2	2	2

Thus for 2 flows, 2 openings, and 2 embankment heights, 8 damage values would be expected in the above order. Damages for the nonconstricted case (no bridge in place) are listed first by flow.

12:61	1-3	END	A	Indicates End of Damage Information
13:1	11-20	PLIFE	F	Project Life (yr)
13:1	21-30	RATE	F	Interest Rate (%)
13:1	31-40	TC	V	Value of Time ($/hr)
14:1	21-30	TRF(1)	F	Average Traffic Level (Vehicle/day)
14:2	21-30	TRF(2)	F	Passenger Car Fraction of Total Traffic Level (0-1)
14:3	21-30	TRF(3)	F	Commercial Delivery Vehicle Fraction of Total Traffic Level (0-1)
14:4	21-30	TRF(4)	F	Single Unit Truck Fraction of Total Traffic Level (0-1)
14:5	21-30	TRF(5)	F	Gasoline Truck Fraction of Total Traffic Level (0-1)

Card Sequence: Number of Cards	Card Columns	FORTRAN Name	Format Type	Description of Input Values
14:6	21-30	TRF(6)	F	Diesel Semitrailers Fraction of Total Traffic Level (0-1)
14:7	21-30	TRF(7)	F	Normal Travel Distance (Miles)
14:8	21-30	TRF(8)	F	Normal Route Speed (mph)
15:1	1-10	DRATN	F	Normal Death Rate (Deaths/100 Million Vehicle Miles)
15:1	11-20	PERINN	F	Number of Personal Injuries/Death-Normal Case
15:1	21-30	PRODAN	F	Number of Property Damages/Death-Normal Case
15:1	31-40	PERINU	F	Number of Personal Injuries/Death-Unexpected Obstacle Case
15:1	41-50	PRODAU	F	Number of Property Damages/Death-Unexpected Obstacle Case
15:1	51-60	DRATU	F	Unexpected Obstacle Death Rate Multiplier (Deaths Unexpected Obstacle/Normal Rate)
15:1	61-70	DEATH	F	Cost of Death
15:1	71-80	CPERI	F	Cost of a Personal Injury
15:2	1-10	CPRODM	F	Cost of Property Damage
16:1	21-30	WCL	F	Length of Longest Watercourse (Miles)
16:1	31-40	WCH	F	Elevation Difference of Longest Watercourse (ft)
17:1	1-10	TYP	F	0 - Piles Rest on Solid Rock 1 - Footing on Solid Rock 2 - Solid Rock not Found
17:1	11-20	CSCR	F	\$Cost/ft of Pile for TYP-0 \$Cost/ft of Scour for TYP-2

Card Sequence: Number of Cards	Card Column	FORTRAN Name	Format Type	Description of Input Value
17:1	21-30	HSCR	F	Maximum Scour Depth for TYP-2
17:1	31-40	NSCR	I	Node at Which Velocity is Used for Scour Calculations
17:1	41-50	WSCR	F	Width of Rectangular Pier Facing Upstream
17:1	51-60	NPILE	I	Number of Piles for TYP-0
17:1	61-70	DPILE	F	Average Depth of Piles for TYP-0
17:1	71-80	CETA	F	Loss per Foot of Bridge Submergence
18:1	1-10	VINCP	F	Incipient Velocity for Erosion (ft/sec)
18:1	11-20	WT	F	Specific Weight of Embankment (lbs/ft^3)
18:1	21-30	FAC	F	Cost Adjustment Factor
18:1	31-40	TTIP	F	Inspection Time (hrs)
19:1	1-4	XAXIS	F	XAXIS=9999 No. of Plots Desired X=Coordinate of Origin
19:2	7-10	YAXIS	F	Y=Coordinate of Origin
19:3	13-14	ITEL	I	Always 1
19:4	14-16	IJOIN	I	1-Join Points on Plot 0-Don't Join Points on Plot
20:1*	1-40	TOP	A	Top of Plot Information
20:2	1-40	BOTTOM	A	Bottom of Plot Information
20:3	1-50	SIDE	A	Side of Plot Information
21:1**	1-40	TOP	A	Top of Plot Information
21:2	1-40	BOTTOM	A	Bottom of Plot Information
21:3	1-50	SIDE	A	Side of Plot Information

*Include card group 20 for each bridge length.

**Include card group 21 for each embankment height.

A listing of the trial data set for the example problem discussed in Chapter IV of this volume is shown in Table 25 as an aid to the model user in formulating his own input data set.

DEFINITION OF PROGRAM VARIABLES

The following variables are passed from the FEM module to the RISK module by means of the hydraulic tape.

	ICK	Overtopping indicator (1 - Overtopping, 2 - No overtopping).
	NP	Number of overtopping nodes in the system.
	VEL(1,20)	X = Velocity of flow at all overtopping nodes in the system.
VEL (4,20)	VEL(2,20)	Z = Velocity of flow at all overtopping nodes in the system.
	VEL(3,20)	Depth of all overtopping nodes in the system.
	VEL(4,20)	Water surface elevation at all nodes in the system.

The following variables are used in the RISK module alone:

NI	Input file number.
NO	Output file number.
ITYPE	Tape number of the hydraulic tape.
IBC	Bridge cost function option (1 - User Supplied, 0 - Model Supplied)
TITLE(2,20)	Heading information.

	B(*,1)	Intercept for bridge superstructure cost.
B(4,4)	B(*,2)	Slope for bridge superstructure cost.
	B(*,3)	Pier, footing and abutment cost.
	B(*,4)	Spur dike cost.
	CY	Embankment fill cost ($/cu yd).
	RWCST	Roadway cost ($/ft).
	BWID	Bridge width (ft).
	USLP	Upstream embankment slope (%).
	DSLP	Downstream embankment slope (%).
	NC(4)	Number of nodes to the bridge.
	CEN(4)	Bridge clearance (ft).
	NLEN	Number of bridge lengths.
	FLEN(5)	Bridge lengths (ft).
FLFR (6,2)	FLFR(6,1)	Flow (cfs).
	FLFR(6,2)	Return frequency weights.
	NRLFR	Number of flows.
	NEMB(4)	Number of embankment heights for each bridge length.
	EMB(4,3)	Delta embankment heights for each bridge length.
	NNDS(4)	Number of overtopped nodes (overtopped nodes are also embankment section nodes).
	NUP(4,40)	Overtopping and embankment nodes.
	BTEL(4,40)	Bottom of embankment elevations.
	BTL(4,40)	Distance between embankment and overtopping nodes.
	WELEV(4,40)	Top of embankment elevations.
	NRISK	Number of backwater damages.
	DAM(60)	Backwater damages.
	PLIFE	Projected life (yr).
	RATE	Interest rate.
	TC	Value of time ($/hr).

* Repeated for each bridge design to be considered.

	DRATN	Number of deaths/100 x 10^6 vehicle miles.
	PERINN	Number of personal injuries/death.
	PRODAN	Number of property damages/death.
	DRATU	Death rate multiplier for obstacles (death obstacles/deaths normally).
	PRODAU	Number of property damages, obstacle case/death.
	PERINU	Number of personal injuries, obstacle case/death.
	DEATH	Average cost of death by accident.
	CPERI	Average cost of personal injury.
	CPRODM	Average cost of property damage.
	TRF(1)	Average traffic level (vehicles/day).
	TRF(2)	Passenger car traffic level fraction (0-1).
	TRF(3)	Commercial delivery vehicle traffic level fraction (0-1).
	TRF(4)	Single unit truck traffic level fraction (0-1).
TRF(11)	TRF(5)	Gasoline truck traffic level fraction (0-1).
	TRF(6)	Diesel semitrailer traffic level fraction (0-1).
	TRF(7)	Normal travel distance (miles).
	TRF(8)	Normal route speed (mi/hr).
	TRF(9)	Detour travel distance (miles).
	TRF(10)	Detour travel speed (mi/hr).
	TRF(11)	Average occupancy rate ($/persons/vehicle).
	WCL	Length of longest watercourse (miles).
	TYP	Type of scour (0 - Piles rest on solid rock; 1 - Footing on solid rock, no scour; 2 - Solid rock not found).
	CSCR	Cost per foot of pier for TYP-0.
	CSCR	Cost per foot of scour for TYP-2.

HSCR	Maximum allowable scour depth for TYP-2.
NSCR	Node at which velocity is used for scour calculations.
WSCR	Width of rectangular pier facing upstream.
NPILE	Number of piles for TYP-0.
DPILE	Depth of piles for TYP-0.
CETA	Damage ($) per foot of bridge submergence.
VINCP	Incipient velocity for erosion (ft/sec).
WT	Specific weight (lb/cu ft) of embankment soil.
FAC	Cost adjustment factor.
TTIP	Inspection time (hr).

Table 25 Trial Data Set

```
UNLABELED OLDPL              MASTER AUDIT, IDENT CARD TOTAL           UPDATE V1.2          09/20/74  14.22.14.        PAGE   1

         LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN RISKD

RISKD    *DECK RISKD                                                                       RISKD        1      A
RISKD         RISK FACTOR ANALYSIS MODEL.....AUGUST 1974                                   RISKD        2      A
RISKD         TALLAHALLA CREEK AT WALDRUP, MISSISSIPPI                                     RISKD        3      A
RISKD                               7                                                      RISKD        4      A
RISKD                 4.830E3                                                              RISKD        5      A
RISKD                                                                                      RISKD        6      A
RISKD                                                                                      RISKD        7      A
RISKD                                                                                      RISKD        8      A
RISKD                 1.547E3                                                              RISKD        9      A
RISKD                                                                                      RISKD       10      A
RISKD            58.          2.          67.          67.       108.                      RISKD       11      A
RISKD           4                                                                          RISKD       12      A
RISKD           0.       300.       500.       1000.                                       RISKD       13      A
RISKD           4                                                                          RISKD       14      A
RISKD      16200.     .01      19700.     .02      23500.      .01       27500.     .01    9/20/74      1      A
RISKD        1                                                                             RISKD       16      A
RISKD                    0.                                                                RISKD       17      A
RISKD        6      10.                                                                    RISKD       18      A
RISKD        8                                                                             RISKD       19      A
RISKD           158      309.0        0.       315.                                        RISKD       20      A
RISKD           147      307.7      365.       315.                                        RISKD       21      A
RISKD           136      306.5      365.       315.                                        RISKD       22      A
RISKD           125      305.7      220.       315.                                        RISKD       23      A
RISKD           114      305.0      220.       315.                                        RISKD       24      A
RISKD           104      300.0      320.       315.                                        RISKD       25      A
RISKD           115      304.0      330.       315.                                        RISKD       26      A
RISKD           126      308.0      330.       315.                                        RISKD       27      A
RISKD        3                                                                             RISKD       28      A
RISKD                    0.        -5.         5.                                          RISKD       29      A
RISKD        6      10.                                                                    RISKD       30      A
RISKD        8                                                                             RISKD       31      A
RISKD           158      309.0        0.       315.                                        RISKD       32      A
RISKD           147      307.7      365.       315.                                        RISKD       33      A
RISKD           136      306.5      365.       315.                                        RISKD       34      A
RISKD           125      305.5      120.       315.                                        RISKD       35      A
RISKD           114      304.6      120.       315.                                        RISKD       36      A
RISKD           104      300.0      520.       315.                                        RISKD       37      A
RISKD           115      304.0      330.       315.                                        RISKD       38      A
RISKD           126      308.0      330.       315.                                        RISKD       39      A
RISKD        3                                                                             RISKD       40      A
RISKD                    0.        -5.         5.                                          RISKD       41      A
RISKD        6      10.                                                                    RISKD       42      A
RISKD        8                                                                             RISKD       43      A
RISKD           158      309.0        0.       315.                                        RISKD       44      A
RISKD           147      307.5      265.       315.                                        RISKD       45      A
RISKD           136      306.0      265.       315.                                        RISKD       46      A
RISKD           125      306.3      107.5      315.                                        RISKD       47      A
RISKD           114      306.5      107.5      315.                                        RISKD       48      A
RISKD           104      307.0     1020.0      315.                                        RISKD       49      A
RISKD           115      307.5      192.5      315.                                        RISKD       50      A
RISKD           126      308.0      192.5      315.                                        RISKD       51      A
RISKD                                          54E2                                        RISKD       52      A
```

These model inputs have been revised and are to be replaced with revised card groups 2 and 3. Consult input data section.

These model inputs have been changed.

Table 25 . Trial Data Set (Cont.)

```
UNLABELED OLDPL              MASTER AUDIT, IDENT CARD TOTAL             UPCATE V1.2          09/17/74  15.29.02.        PAGE   2

         LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN RISKD

RISKD                                     75E2                                               RISKD       53       A
RISKD                                     94E2                                               RISKD       54       A
RISKD                                    113E2                                               RISKD       55       A
RISKD                                    100E2                                               RISKD       56       A
RISKD                                    133E2                                               RISKD       57       A
RISKD                                    152E2                                               RISKD       58       A
RISKD                                    173E2                                               RISKD       59       A
RISKD                                     82E2                                               RISKD       60       A
RISKD                                    109E2                                               RISKD       61       A
RISKD                                    137E2                                               RISKD       62       A
RISKD                                    156E2                                               RISKD       63       A
RISKD                                     34E2                                               RISKD       64       A
RISKD                                     72E2                                               RISKD       65       A
RISKD                                    115E2                                               RISKD       66       A
RISKD                                     64E2                                               RISKD       67       A
RISKD                                     82E2                                               RISKD       68       A
RISKD                                    109E2                                               RISKD       69       A
RISKD                                    139E2                                               RISKD       70       A
RISKD                                    169E2                                               RISKD       71       A
RISKD                                     65E2                                               RISKD       72       A
RISKD                                     89E2                                               RISKD       73       A
RISKD                                    113E2                                               RISKD       74       A
RISKD                                    138E2                                               RISKD       75       A
RISKD                                     30E2                                               RISKD       76       A
RISKD                                     43E2                                               RISKD       77       A
RISKD                                     83E2                                               RISKD       78       A
RISKD                                    111E2                                               RISKD       79       A
RISKD                                     65E2                                               RISKD       80       A
RISKD                                     89E2                                               RISKD       81       A
RISKD                                    113E2                                               RISKD       82       A
RISKD                                    139E2                                               RISKD       83       A
RISKD    END                                                                                 RISKD       84       A
RISKD                100.       7.       2.73                                                RISKD       85       A
RISKD                       16000.                                                           RISKD       86       A
RISKD                          .85                                                           RISKD       87       A
RISKD                          .01                                                           RISKD       88       A
RISKD                          .02                                                           RISKD       89       A
RISKD                          .03                                                           RISKD       90       A
RISKD                          .09                                                           RISKD       91       A
RISKD                          4.5                                                           RISKD       92       A
RISKD                          55.                                                           RISKD       93       A
RISKD                          18.                                                           RISKD       94       A
RISKD                          40.                                                           RISKD       95       A
RISKD                          1.7                                                           RISKD       96       A
RISKD      5.5     30.     300.      1000.      150.      15.     50000.    2000.            RISKD       97       A
RISKD     400.                                                                               RISKD       98       A
RISKD                          17.       53.                                                 RISKD       99       A
RISKD          I                                                                             RISKD      100       A
RISKD        3.5     128.       2.        2.                                                 RISKD      101       A
RISKD             2 1                                                                        RISKD      102       A
RISKD    TOTAL ECONOMIC RESPONSE 500 FT. BRIDGE                                              RISKD      103       A
RISKD    EMBANKMENT HEIGHT (TEN*10=3)                                                        RISKD      104       A
```

Table 25 . Trial Data Set (Cont.)

```
UNLABELED OLDPL              MASTER AUDIT, IDENT CARD TOTAL          UPDATE V1.2          09/17/74  15.29.02.      PAGE   3

          LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN RISKD

RISKD    TER                                                                              RISKD         105        A
RISKD    TOTAL ECONOMIC RESPONSE 1000 FT. BRIDGE                                          RISKD         106        A
RISKD    EMBANKMENT HEIGHT (TER*10=3)                                                     RISKD         107        A
RISKD    TER                                                                              RISKD         108        A
RISKD    TOTAL ECONOMIC RESPONSE 315 FT.EMBK. HT.                                         RISKD         109        A
RISKD    BRIDGE LENGTH (TER*10=3)                                                         RISKD         110        A
RISKD    TER                                                                              RISKD         111        A
```

PROGRAM LISTING

The FORTRAN IV program for the RISK module follows. The program was run on the CDC 6400 unit at the Naval Ship Research and Development Center computer facilities, Carderock, Maryland.

```
      PROGRAM RISK (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
     1   TAPE7)
      COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),
     1NNDS(4),RELEV(4,40),NUP(4,40)
      COMMON/ICOUNT/IDAM
      DIMENSION TIME(40)
      DIMENSION R(3,3)
      DIMENSION S(3,3)
      CALL INRISK
      IDAM=0
      DO 250 I1=2,NLEN
      LIM=NMB(I1-1)
      DO 240 I2=1,LIM
      CNSTR=CONCST(I1,I2)
      COSTR=0.
      DO 230 I3= 1,NFLFR
      IDAM=IDAM+1
      CALL ROHYDR(I1)
C  FIND TIME OF OVERTOPPING
      CALL OVTME(I1,I2,I3,XAM,TIME)
C   FIND  EROSION
      CALL EROSIN(I1,I2,I3,TIME,ERS,TRP)
C     CALL TRAFFIC DETOUR
      DTR=DETOUR(I1,I2,I3,XAM,TRP)
C  FIND COST OF BRIDGE SCOUR
      SCR=SCOUR(I1,I2,I3,CNSTR)
C  FIND COST OF BACKWATER DAMAGE
      BKR=BACKWR(I1,I2,I3)
      CALL OUTPUT(I1,I2,I3,XAM,TRP,COSTR,DTR,SCR,ERS,BKR)
  230 CONTINUE
      CALL OUTPT1(I1,I2,COSTR,CNSTR,R,S)
  240 CONTINUE
  250 CONTINUE
      CALL CONSDA(R,S)
      CALL PLOT(R)
      STOP 22
      END
```

```
SUBROUTINE  CONSDA                                   CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.      PAGE    1

            SUBROUTINE CONSDA(R,S)                                                          9/6/74      4
            COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),                     9/6/74      5
           1NNDS(4),RELEV(4,40),NUP(4,40)                                                   9/6/74      6
            COMMON/DUMMY/TITLE(2,20),NI,NO,ITPE,B(6)                                        9/6/74      7
            COMMON/ECON/PLIFE,RATE,AINCUM                                                   9/6/74      8
            DIMENSION R(3,3),S(3,3)                                                         9/6/74      9
            WRITE(NO,9000)                                                                  9/6/74     10
      9000  FORMAT(1H1,//,10X,*RISK FACTOR ANALYSIS MODEL*,                                 9/6/74     11
           1/,10X,*PREPARED FOR THE*,                                                       9/6/74     12
           2,/10X,*FEDERAL HIGHWAY ADMINISTRATION,WASH.,D.C.*,                              9/6/74     13
           4/,10X,*BY WATER RESOURCES ENGINEERS*,                                           9/6/74     14
           3/,10X,*SPRINGFIELD,VA.*)                                                        9/6/74     15
            WRITE(NO,9001)                                                                  9/6/74     16
      9001  FORMAT(//,15X,*RISK FACTOR ANALYSIS RESULTS*,/,10X,                             9/6/74     17
           1,/,10X,*BRIDGE CONFIGURATION (FT)*,20X,*ECONOMIC RESPONSE*,                     9/17/74     3
           1,1X,*COMPONENTS (DOLLARS)*,                                                     9/17/74     4
           2/,10X,*LENGTH*,5X,*EMBKT. HT.*,15X,*CONSTRUCTION COST*,5X,*RISK*,               9/6/74     19
           35X,*TOTAL ECONOMIC RESPONSE*)                                                   9/6/74     20
            LIM1=NLEN-1                                                                     9/6/74     21
            DO 1 I=1,LIM1                                                                   9/6/74     22
            LIM2=NMB(I)                                                                     9/6/74     23
            DO 1 J=1,LIM2                                                                   9/6/74     24
            EBKM=RELEV(I,1)+EMB(I,J)                                                        9/6/74     25
            RISK=R(I,J)*S(I,J)                                                              9/6/74     26
            WRITE(NO,9002) FLEN(I+1),EBKM,S(I,J),RISK,R(I,J)                                9/6/74     27
      9002  FORMAT(/,8X,F10.3,4X,F10.3,17X,F10.3,5X,F10.3,8X,F10.3)                         9/6/74     28
      1     CONTINUE                                                                        9/6/74     29
            WRITE(NO,9003) (I,FLFR(I,1),FLFR(I,2),I=1,NFLFR)                                9/6/74     30
      9003  FORMAT(///,20X,*RISK BASED ON FLOOD EVENTS*,/,                                  9/6/74     31
           110X,*FLOW*,5X,*VOLUME(CFS)*,5X,*RECURRENCE INTERVAL*,                           9/6/74     32
           26(/,10X,I3,7X,F10.3,10X,F10.3))                                                 9/6/74     33
            ZR=100.*RATE                                                                    9/6/74     34
            WRITE(NO,9004) PLIFE,ZR                                                         9/6/74     35
      9004  FORMAT(///,20X,*CONSTRUCTION COST CALCULATED AS EQUIVALENT ANNUAL               9/6/74     36
           1COST*,/,10X,*BASED ON PROJECT LIFE*,F10.3,*YEARS*,5X,*INTEREST RAT              9/6/74     37
           3E*,F10.3,5X,*PERCENT*,///,10X,*TOTAL ECONOMIC RESPONSE EQUALS SUM               9/6/74     38
           4OF*,/,10X,*CONSTRUCTION COST AND RISK*)                                         9/6/74     39
            RETURN                                                                          9/6/74     40
            END                                                                             9/6/74     41
```

SUBROUTINE PLOT   CDC 6600 FTN V3.0-P340 OPT=0 09/18/74 06.56.03.   PAGE   1

```
          SUBROUTINE PLOT(K)                                                   9/6/74     42
          DIMENSION X(203,1),Y(203,1),NPT(1)                                   9/6/74     43
          DIMENSION R(3,3)                                                     9/17/74     5
          COMMON/AXES/ XAXIS,YAXIS                                             9/6/74     44
          COMMON/LABELS/TOP(10),BOTTOM(10),SIDE(50)                            9/6/74     45
          COMMON/DUMMY/TITLE(2,20),NI,NO,ITPE,B(6)                             9/6/74     46
          COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),           9/6/74     47
         1NNDS(4),WELEV(4,40),NUP(4,40)                                        9/6/74     48
          READ(NI,200) XAXIS,YAXIS,ITEL,IJOIN                                  9/6/74     49
  200     FORMAT(F4.0,2X,F4.0,2X,2I2)                                          9/6/74     50
          IF(XAXIS.EQ.9999) GO TO 120                                          9/6/74     51
C                                                                              9/6/74     52
C         PLOT TOTAL ECONOMIC RESPONSE VS. EMBANKMENT HEIGHT---8.0. FIXED      9/6/74     53
C                                                                              9/6/74     54
          DO 10 K=2,NLEN                                                       9/6/74     55
          IF(NMB(K-1).LT.3) GO TO 10                                           9/6/74     56
          READ(NI,210) TOP,BOTTOM,SIDE                                         9/6/74     57
  210     FORMAT(10A4/10A4/50A1)                                               9/6/74     58
          NPT(1)=NMB(K-1)                                                      9/6/74     59
          LIM=NPT(1)                                                           9/6/74     60
          DO 5 J=1,LIM                                                         9/6/74     61
          X(J,1)=315.+EMB(K-1,J)                                               9/6/74     62
    5     Y(J,1)=R(K-1,J)/1000.                                                9/17/74     6
          LIM1=LIM-1                                                           9/17/74     7
          DO 12 J=1,LIM1                                                       9/17/74     8
          JJ=J+1                                                               9/17/74     9
          DO 12 KK=JJ,LIM                                                      9/17/74    10
          IF(X(J,1).GT.X(KK,1)) GO TO 13                                       9/17/74    11
          GO TO 12                                                             9/17/74    12
   13     Z1=X(J,1)                                                            9/17/74    13
          Z2=Y(J,1)                                                            9/17/74    14
          X(J,1)=X(KK,1)                                                       9/17/74    15
          Y(J,1)=Y(KK,1)                                                       9/17/74    16
          X(KK,1)=Z1                                                           9/17/74    17
          Y(KK,1)=Z2                                                           9/17/74    18
   12     CONTINUE                                                             9/17/74    19
          WRITE(NO,9001) TITLE                                                 9/6/74     64
 9001     FORMAT(1H1,//,5X,20A4,/5X,20A4)                                      9/6/74     65
          CALL CURVE(X,Y,NPT,1,1,IJOIN,ITEL)                                   9/6/74     66
   10     CONTINUE                                                             9/6/74     67
C                                                                              9/6/74     68
C         PLOT TOTAL ECONOMIC RESPONSE VS. BRIDGE LENGTH FOR FIXED EMBKT. HT   9/6/74     69
C                                                                              9/6/74     70
          LIM=NLEN-1                                                           9/6/74     71
          DO 21 J=1,3                                                          9/6/74     72
          ITOT=0                                                               9/6/74     73
          DO 20 I=1,LIM                                                        9/6/74     74
          IF(NMB(I).LT.J) GO TO 20                                             9/17/74    20
          IF(R(I,J).NE.0.) ITOT=ITOT+1                                         9/17/74    21
   20     CONTINUE                                                             9/17/74    22
          IF(ITOT.LT.3) GO TO 21                                               9/6/74     76
          READ(NI,210) TOP,BOTTOM,SIDE                                         9/6/74     77
          NPT(1)=ITOT                                                          9/6/74     78
          LIM1=NPT(1)                                                          9/6/74     79
          DO 6 JJ=1,LIM1                                                       9/6/74     80
```

```
SUBROUTINE  PLOT                              CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.      PAGE     2

                X(JJ,1)=FLEN(JJ+1)                                       9/6/74     81
                Y(JJ,1)=R(JJ,J)/1000.                                    9/17/74    23
                WRITE(NO,9001) TITLE                                     9/6/74     83
                CALL CURVE(X,Y,NPT,1,1,IJOIN,ITEL)                       9/6/74     84
           21   CONTINUE                                                 9/6/74     85
          120   RETURN                                                   9/6/74     86
                END                                                      9/6/74     87
```

```
      SUBROUTINE OUTPT1(I1,I2,COSTR,CNSTR,R,S)                        9/6/74     88
      DIMENSION S(3,3)                                                9/6/74     89
      DIMENSION R(3,3)                                                8/26/74     7
      NO=6                                                            8/26/74     8
      WRITE(NO,9001)                                                  8/26/74     9
 9001 FORMAT(1H1,//,10X,*RISK FACTOR ANALYSIS*,                       9/6/74     90
     1/,10X,*PREPARED FOR THE*,                                       8/26/74    11
     2/,10X,*FEDERAL HIGHWAY ADMINISTRATION,WASH.,D.C.*,              8/26/74    12
     3/,10X,*BY WATER RESOURCES ENGINEERS*,                           8/26/74    13
     4/,10X,*SPRINGFIELD, VA.*)                                       8/26/74    14
      L=I1-1                                                          9/6/74     91
      WRITE(NO,9000)L,I2                                              9/17/74    24
 9000 FORMAT(//,5X,*FINAL RESULTS FOR BRIDGE*,I2,1X,*EMBK.*,I2,       9/6/74     93
     1/,5X,*FOR TALLAHALLA CREEK AT WALDRUP, MISSISSIPPI SITE*)       9/6/74     94
      R(L,I2)=COSTR+CNSTR                                             9/17/74    25
      S(L,I2)=CNSTR                                                   9/17/74    26
      WRITE(NO,9002) R(L,I2),COSTR,CNSTR                              9/17/74    27
 9002 FORMAT(//,10X,*TOTAL ECONOMIC RESPONSE*,T35,E12.3,T50,*DOLLARS*,  8/26/74    17
     1/20X,*TOTAL RISK*,T45,E12.3,T60,*DOLLARS*,                      8/26/74    18
     3/20X,*CONSTRUCTION COSTS*,T45,E12.3,T60,*DOLLARS/YEAR*)         8/26/74    19
      RETURN                                                          8/26/74    20
      END                                                             8/26/74    21
```

```
      SUBROUTINE INRISK                                                RISK      47
      INTEGER NC                                                       7/18/74    5
      COMMON/SCOR/TYP,CSCR,HSCR,NSCR,WSCR,CEN(4),NPILE,DPILE           7/18/74    6
      COMMON/EMBANK/CY,BWID,RWCST,USLP,DSLP,NC(4),CLER,PIERS,          7/18/74    7
     1BTL(4,40),VOL(40),BTEL(4,40)                                     7/18/74    8
      COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                      RISK      52
      COMMON /ECON/ PLIFE,RATE,AINCOM                                  RISK      53
      COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),       8/28/74    5
     1NNDS(4),#ELEV(4,40),NUP(4,40)                                    8/28/74    6
      COMMON  /BKWH/ DAM(60),NRISK                                     RISK      57
      COMMON/HYDR/ WCL,WCV,WCH,WCT,WCR,LNE,QNRM(6,2),VEL(4,200),NP,ICK RISK      58
      COMMON /TRAF/ TRP(11),DRATN,PENINN,PRODAN,DRATU,PRODAU,          RISK      60
     1   PENINU,DEATH,CPENI,CPRODM                                     RISK      61
      COMMON/INSP/TTIP                                                 7/18/74    9
      COMMON/INRO/IC                                                   7/18/74   10
      COMMON/INEN/VINCP,WT,FAC                                         7/18/74   11
      DATA END/4HEND /                                                 RISK      62
      NI=5                                                             RISK      63
      NO=6                                                             RISK      64
      READ (NI,8001) ((TITLE(I,J),I=1,2),J=1,20)                       RISK      65
 8001 FORMAT (20A4)                                                    RISK      66
      WRITE(NO,8099)                                                   9/6/74    96
8099  FORMAT(1H1)                                                      9/6/74    97
      WRITE (NO,9000)                                                  RISK      67
9000  FORMAT(1H1,//,10X,*RISK FACTOR ANALYSIS MODEL*,                  9/6/74    98
     1   /,10X,*PREPARED FOR THE *,                                    RISK      69
     2   /,10X,*FEDERAL HIGHWAY ADMINISTRATION, WASH., D. C., *,       RISK      70
     3   /,10X,*BY WATER RESOURCES ENGINEERS, *,                       RISK      71
     4   /,10X,*SPRINGFIELD, VA.*)                                     RISK      72
      WRITE(NO,9001)                                                   9/6/74    99
9001  FORMAT(//,5X,*---------------INFORMATION FOR TALLAHALLA CREEK AT WA 9/6/74   100
     1LDRUP, MISSISSIPPI BRIDGE SITE--------------------*)             9/6/74   101
      READ (NI,8003) ITPE                                              RISK      75
 8003 FORMAT (20X,I5)                                                  RISK      76
      WRITE (NO,9003)  ITPE                                            RISK      77
 9003 FORMAT(///,5X,*HYDRAULIC INFORMATION IS ON TAPE  *,I5)           RISK      78
C  *****  READ BRDG COST COEF                                          RISK      79
      DO 220 I=1,6                                                     RISK      80
      B(I)=0.                                                          RISK      81
  220 READ (NI,8007) B(I)                                              RISK      82
8007  FORMAT(10X,E10.3)                                                RISK      83
      WRITE (NO,9007) B                                                RISK      84
 9007 FORMAT (//,5X,#BRIDGE COST FUNCTION#,/,5X,                       RISK      85
     1   #BRIDGE COST = #,E12.3,# + #,E12.3,# * AREA + #,              RISK      86
     2E12.3,#*PIERS +#,E12.3,/,24X,#*CLEAR, +#,E12.3,                  9/17/74   28
     3   # * LNGTH + #,E12.3,# * RDWY WIDTH#)                          RISK      88
C     READ EMBANKMENT INFO                                             RISK      89
      READ(NI,8010) RWCST,CY,USLP,DSLP,BWID                            7/18/74   12
 8010 FORMAT (10X,7F10.0)                                              RISK      91
      WRITE(NO,5000)                                                   9/6/74   102
5000  FORMAT(//,5X,*EMBANKMENT INFORMATION*)                           9/6/74   103
      WRITE(NO,9010) CY,USLP,DSLP,BWID,RWCST                           7/18/74   13
9010  FORMAT(//,5X,*FILL COST ($/CY)*,T40,F10.3,                       9/5/74     2
     17,5X,*UPSTREAM SLOPE (PERCENT)*,T40,F10.3,                       9/5/74     3
     2/,5X,*DOWNSTREAM SLOPE (PERCENT)*,T40,F10.3,                     9/5/74     4
```

```
SUBROUTINE  INRISK                         CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.      PAGE    2
          3/,5X,*BRIDGE WIDTH (FT)*,T40,F10.3,                                9/5/74      5
          J/,5X,*ROADWAY COST ($/FT)*,T40,F10.3)                              9/5/74      6
           READ(NI,1) NLEN,(FLEN(J),J=1,NLEN)                                 RISK      101
     1     FORMAT(I10/(8F10.4))                                               9/4/74      1
           READ(NI,1) NFLFR,(FLFR(J,1),FLFR(J,2),J=1,NFLFR)                   RISK      103
           L=NLEN-1                                                           RISK      109
           DO 230 J=1,L                                                       RISK      110
           READ(NI,2) NMB(J)                                                  8/28/74     7
     2     FORMAT(16I5)                                                       8/28/74     8
           LIM=NMB(J)                                                         8/28/74     9
           READ(NI,8010) (EMB(J,K),K=1,LIM)                                   9/4/74      2
           READ(NI,8020) NC(J),CEN(J)                                         7/18/74    14
  8020     FORMAT(I5,F10.4)                                                   C1          2
           READ(NI,2) NNDS(J)                                                 8/28/74    11
           NI=NNDS(J)                                                         7/18/74    16
           DO 240 N=1,NI                                                      RISK      114
  8025 FORMAT(5X,I5,4F10.3)                                                   RISK      115
  240      READ(NI,8025) NUP(J,N),BTEL(J,N),BTL(J,N),WELEV(J,N)               7/18/74    17
   230 CONTINUE                                                               RISK      117
           WRITE(NO,5002)                                                     9/6/74    104
  5002     FORMAT(//,5X,*BRIDGE INFORMATION FOLLOWS*,/5X,*ON THE NEXT THREE P 9/6/74    105
          1AGES*)                                                             9/6/74    106
           DO 247 J=1,L                                                       RISK      118
           WRITE(NO,5001)                                                     9/6/74    107
  5001     FORMAT(1H1)                                                        9/6/74    108
           WRITE(NO,9020) J,FLEN(J+1),CEN(J)                                  D           1
  9020     FORMAT(//,10X,*BRIDGE NO.*,I2,5X,*BRIDGE OPENING(FT)*,F10.2,       7/18/74    19
          15X,*BRIDGE HT.(FT)*,F7.2)                                          7/18/74    20
           NI=NNDS(J)                                                         8/28/74    12
           DO 247 N=1,NI                                                      RISK      123
  247      WRITE(NO,9021) NUP(J,N),BTEL(J,N),BTL(J,N),WELEV(J,N)              7/18/74    21
  9021 FORMAT(//,10X,*NODE*,T40,*GRADE ELEV*,T60,*LENGTH*,T83,*TOP ELEV*,     RISK      125
          1/,10X,I10,T40,F10.3,T60,F10.3,T80,F10.3)                           RISK      126
C   READ BACKWATER INPUT                                                      RISK      127
           DO 260 J= 1,60                                                     RISK      128
           READ (NI,8030) H,  DAM(J)                                          RISK      129
  8030 FORMAT (A4,16X,E20.0)                                                  RISK      130
           IF (H .EQ. END)  GO TO 270                                         RISK      131
           GO TO 260                                                          RISK      132
   270 NRISK=J-1                                                              RISK      133
           GO TO 280                                                          RISK      134
   260 CONTINUE                                                               RISK      135
   280 CONTINUE                                                               RISK      136
           WRITE(NO,5003)                                                     9/6/74    109
  5003     FORMAT(1H1,//,25X,*FLOOD DAMAGE INFORMATION*)                      9/6/74    110
           WRITE(NO,10010)                                                    8/28/74    13
  10010 FORMAT(//,15X,*DAMAGES WITH NO BRIDGE*,                               8/28/74    14
          1/,6X,*FLOW*,7X,*VOLUME (CFS)*,2X,*RETURN INTERVAL*,2X,*DAMAGE ($)* 8/28/74    15
          2)                                                                  8/28/74    16
           M=0                                                                8/28/74    17
           DO 500 I=1,NFLFR                                                   8/28/74    18
           M=M+1                                                              8/28/74    19
  500      WRITE(NO,9050) M,FLFR(I,1),FLFR(I,2),DAM(I)                        8/28/74    20
           WRITE (NO,9040)                                                    RISK      141
           DO 290 J=1, NFLFR                                                  RISK      142
```

```
      DO 300 K=2,NLEN                                                    RISK      143
      LIM=NMB(K-1)                                                       9/4/741     1
      DO 310 L=1,LIM                                                     8/28/74    22
      M=M+1                                                              RISK      145
      WRITE(NO,9050) M,FLFR(J,1),FLFR(J,2),FLEN(K),EMB(K-1,L),DAM(M)    9/5/74      7
 9040 FORMAT(//,6X,*FLOW*,7X,*VOLUME (CFS)*,2X,*RETURN INTERVAL*,2X,    8/28/74    23
     1*BRIDGE OPENING*,2X,*DELTA EMBK. HT.*,2X,*DAMAGE ($)*)             8/28/74    24
 9050 FORMAT(/,5X,I5,5X,5F15.4)                                          RISK      149
  310 CONTINUE                                                           RISK      150
  300 CONTINUE                                                           RISK      151
  290 CONTINUE                                                           RISK      152
C   READ ECONOMICS INPUT                                                 RISK      153
      READ(NI,8060) PLIFE,RATE,TC                                        7/18/74    22
 8060 FORMAT(10X,3F10.4)                                                 7/18/74    23
      WRITE(NO,5004)                                                     9/6/74    111
 5004 FORMAT(1H1,//,25X,*ECONOMIC AND TRAFFIC INFORMATION*).             9/6/74    112
      WRITE(NO,9060) PLIFE,RATE,TC                                       7/18/74    24
 9060 FORMAT(//,5X,*PROJECT LIFE (YRS) = *,T35,F10.3,                    RISK      158
     1/,5X,*INTEREST RATE(PER CENT) =*,T35,F10.3,                        RISK      159
     2/,5X,*AVE. VALUE OF TIME ($/HR)*,T35,F10.3)                        8/28/74    25
      RATE=.01*RATE                                                      RISK      161
C   READ TRAFFIC INPUT                                                   RISK      162
      DO 320 J=1,11                                                      RISK      163
  320 READ (NI,8070) THF(J)                                              RISK      164
 8070 FORMAT (20X,F10.3)                                                 RISK      165
      READ(NI,3) DRATN,PERINN,PRODAN,DRATU,PERINU,PRODAU,DEATH,CPERI,    RISK      166
     1CPROOM                                                             RISK      167
    3 FORMAT((8F10.3))                                                   RISK      168
      WRITE(NO,9070) THF                                                 RISK      169
 9070 FORMAT (///,5X,*AVERAGE DAILY TRAFFIC LEVEL *,T50,F10.3,           RISK      170
     1    /,5X,*PASSENGER CAR TRAFFIC LEVEL *,T50,F10.3,                 RISK      171
     2    /,5X,*COMMERCIAL DELIVERY VEHICLE LEVEL *,T50,F10.3,           RISK      172
     3    /,5X,*SINGLE UNIT TRUCK LEVEL *,T50,F10.3,                     RISK      173
     4    /,5X,*GASOLINE TRUCK LEVEL *,T50,F10.3,                        RISK      174
     5    /,5X,*DIESEL SEMI TRAILER LEVEL *,T50,F10.3,                   RISK      175
     6    /,5X, *NORMAL TRAVEL DISTANCE *,T50,F10.3,                     RISK      176
     7    /,5X,*NORMAL TRAVEL SPEED*,T50,F10.3,                          RISK      177
     8    /,5X,*DETOUR TRAVEL DISTANCE*,T50,F10.3,                       RISK      178
     9    /,5X,*DETOUR TRAVEL SPEED (M/HR)*,T50,F10.3,                   RISK      179
     A    /,5X,*AVE. VEH. OCCUPANCY RATE *,T50,F10.3)                    RISK      180
      WRITE(NO,10000) DRATN,PERINN,PRODAN,PERINU,PRODAU,DRATU,DEATH,     RISK      181
     1CPERI,CPROOM                                                       RISK      182
10000 FORMAT(//,5X,*ACCIDENT RATE DATA*,                                 RISK      183
     B/,5X,*DEATH RATE/100 MILLION MILES (NORMAL)*,T50,F10.3,            RISK      184
     C/,5X,*PERSONAL INJURIES (NO./DEATH) (NORMAL)*,T50,F10.3,           RISK      185
     D/,5X,*PROPERTY DAMAGE (NO./DEATH) (NORMAL)*,T50,F10.3,             RISK      186
     E/,5X,*PERSONAL INJURY RATE OBSTACLE*,T50,F10.3,                    RISK      187
     F/,5X,*PROPERTY DAMAGE RATE OBSTACLE*,T50,F10.3,                    RISK      188
     G/,5X,*DEATH RATE FOR OBSTACLES*,T50,F10.3,                         RISK      189
     G    //,10X,*ACCIDENT RELATED COST DATA*,                           RISK      190
     H    /,5X,*COST PER DEATH*,T50,F10.3,                               RISK      191
     I    /,5X,*COST OF PERSONAL INJURY *,T50,F10.3,                     RISK      192
     J    /,5X,*PROPERTY DAMAGE *,T50,F10.3)                             RISK      193
C     READ HYDROLOGIC INPUT                                              RISK      194
      READ(NI,8080) WCL,WCH                                              9/4/74      3
```

```
        8080  FORMAT(20X,3F10.3)                                                   7/18/74    27
              WRITE(NO,5005)                                                       9/6/74    113
        5005  FORMAT(1H1,//,25X,*HYDROLOGIC, SCOUR, AND EROSION DATA*)             9/6/74    114
              WRITE(NO,9080) WCL,WCH                                               8/26/74    23
        9080  FORMAT(//,20X,*HYDROLOGIC DATA*,                                     9/6/74    115
             1/,10X,*LENGTH OF LONGEST WATERCOURSE*,T55,F10.3,T67,*MILES*,         9/5/74      8
             2/,10X,*ELEVATION DIFFERENCE*,T55,F10.3,T67,*FEET*)                   9/5/74      9
        C  READ SCOUR INFORMATION                                                  RISK      204
              READ(NI,8090) TYP,CSCR,HSCR,NSCR,WSCR,NPILE,DPILE                    7/18/74    28
        8090  FORMAT(3F10.0,I10,F10.0,I10,F10.4)                                   C1          5
              WRITE(NO,9090) TYP,CSCR,HSCR,NSCR,WSCR,NPILE,DPILE                   7/18/74    30
        9090  FORMAT(///,20X,*SCOUR INFORMATION (ALL LENGTHS IN FEET)*,            9/6/74    116
             1   /,10X,*CHANNEL TYPE IS *,F10.3,                                   RISK      210
             3   /,10X,*COST PER FOOT OF SCOUR IS *,F10.3,                         RISK      211
             2   /,10X,*MAXIMUM SCOUR DEPTH IS *,F10.3,                            RISK      212
             4   /,10X,*VELOCITY NODE FOR SCOUR IS *,I10,                          RISK      213
             5  /,10X,*RECTANGULAR WIDTH OF PIER IS*,F10.3,                        7/18/74    31
             6  /,10X,*NUMBER OF PILES IS *,I10,                                   7/18/74    32
             7  /,10X,*PILE DEPTH IS *,F10.3)                                      7/18/74    33
        C     READ EROSION DATA                                                    7/18/74    34
              READ(NI,7000) VINCP,WT,FAC,TTIP                                      7/18/74    35
        7000  FORMAT(4F10.4)                                                       7/18/74    36
              WRITE(NO,7001) VINCP,WT,FAC,TTIP                                     7/18/74    37
        7001  FORMAT(///,20X,*EROSION INFORMATION*,                                7/18/74    38
             1  /,10X,*INCIPIENT VEL.(FT/SEC) IS*,F10.4,                           7/18/74    39
             2  /,10X,*WEIGHT (LBS/FT3) OF SOIL IS*,F10.4,                         7/18/74    40
             3  /,10X,*COST ADJUSTMENT FACTOR IS*,F10.4,                           7/18/74    41
             4/,10X,*INSPECTION TIME(HR) IS*,F10.4)                                C1          6
              RETURN                                                               RISK      215
              END                                                                  RISK      216
```

```
      FUNCTION CONCST(L,NB)                                          8/26/74    24
      INTEGER NC                                                     7/18/74    43
      COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),     8/28/74    27
     1NNDS(4),WELEV(4,40),NUP(4,40)                                  8/28/74    28
      COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                    RISK      222
      COMMON/EMBANK/CY,BWID,RWCST,USLP,DSLP,NC(4),CLER,PIERS,        7/18/74    44
     1BTL(4,40),VOL(40),BTEL(4,40)                                   7/18/74    45
      COMMON /ECON/ PLIFE,RATE,AINCOM                                RISK      225
      COMMON/SCOM/TYP,CSCR,HSCR,NSCR,WSCR,CEN(4),NPILE,OPILE         9/17/74    29
      ELF=FLEN(L)                                                    RISK      226
      L1=L-1                                                         RISK      227
      AREA=ELF*BWID                                                  RISK      228
      C=B(1)+B(2)*AREA+B(3)*PIERS+B(4)*CLER+B(5)*ELF+B(6)*BWID       RISK      231
      LIFE=PLIFE                                                     RISK      232
      C1=C*((RATE/(((1.+RATE)**LIFE)-1.))+RATE)                      RISK      233
      J3=NNDS(L1)                                                    7/18/74    46
      C2=0.                                                          RISK      235
      DO 240 J=1,J3                                                  RISK      236
  240 C2=C2+BTL(L1,J)                                                RISK      237
      C2=C2*RWCST                                                    RISK      238
C     CALC EMBANKMENT COST                                           RISK      239
      US=USLP/100.                                                   RISK      240
      DS=DSLP/100.                                                   RISK      241
      DO 250 J=2,J3                                                  RISK      243
      VOL(J)=0.                                                      RISK      244
      IF(J.EQ.NC(L1)) GO TO 250                                      RISK      245
      ATP=(WELEV(L1,J-1)+WELEV(L1,J))/2.+EMB(L1,NB)                  8/28/74    29
      ABT=(BTEL(L1,J-1)+BTEL(L1,J))/2.                               RISK      247
      AH=ATP-ABT                                                     RISK      248
      IF (AH .LE.0.) AH=0.                                           RISK      249
      VOL(J)=AH*BWID*BTL(L1,J)                                       RISK      250
      VOL(J)=VOL(J)+.5*(1./US+1./DS)*AH*AH*BTL(L1,J)                 RISK      251
  250 CONTINUE                                                       RISK      252
      V=0.                                                           RISK      253
      DO 255 J=2,J3                                                  RISK      254
  255 V=VOL(J)+V                                                     RISK      255
      C2=C2+CY*V/27.                                                 RISK      256
      IF(TYP.EQ.0.) C2=C2+OPILE*CSCR*NPILE                           8/26/74    26
      C2=C2*((RATE/(((1.+RATE)**LIFE)-1.))+RATE)                     RISK      257
      CONCST=C1+C2                                                   RISK      258
      WRITE(NO,9000)                                                 8/26/74    27
 9000 FORMAT(1H1,//,10X,*RISK FACTOR ANALYSIS MODEL*,                9/6/74    117
     1/,10X,*PREPARED FOR THE*,                                      8/26/74    29
     2/,10X,*FEDERAL HIGHWAY ADMINISTRATION,WASH.,D.C.,*,            8/26/74    30
     3/,10X,*BY WATER RESOURCES ENGINEERS*,                          8/26/74    31
     4/,10X,*SPRINGFIELD,VA.*)                                       8/26/74    32
      L1=L-1                                                         9/6/74    118
      WRITE(NO,9001) TITLE,L1,NB                                     9/6/74    119
 9001 FORMAT(//,5X,20A4,/5X,20A4,///,15X,*BRIDGE*,I2,1X,*EMBK.*,I2,  9/6/74    120
     11X,*RISK ANALYSIS*)                                            9/6/74    121
      ZR=100.*RATE                                                   8/26/74    36
      WRITE(NO,9010) FLEN(L),EMB(L1,NB),CONCST,ZR,PLIFE              8/28/74    30
 9010 FORMAT(///,20X,*BRIDGE CHARACTERISTICS*,                       8/26/74    38
     2/,10X,*BRIDGE LENGTH*,T30,E12.3,T50,*FEET*,                    8/26/74    39
     3/,10X,*DELTA EMBKT. HT.*,T30,E12.3,T50,*FEET*,                 8/28/74    31
```

```
          4//,10X,*CONSTRUCTION COST*,T30,E12.3,T50,*DOLLARS/YEAR*,            8/26/74    41
          5/,10X,*INTEREST RATE*,T30,E12.3,T50,*PER CENT*,                     8/26/74    42
          6/,10X,*PROJECT LIFE*,T30,E12.3,T50,*YEARS*)                         8/26/74    43
           J3=J3-1                                                             9/6/74    122
           WRITE(NO,9410) C1,C2,(J,VOL(J+1),J=1,J3)                            9/6/74    123
     9410  FORMAT(//,10X,*BRIDGE COST*,T50,F20.3,T75,*DOLLARS*,                9/6/74    124
          2/,10X,*FILL, ROAD, AND PILING COSTS*,T50,F20.3,T75,*DOLLARS*,       9/6/74    125
          3//,10X,*SECTION*,10X,*ROADWAY VOLUME(FT3)*,40(/,10X,I5,12X,F20.5))  9/6/74    126
           RETURN                                                              RISK      264
           END                                                                 RISK      265
```

```
SUBROUTINE  OUTPUT                                 CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.05.       PAGE      1

          SUBROUTINE OUTPUT(I1,I2,I3,T1,T2,COSTR,DTR,SCR,ERS,BKR)            8/26/74     44
          COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                        RISK       271
          COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),         8/28/74     32
         1NNDS(4),KELEV(4,40),NUP(4,40)                                      8/28/74     33
          COMMON/INSP/TTIP                                                   7/18/74     49
          WRITE(NO,9010) I3,FLFR(I3,1),FLFR(I3,2)                            8/26/74     45
          WRITE(NO,9030) DTR,SCR,ERS,BKR                                     7/18/74     50
          TTI=TTIP                                                           7/25/74      1
          IF(TI.LE.0.) TTI=0.                                                7/25/74      2
          T2=T1+TTI+24.*T2                                                   7/25/74      3
          WRITE (NO,9050) T1,T2                                              RISK       282
     9050 FORMAT(///,20X,*OVERTOPPING LASTED *,F10.3,* HOURS CAUSING A DELAY RISK       283
         1 OF *,F10.3,*HOURS*)                                               RISK       284
     9010 FORMAT(//,20X,*FLOW*,I3,2X,*CHARACTERISTICS*,                      8/26/74     46
         2/,10X,*FLOW*,T30,E12.3,T50,*CFS*,                                  8/26/74     47
         4   /,10X,*RETURN INTERVAL*,T30,E12.3)                              RISK       289
     9030 FORMAT(///,20X,*ASSOCIATED RISK COMPONENTS*,                       8/26/74     48
         1   /,10X,*DETOUR*,T30,E12.3,T50,*DOLLARS*,                         RISK       295
         2   /,10X,*SCOUR*,T30,E12.3,T50,*DOLLARS*,                          RISK       296
         4   /,10X,*EROSION*,T30,E12.3,T50,*DOLLARS*,                        RISK       298
         5   /,10X,*BACKWATER*,T30,E12.3,T50,*DOLLARS*)                      RISK       299
          C1=DTR+SCR+ERS+BKR                                                 8/26/74     49
          COSTR=COSTR+C1                                                     8/26/74     50
          WRITE(NO,9040) I3,C1                                               8/26/74     51
     9040 FORMAT(///,20X,*TOTAL RISK COMPONENT FOR STORM*,I3,/,              8/26/74     52
         2T35,E12.3,T50,*DOLLARS*)                                           8/26/74     53
          RETURN                                                             RISK       303
          END                                                                RISK       304
```

```
      FUNCTION DETOUR(L,NB,NF,T1,TRP)                                   7/25/74     4
      COMMON /ECON/ PLIFE,RATE,AINCUM                                   RISK      306
      COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),        8/28/74    34
     1NND3(4),MELEV(4,40),NUP(4,40)                                     8/28/74    35
      COMMON /TRAF/ TRF(11),DRATN,PERINN,PRODAN,DRATU,PRODAU,           RISK      310
     1   PERINU,DEATH,CPERI,CPRODM                                      RISK      311
      COMMON/INSP/TTIP                                                  7/18/74    54
      COMMON/INRD/TC                                                    7/18/74    55
      IF(T1.LE.0.) GO TO 900                                            7/25/74     5
      T=24.*TRP+T1+TTIP                                                 7/25/74     6
C                                                                       RISK      313
      CD=42.5-.455*TRF(10)+.0068*TRF(10)**2                             RISK      314
      CD=CD*TRF(9)/1000.                                                RISK      315
      CN=42.5-.455*TRF(8)+.0068*TRF(8)**2                               RISK      316
      CN=CN*TRF(7)/1000.                                                RISK      317
      XM=TRF(2)+1.2*TRF(3)+2.*TRF(4)+3.2*TRF(5)+3.1*TRF(6)              RISK      318
      X=CD-CN                                                           RISK      319
      IF (X .LT. 0.) X=0.                                               RISK      320
C   CALC DETOUR TRAVEL COST                                             RISK      321
      C1=T*TRF(1)*X*XM/24.                                              RISK      322
C   CALCULATE ACCIDENT COSTS                                            RISK      323
      DELT=TRF(9)-TRF(7)                                                RISK      324
      C2=T*TRF(1)*DELT*DRATN/24.                                        RISK      325
      C2=C2*(DEATH+PERINN*CPERI+PRODAN*CPRODM)/1.0E8                    RISK      326
C  CALC UNEXPECTED OBSTACLE COSTS                                       RISK      327
      C3=TRF(1)*DRATN*DRATU                                             RISK      328
      C3=C3*(DEATH+PERINU*CPERI+PRODAU*CPRODM)/2.4E9                    RISK      329
C  CALC COST OF TIME DELAY                                              RISK      330
       C4=(TRF(9)/TRF(10))-(TRF(7)/TRF(8))                              RISK      331
      C4=T*TRF(1)*TRF(11)*C4*TC/24.                                     RISK      333
      C5=C1+C2+C3+C4                                                    RISK      334
      C6=FLFR(NF,2)*C5                                                  RISK      335
      DETOUR=C6                                                         RISK      336
      GO TO 999                                                         RISK      337
  900 DETOUR=0.0                                                        RISK      338
  999 RETURN                                                            RISK      339
      END                                                               RISK      340
```

```
          SUBROUTINE OVTME(L,NB,NF,XAM,TIME)                                   7/18/74     58
          COMMON/BLKIK/FLEN(5),NLEN,FLFH(6,2),NFLFH,EMB(4,3),NMB(4),           8/28/74     36
         1NNDS(4),*ELEV(4,40),NUP(4,40)                                        8/28/74     37
          COMMON /DUMMY/ TITLE (2,20),NI,NU,ITPE,B(6)                          RISK       345
          COMMON/HYDR/ WCL,WCV,WCH,WCT,WCR,LNE,ONRM(6,2),VEL(4,200),NP,ICK     RISK       346
          DIMENSION X(10),Y(10),TIME(40)                                       RISK       347
          XAM=0.                                                               RISK       354
          DO 100 I=1,40                                                        RISK       356
  100     TIME(I)=0.                                                           RISK       357
C         IF NO OVERTOPPING THEN EXIT                                          RISK       358
C                                                                              RISK       359
          IF(ICK.EQ.0) GO TO 990                                               RISK       360
C                                                                              RISK       361
C         CALCULATE WCR AND WCT                                                RISK       362
C                                                                              RISK       363
          WCT=((11.9*WCL**3)/WCH)**.385                                        RISK       364
          WCR=1.67*WCT                                                         RISK       365
C                                                                              RISK       366
C         CALCULATE OVERTOPPING TIME FOR EACH EMBANKMENT SECTION               RISK       367
C                                                                              RISK       368
          L1=L-1                                                               RISK       369
          A=EMB(L1,NB)                                                         8/28/74     38
          NN=NNDS(L1)                                                          RISK       371
          DO 400 J=2,NN                                                        RISK       372
          N1=NUP(L1,J-1)                                                       RISK       373
          N2=NUP(L1,J)                                                         RISK       374
          V12X=(VEL(1,N1)+VEL(1,N2))/2.                                        RISK       375
          IF(V12X.LE.0.) GO TO 400                                             RISK       376
          E12=(*ELEV(L1,J-1)+*ELEV(L1,J))/2.+A                                 RISK       377
          CD=(VEL(4,N1)+VEL(4,N2))/2.                                          7/18/74     59
          IF(E12.GT.CD) GO TO 400                                              7/18/74     60
          TCT=WCT*E12/CD                                                       7/18/74     61
          TCR=WCR*(1.-E12/CD)+WCT                                              7/18/74     62
          TIME(J)=TCR-TCT                                                      7/18/74     63
  400     CONTINUE                                                             C1           7
C                                                                              RISK       388
C         CALCULATE THE MAXIMUM DELAY                                          RISK       389
C                                                                              RISK       390
          XAM=-999.                                                            RISK       391
  990     WRITE(NO,3)                                                          9/6/74     127
    3     FORMAT(//,20X,*OVERTOPPING RESULTS*)                                 9/6/74     128
          NN=NNDS(L-1)                                                         9/18/74      1
          DO 500 J=1,NN                                                        RISK       392
  500     XAM=AMAX1(XAM,TIME(J))                                               RISK       393
          DO 600 J=2,NN                                                        7/25/74      7
          LL=J-1                                                               7/25/74      8
          WRITE(NO,700) LL,TIME(J)                                             7/25/74      9
  700     FORMAT(/,10X,*SECTION*,I2,10X,*TIME DELAY*,F10.3,2X,*HOURS*)         9/6/74     129
  600     CONTINUE                                                             RISK       409
          WRITE(NO,710) XAM                                                    7/18/74     65
  710     FORMAT(//,10X,*MAXIMUM DELAY*,F10.3,2X,*HOURS*)                      9/6/74     130
          RETURN                                                               9/6/74     131
          END                                                                  RISK       413
```

```
      SUBROUTINE EROSIN(L,NB,NF,T,ERS,TRP)                              C3         1
      INTEGER NC                                                        D          2
      COMMON/HYDR/ WCL,WCV,WCH,WCT,WCK,LNE,QNRM(6,2),VEL(4,200),NP,ICK  RISK     416
      COMMON/BLKTK/FLEN(5),NLEN,FLFM(6,2),NFLFM,EMB(4,5),NMB(4),        8/28/74   39
     1NNDS(4),WELEV(4,40),NUP(4,40)                                     8/28/74   40
      COMMON/EMBANK/CY,BWID,RWCST,USLP,DSLP,NC(4),CLER,PIERS,           7/18/74   67
     1BTL(4,40),VOL(40),BTEL(4,40)                                      7/18/74   68
      COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                       RISK     422
      COMMON/INER/VINCP,WT,FAC                                          7/18/74   69
      DIMENSION ERDE(40)                                                7/18/74   70
      DIMENSION B1(40)                                                  7/18/74   71
      DIMENSION T(40)                                                   C4         1
      WRITE(NO,9000)                                                    9/6/74   132
 9000 FORMAT(//,20X,*EROSION RESULTS*,//,5X,*SECTION*,5X,*FROM EMBK, NOD 9/6/74  133
     1E*,5X,*TO EMBK, NODE*,5X,*VOLUME(FT3)*,5X,*EROSION(FT3)*,5X,*PERCE 9/6/74  134
     2NT EROSION*)                                                      9/6/74   135
C                                                                       RISK     426
C     ZERO TEMP, VARIABLES                                              RISK     427
C                                                                       RISK     428
      DO 100 J=1,40                                                     C1         8
      ERDE(J)=0.                                                        RISK     430
  100 B1(J)=0.                                                          RISK     431
C     CALCULATE EROSION SECTION BY SECTION                              RISK     439
C                                                                       RISK     440
      L1=L-1                                                            RISK     441
      J1=NNDS(L1)-1                                                     RISK     442
C                                                                       RISK     443
C     CHECK FOR NO EROSION                                              RISK     444
C                                                                       RISK     445
      JK=NNDS(L1)                                                       RISK     446
      T1=0.                                                             RISK     447
      DO 150 J=2,JK                                                     RISK     448
  150 T1=T1+T(J)                                                        RISK     449
      IF(T1.LE.0.) GO TO 995                                            RISK     450
      ER=0.                                                             RISK     451
      V=0.                                                              7/18/74   73
      DO 500 J=1,J1                                                     RISK     452
C                                                                       RISK     453
C     CHECK FOR OVERTOPPING AND FILL                                    RISK     454
C                                                                       RISK     455
      JP=J+1                                                            RISK     456
      N=NUP(L1,JP)                                                      RISK     457
      M=NUP(L1,J)                                                       RISK     458
      IF(VEL(1,M).LE.0.) GO TO 500                                      RISK     459
      IF(VOL(JP).LE.0.) GO TO 500                                       RISK     460
C                                                                       RISK     461
C     CALC UNIT FLOW AND EROSION                                        RISK     462
C                                                                       RISK     463
      S1=WELEV(L1,JP)+EMB(L1,NB)                                        8/28/74   41
      S2=WELEV(L1,J)+EMB(L1,NB)                                         8/28/74   42
      H1=VEL(4,M)-S1                                                    7/18/74   76
      H2=VEL(4,N)-S2                                                    7/18/74   77
      AH=(H1+H2)/2.                                                     RISK     477
      IF(AH.LT.0.) GO TO 500                                            7/25/74   10
      VCR=4.8*SQRT(AH)                                                  7/25/74   11
```

```
            AL=BTL(L1,JP)                                                        RISK      480
            IF(VCR.LT.VINCP) GO TO 500                                           RISK      481
            ERDE(J+1)=2000.*.25*VCR**3.6*AL*T(JP)/(24.*WT)                       RISK      482
            IF(ERDE(J+1).GE.VOL(J+1)) ERDE(J+1)=VOL(J+1)                         RISK      483
            PER=ERDE(J+1)/VOL(J+1)*100.                                          RISK      484
            ER=ER+ERDE(J+1)                                                      RISK      485
            V=VOL(J+1)+V                                                         7/18/74    78
            WRITE(NO,20000)J,NUP(L1,J),NUP(L1,JP),VOL(JP),ERDE(JP),PER           9/6/74    136
      20000 FORMAT(/,I10,6X,I10,8X,I10,11X,F10.3,7X,F10.3,10X,F10.3)             9/6/74    137
      C                                                                          RISK      488
      C     CALCULATE AMOUNT OF ROADWAY LOST                                     RISK      489
      C                                                                          RISK      490
            H1=(S1+S2)/2.                                                        7/18/74    80
            H2=(BTEL(L1,J)+BTEL(L1,JP))/2.                                       7/18/74    81
            H1=H1-H2                                                             RISK      494
            IF(H1.EQ.0.) GO TO 500                                               7/18/74    82
            B1(JP)=2./100.*VOL(JP)/(H1*AL)*PER                                   RISK      495
            IF(B1(JP).GE.BWID) B1(JP)=BWID                                       RISK      496
            B1(JP)=B1(JP)/BWID*BTL(L1,JP)*RWCST*FAC                              RISK      497
        500 CONTINUE                                                             RISK      498
            IF(V.EQ.0.) GO TO 995                                                9/6/74    138
            PERM=ER/V*100.                                                       7/18/74    83
            B2=0.                                                                RISK      499
            J1=NNOS(L1)                                                          RISK      500
            DO 700 J=2,J1                                                        RISK      501
        700 B2=B1(J)+B2                                                          RISK      502
            ER=ER*CY*FAC/27.                                                     RISK      503
            ERS=(ER+B2)*FLFR(NF,2)                                               RISK      504
            GO TO 996                                                            7/18/74    84
        995 ERS=0.                                                               RISK      506
            PERM=0.                                                              7/18/74    85
        996 IF(PERM.LE.10.) GO TO 991                                            7/18/74    86
            TRP=(PERM-10.)/3.                                                    C1          9
            GO TO 990                                                            7/18/74    88
        991 TRP=0.                                                               7/18/74    89
            WRITE(NO,9001)                                                       9/6/74    139
       9001 FORMAT(/,10X,*--------NO EROSION-----------*)                        9/18/74     2
        990 RETURN                                                               RISK      507
            END                                                                  RISK      508
```

```
FUNCTION    BACKWR                          CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.       PAGE     1

            FUNCTION BACKWR (L,NB,NF)                                          RISK      509
            COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),         8/28/74    43
           1NNDS(4),WELEV(4,40),NUP(4,40)                                      8/28/74    44
            COMMON  /BKWR/ DAM(60),NRISK                                       RISK      513
            COMMON/ICOUNT/IDAM                                                 8/28/741    4
            J=IDAM+NFLFR                                                       8/28/741    5
            BACKWR=DAM(J)*FLFR(NF,2)                                           RISK      517
            RETURN                                                             RISK      518
            END                                                                RISK      519
```

```
SUBROUTINE  RDHYDR                          CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.       PAGE     1

            SUBROUTINE RDHYDR(II)                                                9/5/74     11
            COMMON/HYDR/ WCL,WCV,WCH,WCT,WCR,LNE,DNRM(6,2),VEL(4,200),NP,ICK     RISK      534
            COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                          RISK      535
            COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),           8/28/74    46
           1NNDS(4),WELEV(4,40),NUP(4,40)                                        8/28/74    47
            READ(ITPE,1)NP,ICK,((VEL(I,NUP(II=1,J)),I=1,4),J=1,NP)               9/5/741     2
      1     FORMAT(2I5/(4E12.5))                                                 8/28/74    49
            READ(ITPE,1) IDUM                                                    9/5/744     1
            IF(EOF(ITPE)) 10,30                                                  9/5/743     1
     30     WRITE(NO,6)                                                          9/5/743     2
      6     FORMAT(1H1,5X,*NO EOF ENCOUNTERED ON PREVIOUS READ*)                 9/5/743     3
            STOP 33                                                              9/5/743     4
     10     RETURN                                                               9/5/743     5
            END                                                                  RISK      541
```

```
FUNCTION    SCOUR                              CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.      PAGE     1

            FUNCTION SCOUR(L,NB,NF,CNSTR)                                             RISK      548
            COMMON/SCOR/TYP,CSCR,HSCR,NSCR,WSCR,CEN(4),NPILE,DPILE                    7/18/74    90
            COMMON/HYDR/ WCL,WCV,WCH,WCT,WCR,LNE,ONRM(6,2),VEL(4,200),NP,ICK          RISK      550
            COMMON /DUMMY/ TITLE (2,20),NI,NO,ITPE,B(6)                               RISK      551
            COMMON/BLKTK/FLEN(5),NLEN,FLFR(6,2),NFLFR,EMB(4,3),NMB(4),                8/28/74    50
           1NNDS(4),WELEV(4,40),NUP(4,40)                                             8/28/74    51
            DIMENSION X(10),Y(10)                                                     RISK      555
            DATA X/1.,3.,7.,14.,20.,31.,40.,49.,65.,80./                              RISK      556
            DATA Y/1.,1.2.,3.,4.,5.,6.,7.,8.,9.,10./                                  RISK      557
            WRITE(NO,9000) TYP                                                        9/17/74    30
      9000  FORMAT(//,20X,*SCOUR TYPE*,F5.0,2X,*RESULTS*)                             9/17/74    31
            IF(TYP.LE.1.) GO TO 990                                                   7/18/74    91
            D=VEL(3,NSCR)                                                             RISK      560
            X1=D/WSCR                                                                 RISK      561
            L1=L-1                                                                    0           4
            ZD=CEN(L1)+EMB(L1,NB)                                                     8/28/74    52
            IF(D.GE.ZD) X1=ZD/WSCR                                                    7/18/74    93
            IF (X1 .LT. 1.) GO TO 990                                                 RISK      562
            IF (X1 .GT. 80.) GO TO 980                                                RISK      563
            DO 100 J=2,10                                                             RISK      564
            IF(X1.LE.X(J).AND.X1.GT.X(J-1)) GO TO 101                                 RISK      565
       100  CONTINUE                                                                  RISK      566
       101  JJ=J                                                                      RISK      567
            Y1=(X1-X(JJ-1))/(X(JJ)-X(JJ-1))*(Y(JJ)-Y(JJ-1)) + Y(JJ-1)                 RISK      568
            Y1=Y1*WSCR                                                                RISK      569
            IF (Y1 .GT. HSCR) GO TO 970                                               RISK      570
            SCOUR=Y1*CSCR*FLFR(NF,2)                                                  RISK      571
            GO TO 998                                                                 RISK      572
       970 WRITE(NO,8970) Y1,HSCR                                                     RISK      573
      8970 FORMAT (///,10X,*BRIDGE FAILED*,                                           RISK      574
         1   /,10X,*DEPTH OF SCOUR IS  *,F10.3,                                       RISK      575
         2   /,10X,*PILE DEPTH WAS *,F10.3)                                           RISK      576
            SCOUR=2.*CNSTR*FLFR(NF,2)                                                 RISK      577
            GO TO 998                                                                 RISK      578
       980 WRITE (NO,8980) X1                                                         RISK      579
      8980 FORMAT (///,10X,*WATER DEPTH/WIDTH IS *,F10.3,                             RISK      580
         1   /,10X,*RESET DATA STATEMENT*,                                            RISK      581
         2   /,10X,*BRIDGE IS ASSUMED LOST*)                                          RISK      582
            SCOUR=2.*CNSTR*FLFR(NF,2)                                                 RISK      583
            GO TO 998                                                                 RISK      584
       990 SCOUR=0.                                                                   RISK      585
            WRITE(NO,9001)                                                            9/6/74    143
      9001  FORMAT(/,10X,*-------NO SCOUR-----------*)                                9/6/74    144
       998 CONTINUE                                                                   RISK      587
            RETURN                                                                    RISK      588
            END                                                                       RISK      589
```

```
      SUBROUTINE CURVE(X,Y,NPT,NCV,NPLOT,IJUIN,ITEL)                   9/6/74   145
      DIMENSION X(203,1),Y(203,1),NPT(1)                               9/6/74   146
      COMMON/LAB/ TITLE(18),XLAB(11),YLAB(6)                           9/6/74   147
     1,HORIZ(20),VERT(6)                                               9/6/74   148
      COMMON/AXES/XAXIS,YAXIS                                          9/6/74   149
C ******* CURVE IS THE ENTRY TO A GENERALIZED PRINTER PLOT ROUTINE, THE 9/6/74  150
C         ROUTINE PLOTS SEQUENTIALLY PAIRED VALUES TAKEN FROM THE X AND 9/6/74  151
C         Y ARRAYS, THE SCALING VALUES FOR BOTH ARRAYS ARE STORED IN THE 9/6/74 152
C         LAST TWO ARRAY LOCATIONS IN THE SAME MANNER AS CALCOMP SCALING 9/6/74 153
C                                                                      9/6/74   154
C         THE ARGUEMENTS IN THE CALLING SEQUENCE ARE DEFINED BELOW...  9/6/74   155
C                                                                      9/6/74   156
C                 X...THE ARRAY CONTAINING THE X AXIS COORDINATES OF TH 9/6/74  157
C                     POINTS TO BE PLOTTED.                            9/6/74   158
C                                                                      9/6/74   159
C                 Y...THE ARRAY CONTAINING THE Y AXIS COORDINATES OF TH 9/6/74  160
C                     POINTS TO BE PLOTTED.                            9/6/74   161
C                                                                      9/6/74   162
C               NPT...THE NUMBER OF POINTS TO BE PLOTTED.              9/6/74   163
C                                                                      9/6/74   164
C               NCV...THIS VALUE IS ALWAYS ONE (1).                    9/6/74   165
C                                                                      9/6/74   166
C             NPLOT...USED FOR PLOT IDENTIFICATION, THIS VALUE IS      9/6/74   167
C                     PRINTED ABOVE EACH PLOT FOR EACH CALL TO CURVE... 9/6/74  168
C              IJUIN...FLAG FOR JOINING OR NO JOINING OF DATA POINTS   9/6/74   169
C               ITEL...FLAG FOR GRID SIZE                              9/6/74   170
C                                                                      9/6/74   171
C SET SPECIAL GRID SIZE IF DESIRED                                     9/6/74   172
C                                                                      9/6/74   173
      IF(ITEL-1) 1000,1010,1020                                        9/6/74   174
 1010 XAXIS=60.                                                        9/6/74   175
      YAXIS=40.                                                        9/6/74   176
      GO TO 1000                                                       9/6/74   177
 1020 XAXIS=100.                                                       9/6/74   178
      YAXIS=50.                                                        9/6/74   179
 1000 NPTS=NPT(1)*NCV                                                  9/6/74   180
C                                                                      9/6/74   181
C                                   SET UP X AND Y SCALES              9/6/74   182
C                                                                      9/6/74   183
      IXAX=XAXIS/10.                                                   9/6/74   184
      IYAX=YAXIS/10.                                                   9/6/74   185
      IXAX1=IXAX+1                                                     9/6/74   186
      IYAX1=IYAX+1                                                     9/6/74   187
      AXLEN=IXAX                                                       9/6/74   188
      CALL SCALE(X,AXLEN,NPTS,1)                                       9/6/74   189
      AXLEN=IYAX                                                       9/6/74   190
      CALL SCALE(Y,AXLEN,NPTS,1)                                       9/6/74   191
C                                                                      9/6/74   192
C                                   FORM X LABELS AND FACTORS          9/6/74   193
C                                                                      9/6/74   194
      XMIN=X(NPTS+1,1)                                                 9/6/74   195
      DELTX=X(NPTS+2,1)                                                9/6/74   196
      XLAB(1)=XMIN                                                     9/6/74   197
      DO 260 I=1,IXAX                                                  9/6/74   198
  260 XLAB(I+1)=XLAB(I)+DELTX                                          9/6/74   199
```

```
      XSCAL=XAXIS/(XLAB(IXAX1)-XMIN)                                   9/6/74
C                                                                      9/6/74
C                               FORM Y LABELS AND FACTORS              9/6/74
C                                                                      9/6/74
      YMIN=Y(NPTS+1,1)                                                 9/6/74
      DELTY=Y(NPTS+2,1)                                                9/6/74
      YLAB(IYAX1)=YMIN                                                 9/6/74
      DO 270 I=1,IYAX                                                  9/6/74
  270 YLAB(IYAX1-I)=YLAB(IYAX1+1-I)+DELTY                              9/6/74
      YSCAL=YAXIS/(YLAB(1)-YMIN)                                       9/6/74
C                                                                      9/6/74
C                               INITIALIZE PLOT OUTLINE                9/6/74
C                                                                      9/6/74
      NCD=100                                                          9/6/74
      CALL PPLOT(0,0,NCO,NPLOT)                                        9/6/74
      K = 1                                                            9/6/74
      IF(IJOIN.EQ.0) GO TO 500                                         9/6/74
C                                                                      9/6/74
C                               DRAW IN EACH CURVE                     9/6/74
C                                                                      9/6/74
      DO 450 L=1,NCV                                                   9/6/74
       IF(NPT(L).EQ.0) GO TO 440                                       9/6/74
C                                                                      9/6/74
C                               JOINING XO YO AND XT YT                9/6/74
C                                                                      9/6/74
      XO=XSCAL*(X(1,L)-XMIN)                                           9/6/74
      YO=YSCAL*(Y(1,L)-YMIN)                                           9/6/74
      NPOINT = NPT(L)                                                  9/6/74
      DO 400 N = 2,NPOINT                                              9/6/74
      XT = XSCAL*(X(N,L) - XMIN)                                       9/6/74
      YT = YSCAL*(Y(N,L) - YMIN)                                       9/6/74
      CALL PINE(XO,YO,XT,YT,K,NPLOT)                                   9/6/74
      XO = XT                                                          9/6/74
      YO = YT                                                          9/6/74
  400 CONTINUE                                                         9/6/74
  420 CONTINUE                                                         9/6/74
  440 K = K + 1                                                        9/6/74
  450 CONTINUE                                                         9/6/74
      GO TO 550                                                        9/6/74
C                                                                      9/6/74
C PLOT WITHOUT JOINING POINTS                                          9/6/74
C                                                                      9/6/74
  500 NPOINT=NPT(1)                                                    9/6/74
      DO 510 N=1,NPOINT                                                9/6/74
      XT=XSCAL*(X(N,1)-XMIN)                                           9/6/74
      YT=YSCAL*(Y(N,1)-YMIN)                                           9/6/74
      IXT=XT+.5                                                        9/6/74
      IYT=YT+.5                                                        9/6/74
      CALL PPLOT(IXT,IYT,1,1)                                          9/6/74
  510 CONTINUE                                                         9/6/74
C                                                                      9/6/74
C                               OUTPUT FINAL PLOT                      9/6/74
C                                                                      9/6/74
  550 NC=99                                                            9/6/74
      CALL PPLOT(0,0,NC,NPLOT)                                         9/6/74
      RETURN                                                           9/6/74
      END                                                              9/6/74
```

```
      SUBROUTINE PINE(X1,Y1,X2,Y2,NSYM,NCT)                     9/6/74    257
      COMMON/AXES/XAXIS,YAXIS                                   9/6/74    258
      JXAX=XAXIS                                                9/6/74    259
      JYAX=YAXIS                                                9/6/74    260
      AXA=X1                                                    9/6/74    261
      AXB=X2                                                    9/6/74    262
      AYA=Y1                                                    9/6/74    263
      AYB=Y2                                                    9/6/74    264
      N=1                                                       9/6/74    265
      IF(ABS(AXB-AXA).LT.ABS(AYB-AYA)) GO TO 290                9/6/74    266
C                                                               9/6/74    267
C     SET PARAMETERS FOR X DIRECTION                            9/6/74    268
C                                                               9/6/74    269
      IF(AXB.GT.AXA) GO TO 245                                  9/6/74    270
      AXA=X2                                                    9/6/74    271
      AXB=X1                                                    9/6/74    272
      AYA=Y2                                                    9/6/74    273
      AYB=Y1                                                    9/6/74    274
  245 CONTINUE                                                  9/6/74    275
      IXA=AXA+.5                                                9/6/74    276
      IXB=AXB+.5                                                9/6/74    277
      IYA=AYA+.5                                                9/6/74    278
      IYB=AYB+.5                                                9/6/74    279
  250 CONTINUE                                                  9/6/74    280
      IF(IXA.LT.0.OR.IXA.GT.JXAX) GO TO 260                     9/6/74    281
      IF(IYA.LT.0.OR.IYA.GT.JYAX) GO TO 260                     9/6/74    282
      CALL PPLOT(IXA,IYA,NSYM,NCT)                              9/6/74    283
  260 CONTINUE                                                  9/6/74    284
      IXA=IXA+1                                                 9/6/74    285
      YA=(N*(AYB-AYA))/(AXB-AXA)                                9/6/74    286
      IYA=AYA+YA+0.5                                            9/6/74    287
      N=N+1                                                     9/6/74    288
      IF(IXA.LE.IXB) GO TO 250                                  9/6/74    289
      GO TO 400                                                 9/6/74    290
C                                                               9/6/74    291
C     SET PARAMETERS FOR Y DIRECTION                            9/6/74    292
C                                                               9/6/74    293
  290 CONTINUE                                                  9/6/74    294
      IF(AYB.GT.AYA)   GO TO 295                                9/6/74    295
      AYB=Y1                                                    9/6/74    296
      AYA=Y2                                                    9/6/74    297
      AXB=X1                                                    9/6/74    298
      AXA=X2                                                    9/6/74    299
  295 CONTINUE                                                  9/6/74    300
      IXA=AXA+.5                                                9/6/74    301
      IXB=AXB+.5                                                9/6/74    302
      IYA=AYA+.5                                                9/6/74    303
      IYB=AYB+.5                                                9/6/74    304
  300 CONTINUE                                                  9/6/74    305
      IF(IXA.LT.0.OR.IXA.GT.JXAX) GO TO 310                     9/6/74    306
      IF(IYA.LT.0.OR.IYA.GT.JYAX) GO TO 310                     9/6/74    307
      CALL PPLOT(IXA,IYA,NSYM,NCT)                              9/6/74    308
  310 CONTINUE                                                  9/6/74    309
      IYA=IYA+1                                                 9/6/74    310
      XA=(N*(AXB-AXA))/(AYB-AYA)                                9/6/74    311
```

```
SUBROUTINE  PINE                              CDC 6600 FTN V3.0-P340 OPT=0  09/18/74  08.56.03.        PAGE     2

                IXA=XA+AXA+0.5                                                    9/6/74     312
                N=N+1                                                             9/6/74     313
                IF(IYA-IYB) 300,320,400                                           9/6/74     314
            320 IXA = IXB                                                         9/6/74     315
                GO TO 300                                                         9/6/74     316
            400 RETURN                                                            9/6/74     317
                END                                                               9/6/74     318
```

```
      SUBROUTINE PPLOT(IX,IY,K,NCT)                                     9/6/74    319
      DIMENSION A(51,101),SYM(9)                                        9/6/74    320
      COMMON/AXES/XAXIS,YAXIS                                           9/6/74    321
      COMMON/LABELS/TOP(10),BOTTOM(10),SIDE(50)                         9/6/74    322
      COMMON /LAB/ TITLE(18),XLAB(11),YLAB(6)                           9/6/74    323
     1,HORIZ(20),VERT(6)                                                9/6/74    324
      DATA SYM / 4H****,4H++++, 4H    , 4HXXXX, 4H...., 4H2222,         9/6/74    325
     1 4H    , 4HIIII, 4H---- /                                         9/6/74    326
      IXAXI=XAXIS+1.                                                    9/6/74    327
      IYAXI=YAXIS+1.                                                    9/6/74    328
      JXAXI=XAXIS/10.+1.                                                9/6/74    329
      JYAXI=YAXIS/10.+1.                                                9/6/74    330
      IF(K-99) 200,220,230                                              9/6/74    331
  200 A(IYAXI-IY,IX+1)=SYM(K)                                           9/6/74    332
      RETURN                                                            9/6/74    333
  220 CONTINUE                                                          9/6/74    334
      I=0                                                               9/6/74    335
      WRITE(6,300) TOP                                                  9/6/74    336
  300 FORMAT(20X,10A4/1H /1H )                                          9/6/74    337
      DO 225 II=1,JYAXI                                                 9/6/74    338
      I=I+1                                                             9/6/74    339
      WRITE(6,310) SIDE(I),YLAB(II),(A(I,J),J=1,IXAXI)                  9/6/74    340
  310 FORMAT(A1,F7.1,101A1)                                             9/6/74    341
      IF(II.EQ.JYAXI) GO TO 228                                         9/6/74    342
      DO 224 JJ=1,9                                                     9/6/74    343
      I=I+1                                                             9/6/74    344
  223 WRITE(6,320) SIDE(I),(A(I,J),J=1,IXAXI)                           9/6/74    345
  320 FORMAT(A1,7X,101A1)                                               9/6/74    346
  224 CONTINUE                                                          9/6/74    347
  225 CONTINUE                                                          9/6/74    348
  228 CONTINUE                                                          9/6/74    349
      WRITE(6,102) (XLAB(I),I=1,JXAXI)                                  9/6/74    350
      WRITE(6,330) BOTTOM                                               9/6/74    351
  330 FORMAT(1H /20X,10A4)                                              9/6/74    352
  100 FORMAT(5X,101A1)                                                  9/6/74    353
  101 FORMAT(F4.0,1X,101A1)                                             9/6/74    354
  102 FORMAT(11F10.1)                                                   9/6/74    355
  103 FORMAT(1H1,5X,12A4,I6/)                                           9/6/74    356
  105 FORMAT(/15X,12A4)                                                 9/6/74    357
  106 FORMAT(3X,2A4,7X,101A1)                                           9/6/74    358
  230 IYAX=YAXIS                                                        9/6/74    359
      DO 250 I=1,IYAX                                                   9/6/74    360
      DO 240 J=1,IXAXI                                                  9/6/74    361
  240 A(I,J)=SYM(7)                                                     9/6/74    362
      A(I,1)=SYM(8)                                                     9/6/74    363
  250 CONTINUE                                                          9/6/74    364
      DO 260 J=1,IXAXI                                                  9/6/74    365
  260 A(IYAXI,J)=SYM(9)                                                 9/6/74    366
      DO 270  I=1,IXAXI,10                                              9/6/74    367
  270 A(IYAXI,I)=SYM(8)                                                 9/6/74    368
      IYJ=IYAXI-10                                                      9/6/74    369
      DO 290 I=11,IYJ,10                                                9/6/74    370
      A(I,1)=SYM(9)                                                     9/6/74    371
  290 CONTINUE                                                          9/6/74    372
      RETURN                                                            9/6/74    373
      END                                                               9/6/74    374
```

```
      SUBROUTINE SCALE (ARRAY,AXLEN,NPTS,INC)                    9/6/74   375
      COMMON/AXES/XAXIS,YAXIS                                    9/6/74   376
      DIMENSION ARRAY(NPTS),INT(5)                               9/6/74   377
      DATA INT/2,4,5,8,10/                                       9/6/74   378
      INCT=IABS(INC)                                             9/6/74   379
C                                                                9/6/74   380
C                             SCAN FOR MAX AND MIN               9/6/74   381
C                                                                9/6/74   382
      AMAX=ARRAY(1)                                              9/6/74   383
      AMIN=ARRAY(1)                                              9/6/74   384
      DO 250 N=1,NPTS,INCT                                       9/6/74   385
      IF(AMAX.LT.ARRAY(N)) AMAX=ARRAY(N)                         9/6/74   386
      IF(AMIN.GT.ARRAY(N)) AMIN=ARRAY(N)                         9/6/74   387
  250 CONTINUE                                                   9/6/74   388
      IF( AMAX - AMIN ) 275,255,275                              9/6/74   389
C                                                                9/6/74   390
C                             RESET MAX AND MIN FOR ZERO RANGE   9/6/74   391
C                                                                9/6/74   392
  255 IF( AMIN ) 265, 400, 260                                   9/6/74   393
  260 AMIN = 0.0                                                 9/6/74   394
      AMAX = 2.0 * AMAX                                          9/6/74   395
      GO TO 275                                                  9/6/74   396
  265 AMAX = 0.0                                                 9/6/74   397
      AMIN = 2.0 * AMIN                                          9/6/74   398
  275 CONTINUE                                                   9/6/74   399
C                                                                9/6/74   400
C                             COMPUTE UNITS/INCH                 9/6/74   401
C                                                                9/6/74   402
      RATE=(AMAX-AMIN)/AXLEN                                     9/6/74   403
C                                                                9/6/74   404
C                                   SCALE INTERVAL TO            9/6/74   405
C                                   LESS THAN 10                 9/6/74   406
      A=ALOG10(RATE)                                             9/6/74   407
      N=A                                                        9/6/74   408
      IF(A.LT.0) N=A-0.9999                                      9/6/74   409
      RATE=RATE/(10.**N)                                         9/6/74   410
      L=RATE+1.00                                                9/6/74   411
C                                                                9/6/74   412
C                             FIND NEXT HIGHER INTERVAL          9/6/74   413
C                                                                9/6/74   414
  280 DO 300 I=1,5                                               9/6/74   415
      IF(L-INT(I)) 320,320,300                                   9/6/74   416
  300 CONTINUE                                                   9/6/74   417
C                                                                9/6/74   418
C                             L IS NEXT HIGHER INTERVAL          9/6/74   419
C                             RANGE IS SCALED BACK TO FULL SET   9/6/74   420
C                                                                9/6/74   421
  320 L=INT(I)                                                   9/6/74   422
      RANGE=FLOAT(L)*10.**N                                      9/6/74   423
      IF(INC.LT.0) GO TO 350                                     9/6/74   424
C                                                                9/6/74   425
C                             SET UP POSITIVE STEPS              9/6/74   426
C                                                                9/6/74   427
      K=AMIN/RANGE                                               9/6/74   428
      IF(AMIN.LT.0.) K=K-1                                       9/6/74   429
```

```
      C                                                                9/6/74   430
      C                             CHECK FOR MAX VALUE IN RANGE       9/6/74   431
      C                                                                9/6/74   432
            IF(AMAX.GT.(K+AXLEN)*RANGE) GO TO 330                      9/6/74   433
            I=NPTS*INCT+1                                              9/6/74   434
            ARRAY(I)=K*RANGE                                           9/6/74   435
            I=I+INCT                                                   9/6/74   436
            ARRAY(I)=RANGE                                             9/6/74   437
            RETURN                                                     9/6/74   438
      C                                                                9/6/74   439
      C                             IF OUTSIDE RANGE RESET L AND N     9/6/74   440
      C                                                                9/6/74   441
        330 L=L+1                                                      9/6/74   442
            IF(L.LT.11) GO TO 280                                      9/6/74   443
            L=2                                                        9/6/74   444
            N=N+1                                                      9/6/74   445
        340 GO TO 280                                                  9/6/74   446
      C                                                                9/6/74   447
      C                             SET UP NEGATIVE STEPS              9/6/74   448
      C                                                                9/6/74   449
        350 K=AMAX/RANGE                                               9/6/74   450
            IF(AMAX.GT.0.) K=K+1                                       9/6/74   451
            IF(AMIN.LT.(K+AXLEN)*RANGE) GO TO 330                      9/6/74   452
            I=INCT*NPTS+1                                              9/6/74   453
            ARRAY(I)=K*RANGE                                           9/6/74   454
            I=I+INCT                                                   9/6/74   455
            ARRAY(I)=-RANGE                                            9/6/74   456
            RETURN                                                     9/6/74   457
        400 WRITE(6,100)                                               9/6/74   458
        100 FORMAT(* // 10X, *RANGE AND SCALE ARE ZERO ON PLOT ATTEMPT*  )   9/6/74   459
            RETURN                                                     9/6/74   460
            END                                                        9/6/74   461
```

FHWA

R&D