LEAST TOTAL EXPECTED COST (LTEC) ANALYSIS FOR SELECTING A DEFENSIBLE DESIGN FLOOD FREQUENCY FOR HIGHWAY DRAINAGE STRUCTURES IN WYOMING

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INTRODUCTION

1.1 ISSUES IN DESIGN AND OPERATIONAL PERFORMANCE STANDARDS OF HIGHWAY DRAINAGE STRUCTURES

The purpose of a highway is to serve the public. Among many things that affect the service performance of a highway, the design and operational performance of a drainage structure on the highway crossing is one of the main concerns. With regard to the design and operational performance of a highway drainage structure, the commonly used design parameter is the design flood frequency (or design flood return period). In regard to the current Wyoming Department of Transportation (WDT) Operating Policy 18-6 which would be impacted by this research, it is expected that design flood frequencies of highway drainage structures currently adopted in the Policy will be affected. As with most state transportation agencies, the present design flood frequencies in Operating Policy 18-6 are arbitrary and are based on practices that have "evolved" over the years.

During the late 1970's and early 1980's, the concept of ***Least Total Expected Cost (LTEC) analysis*** was developed for determining the design flood frequency for various hydraulic structures. Because of the burden of applying this concept to all drainage structures, state transportation agencies opted to apply an assessment procedure in lieu of a rigorous application of the LTEC analysis. The LTEC analysis would result in a structural design associated with the minimum total amount of structural installation cost and expected future flood related damage cost. The corresponding design frequency is called ***LTEC design frequency***. Note that while the design frequency as determined from the conventional LTEC analysis is purely based on the economic efficiency involving the evaluation of tangible items, there are many intangible factors that might affect the final adoption of a design flood frequency in the WDT's Operating Policy. Currently, the effect of intangible factors, in general, are subjectively evaluated. It is felt that, in our present and future legal environment, having used the findings from an LTEC analysis to reach a conclusion on an appropriate design frequency for a site may have some merit in avoiding a negligence claim. Clearly, the use of such findings must be tempered by judgement and experience.

In this research, two types of design frequencies are the targets of the extensive study, namely, the LTEC design frequency and ***extended-LTEC design frequency***. The LTEC design frequency is the conventional, solely economically-based design frequency using tangible factors whereas the extended-LTEC design frequency incorporates the effect of other intangible factors in the determination of flood design frequency for highway drainage structures. The difference between the extended-LTEC design frequency and the LTEC design frequency represents the "***intangible return interval (RI)***". Note that this intangible RI depends on the LTEC design frequency and other intangible criteria.

A question can be raised about the feasibility or practicality of including such an intangible RI as a policy guideline, because judgements given to each of the intangible factors would vary from one site to another and from one individual to another. That is, each design problem is site specific. Clearly, to ignore these intangible factors is not acceptable. Therefore, in addition to providing a simple and reliable means of addressing the tangible factors, it is necessary to provide a uniform and reliable means of assessing the intangible factors.

1.2 SCOPE, OBJECTIVES, AND TASKS OF THE STUDY

The main thrust of this study is to develop a scientifically and technically defensible procedure for quickly and easily estimating the design flood frequency associated with the least total expected cost for almost all highway drainage structures in Wyoming by considering the important tangible and intangible factors. The results of the study would provide a mechanism, when coupled with WDT design practice and policy, for selecting a design frequency for various roadway crossing structures in Wyoming. As such these research findings will complement current WDT Design and Operating Policy 18-6. Types of highway drainage structures considered are bridges as well as box and pipe culverts. Storm drains and other unique drainage facilities are not addressed by this research. However, the methodological framework developed in this study can equally be applied to other types of highway drainage facilities. The LTEC analysis adopted in this study considers only the inherent hydrologic randomness of floods without incorporating uncertainties from other aspects such as hydraulic uncertainties. Furthermore, the cost associated with the loss of highway drainage structures during their expected service life is not considered in the LTEC analysis.

The original goal of the study was to develop empirical working equations that relate LTEC design frequency to relevant economic, social, and drainage basin characteristics. Later, it was felt that the goal could be extended to bring both tangible and intangible factors into the overall decision-making process for determining a more appropriate design frequency for highway drainage structures. Such multi-dimensional decision-making framework would result in a balanced decision between the tangible technical quantities, and the intangible items such as available funds, public convenience, future maintenance budget, and legal liability of the WDT. This balanced design framework would provide a finding to be tempered by judgement in selecting a design flood frequency to be considered.

To address the issues and problems considered in this research, it appears practical to perform the task of determining the appropriate design frequency for highway drainage structures in the following three phases:

Phase 1 Determine the LTEC design frequency solely based on tangible physical and economic characteristics of the sites typical to Wyoming.

Phase 2 For each site typical to Wyoming, develop a mechanism for determining the extended-LTEC design frequency by incorporating relevant intangible factors.

Phase 3 Based on all relevant sites typical to Wyoming, develop working relationships between the LTEC /extended-LTEC design frequencies and various site conditions, tangible and intangible factors.

Based on the above outline, the approach adopted in this research was to first develop algorithms for estimating the significant tangible factors and costs necessary for reliably applying LTEC practices to WDT road-crossing drainage facilities such as culverts and bridges. Next, efforts were directed at identifying and quantifying the various intangible factors commonly considered important in highway drainage structure designs. Following this rather unique investigation a vast data base was assembled which is representative of wide range of watershed and drainage site characteristics found in Wyoming and perhaps other states. This data base was then analyzed and equations formulated to allow a hydraulics engineer or designer to quickly, *and with known accuracy limits*, identify an LTEC design frequency for comparison with the design frequency set by WDT policy. The findings from the aforementioned analysis of intangible factors affecting a drainage design were then analyzed and guidance formulated so they could be objectively considered by the hydraulics engineer or designer in selecting a scientifically defensible design flood frequency.

More specifically, the major tasks performed to accomplish the study objectives involves:

(1) Identification, definition, and collection of social, economical, and physical parameters and variables relevant to the design of highway drainage structures;
(2) Determination of a flood frequency associated with the LTEC design practice;
(3) Determination of an extended-LTEC frequency by considering, in addition to the economic aspect, certain intangible factors that affect the selection of design frequency;
(4) Development of a mechanism to relate LTEC design frequency and/or extended-LTEC design frequency to economic, social, hydrologic/hydraulic characteristics of drainage basins which are typical to Wyoming and perhaps other states.

1.3 ORGANIZATION OF THE REPORT

This project report summarizes the work performed for the cooperative research project entitled, "Selecting Appropriate Flood Design Frequencies for Drainage Basins in Wyoming" between the WDT and the Wyoming Water Resources Center (WWRC). According to the three task phases, this report is organized in three major parts. The first part contains Chapters 2-8 describing the procedures taken to determine the LTEC design frequency for a specified condition representative of Wyoming sites. In this first part, Chapter 2 briefly describes the theoretical basis of the LTEC design procedure. Then, developments of cost functions for the three types of highway drainage structures, based on the construction records in Wyoming, are described in Chapter 3. In Chapter 4, identification and definition of relevant variables and parameters in the LTEC analysis of highway drainage structures were made followed by the collections of relevant basin and channel characteristics as well as economic variables representative of State of Wyoming in Chapters 5-6. In Chapter 7, simplified working relationships of hydraulic responses of culverts and bridges were derived from the complete hydraulic simulators. The purpose of deriving such working relationships is to use them in the LTEC design procedure to accurately represent the hydraulic responses of highway drainage structures without using the complete hydraulic simulators. In Chapter 8, the algorithm for the LTEC design of highway drainage structures is described.

Part two of the report deals with analysis of effects of intangible factors on the determination of design frequency of highway drainage structures. Chapter 9 discusses various tangible and intangible factors that are potentially important in designing highway drainage structures and the mechanisms for dealing with them. A description was given in Chapter 10 of design of survey questionnaires for obtaining information with regard to preference judgements on various tangible and intangible factors. The analyses of survey responses was made in Chapter 11 which provide the basis to objectively develop quantitative relationships for determining the extended-LTEC design frequency. Chapter 12 describes the method employed in this research to incorporate uncertainty feature of the survey responses in a multi-attribute decision-making framework for determining the extended-LTEC design frequency. Specifically, fuzzy set theory was used and its basic features were described.

In Part three, Chapter 13 describes the framework that integrates all aspects of this study in constructing the data base for establishing practical working relationships between the LTEC and extended-LTEC design frequencies and various characteristics at a drainage structure site. Chapter 14 details the analysis for the establishment of the working relationships based on the data base generated in Chapter 13. Summary and conclusions from this research study were given in Chapter 15.

Also included at the end of this report are appendices containing some background information and user's instructions for the computer program developed in this study. Appendix A.1 contains the survey questionnaire for gathering opinions of 'experts' in the field of highway drainage structure design about the relative importance of various tangible and intangible factors. Appendix A.2 contains the summary of raw data obtained from the survey. Appendix A.3 is the user's manual for the computer program, DSGNFREQ, developed from this research which is the working tool for determining the LTEC and extended-LTEC design frequencies of for various highway drainage structures in Wyoming. Source code of the computer program was provided to the WDT.

2.
THE LTEC DESIGN OF HIGHWAY DRAINAGE STRUCTURES

2.1 THEORETICAL BACKGROUND OF THE LTEC DESIGN

The LTEC (or risk-based) hydraulic design is a procedure which evaluates among alternatives by considering the tradeoff between the investment cost and the expected economic losses. Specifically, the conventional LTEC design considers the inherent hydrologic uncertainty in the calculation of the expected economic losses. The design return period is a decision variable instead of being a pre-selected design parameter value as with the traditional return period design procedures.

The concept of LTEC design has been recognized for many years. As early as in 1936, Congress passed the Flood Control Act of (U. S. Statutes 1570) in which consideration of failure consequence in the design procedure was advocated. The economic risks or the expected flood losses were not explicitly considered until the early 1960's. Harold D. Pritchett's work (1964) was one of the early attempts to apply the risk-based hydraulic design concept to highway culverts. At four actual locations, Pritchett calculated the investment costs and the expected flood damage costs on the annual basis for several design alternatives among which the most economical one was selected. The results indicated that a more economical solution could be reached by selecting smaller culvert sizes compared with the conventional return period method used by the California Division of Highways. Several papers followed this initial investigation on the evaluation of economic risks and optimal design was performed for box culverts and pipe culverts (Young et al., 1970; 1974) and bridges and pipe culverts (Tseng et al., 1975; Bradley, 1973). Two reports published by Federal Highway Administration of the U. S. Department of Transportation in 1980 were good examples of this type of risk-based design (Corry et al., 1980; Schneider and Wilson, 1980). Recently, an overall view of the LTEC design of highway drainage structures were given by Tung and Bao (1990).

The LTEC design procedure attempts to obtain the optimal engineering design associated with the least total expected cost. The problem can be cast into

$$\textit{Minimize} \quad TEC = FC(\boldsymbol{x}) \times CRF + SC(\boldsymbol{x}) \tag{2.1}$$

subject to

$$g(\boldsymbol{x}) = \mathbf{0} \tag{2.2}$$

in which TEC represents the total expected cost; bold-faced $\mathbf{x}=(x_1, x_2, \ldots, x_n)$ represents a vector of n design variables pertinent to those describing the features of a highway drainage structure; FC(**x**) is the installation cost of the drainage structure converted to the annual value using the capital recovery factor (CRF); SC(**x**) is the second cost representing the annual cost associated with flood damage; and $\mathbf{g}(\mathbf{x})=\mathbf{0}$ is a vector of constraints representing the design specifications.

Because the exact amount of annual flood damage over the service life of the project is not known and could vary one year from the other, it is, therefore, practical to use the expected annual flood damage to present the extent of the second cost. Some examples of the LTEC design of highway drainage structures can be found elsewhere (Corry et al., 1980; Schneider and Wilson, 1980; Tung and Mays, 1982; Mays and Tung, 1992). In essence, the LTEC design seeks to identify the highway drainage structure configuration and the corresponding design flood frequency by obtaining a balance between the first and second costs as shown in Figure 2.1.

2.2 PROCEDURES FOR DETERMINING ANNUAL EXPECTED DAMAGE (SECOND COST)

In general, the determination of first cost related to the installation of structural is straightforward. It primarily depends on the size of the structure. The thrust of the exercise in the LTEC design is to evaluate SC(**x**) in Eq.(2.1) which is a function of the statistical properties of loading and resistance, damage function, and the types of uncertainty considered. In the context of highway drainage structure designs, the loadings are floods of different return periods while the resistance is the flow capacity of the highway drainage structure. This study adopts the conventional LTEC design in which only the inherent hydrologic uncertainty associated with the flood is considered. With that, the annual expected damage cost can be evaluated as

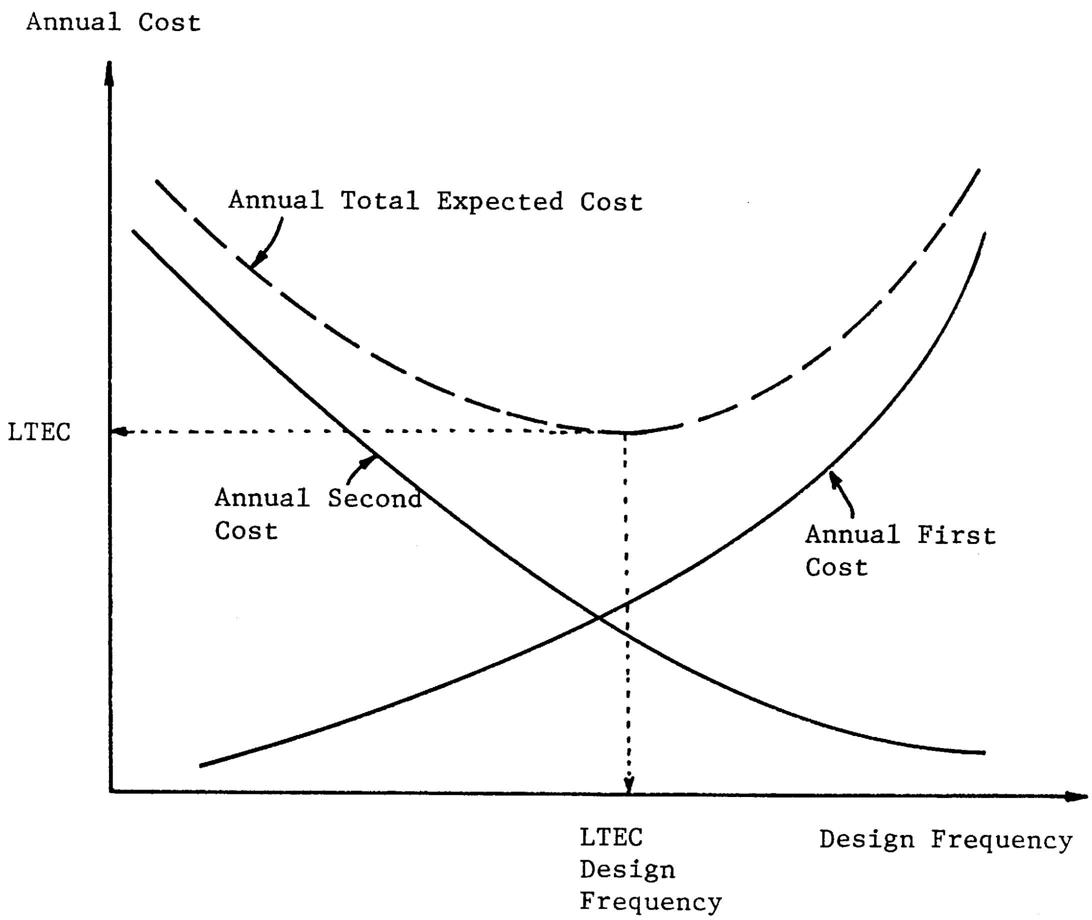


Figure 2.1 Schematic Diagram of the LTEC Design

$$E(D) = \int_{q_o}^{\infty} D(q) f(q) dq \tag{2.3}$$

where SC(x)=E(D) is the annual expected flood damage cost; q_o is a deterministic quantity representing the threshold discharge of the highway drainage structure beyond which flood damage would occur; f(q) is the probability density function of the annual flood; and D(q) is the damage function in highway drainage structural design which consists of the four components in Eq.(2.4),

$$D(q) = D_B(q) + D_C(q) + D_E(q) + D_T(q) \tag{2.4}$$

in which $D_B(q)$ is the damage to buildings; $D_C(q)$ is the damage to crops; $D_E(q)$ is the damage to the embankment and pavement; and $D_T(q)$ is the traffic-related damage.

In general, Eq.(2.3) is evaluated by performing numerical integration considering flood magnitudes at discrete return periods. Using the regional flood frequency equations such as those developed by Druse et al. (1988) for Wyoming, as they are developed for various discrete return periods, Eq.(2.3) can be replaced by

$$E(D) \approx \sum_i \overline{D_i(q)} \Delta F_i \tag{2.5}$$

where ΔF_i is the incremental probability for the i-th interval of the frequency scale and $D_i(q)$ is the average damage for the i-th interval. Detail computational procedure is illustrated by Mays and Tung (1992, Chapter 12).

Strictly speaking, the annual expected flood damage cost in the LTEC design should be the incremental damage as the result of the presence of the roadway crossing structures. The annual expected flood damage for the pre-construction condition should be calculated. Area of inundation in the floodplain for the pre-construction condition can be estimated using the depth computed from the uniform flow equation. A schematic diagram illustrating the inundated areas before and after the construction for a given flood discharge is shown by Figure 2.2.

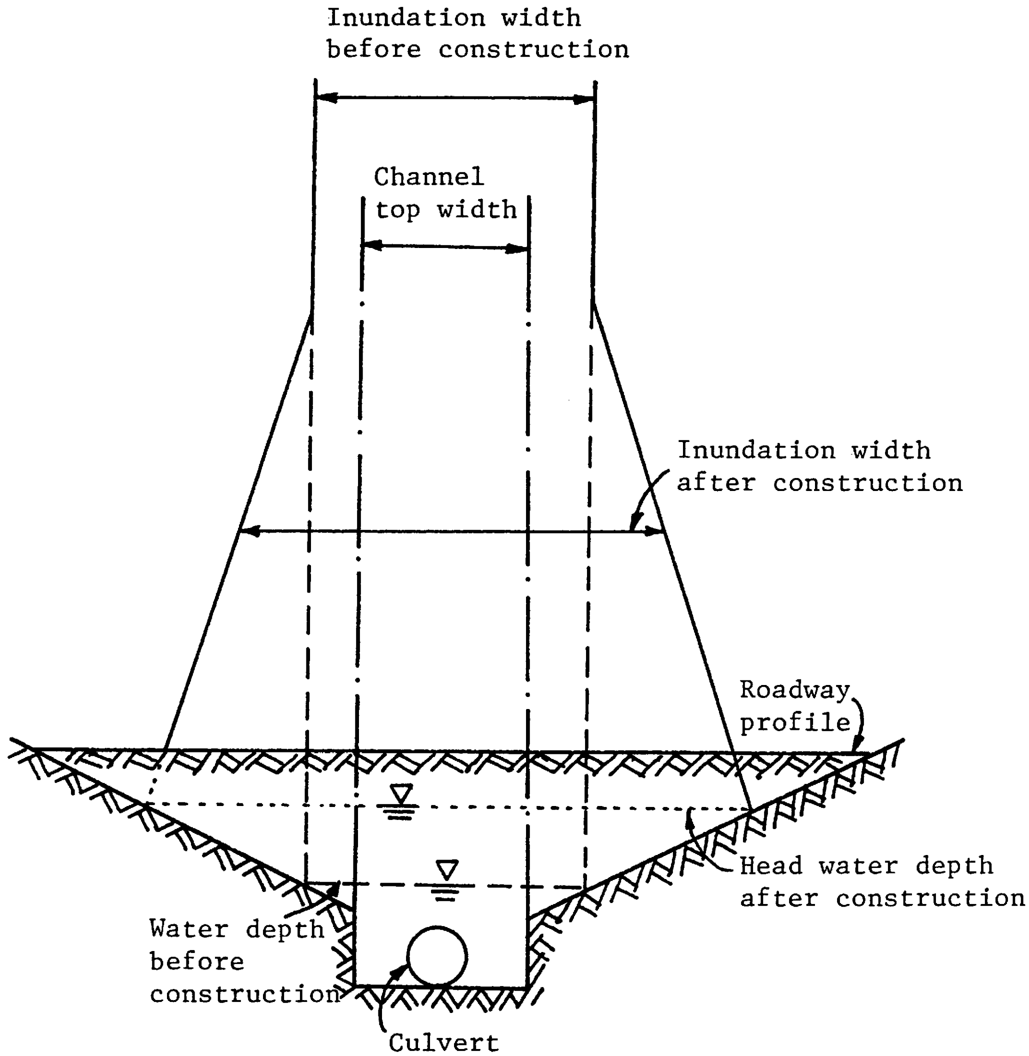


Figure 2.2 Schematic Diagram Showing the Inundated Area Before and After Construction.

It must be recognized that flood magnitudes obtained from the regional regression equations such as those by Druse et al. (1988), or from other means, are only estimates of the true but unknown discharges. They are associated with uncertainties indicated by their standard errors. Inclusion of the uncertainty in a regional flood regression is theoretically possible according to Bao et al. (1987). However, the computational intensiveness makes the implementation of such a scheme infeasible for the application of this study.

3.
DEVELOPMENT OF COST FUNCTIONS FOR PIPE CULVERTS, BOX CULVERTS, AND BRIDGES

The main objective of this chapter is to present and summarize the effort in attempting to establish cost functions for the three types of highway drainage structures considered in this study. Cost information was extracted from various publications provided by the WDT such as Wyoming Construction Weighted Average Bid price forms (Wyoming Construction, 1965 - 1985). Adjustment of costs from the Bid in different years was made according to the Wyoming Construction Cost Index (Wyoming Highway Department, 1964-1984) shown in Table 3.1 with 1977 as the base year. Therefore, it should be noted that the cost figure computed for drainage structures (i.e., the first cost) based on the cost functions developed in this chapter are 1977 figures. They are adjusted by a multiplier in the LTEC analysis described in the later chapters of this report.

3.1 PIPE CULVERTS

After several revisions, cost functions for pipe culverts of various materials and types were developed and are shown in Table 3.2. Originally, cost functions were developed for pipe culverts for different highway systems. However, it was later found that the differences in the mean unit pipe culvert costs among different highway systems were insignificant. Therefore, pipe culverts of a given material in various highway systems were combined into one category to develop the cost functions. It should be pointed out that pipe culverts of a given material with flared ends and without flared ends were considered separately because of the incompatibility of the cost units; the former has the unit of $/each pipe and the latter $/linear foot.

Statistics such as standard errors associated with each cost function provide important information on the degree of uncertainty associated with the developed cost functions. They can be used as the basis to evaluate the sensitivity or uncertainty in installation cost on the LTEC design frequency. In fact, the standard errors associated with cost functions are used later to generate a synthetic data base.

Table 3.1 Annual Construction Index.(Wyoming State Highway Department, 1984c)

YEAR	INDEX (1977=100%)
1964	34.769
1965	45.471
1966	44.671
1967	44.405
1968	46.270
1969	50.666
1970	52.265
1971	56.883
1972	55.773
1973	62.167
1974	90.187
1975	95.160
1976	99.512
1977	100.000
1978	127.500
1979	148.700
1980	158.100
1981	153.000
1982	139.800
1983	144.300
1984	146.400
1985	151.900

Table 3.2 Pipe Culvert Cost Functions

Case No.	Type of Pipe	Unit	Equation	Data Limitation	R	Standard Error	Sample Size n					
							I*	P*	U*	S*	CFM*	Total
1	Pipe	$/LF; Inches	ln(C) is the $1.51 + 0.0142D + 0.0759[\ln(D)]^2$	6" to 120"	0.932	0.2355	54	110	88	20	2	272
2	RCP (Instld)	$/LF; Inches	C is the $11.6 + 0.0212D^2$	12" to 96"	0.919	14.51	31	28	13	29	7	108
3	CMP (Instld)	$/LF; Inches	C is the $13.2 + 0.0102D^2$	6" to 96"	0.857	9.763	46	53	58	19	78	253
4	CMP Arch	$/LF; Inches	C is the $0.41 + 0.00378D^2 + 0.521D$	18"$_x$ to 142"$_x$	0.941	10.94	16	18	19	13	21	87
5	Pipe (Instld)	$LF; Inches	C is the $10.9 + 0.00898D^2$	6" to 72"	0.907	4.551	14	27	23	6	15	85
6	CMP Arch	$/LF; Inches	C is the $15.3 + 0.00732D^2$	18"$_x$ to 142"$_x$	0.877	20.36	24	40	43	2	18	124
7	RCP FE	$/EA; Inches	ln(C) is the $3.32 + 0.187[\ln(D)]^2$	12" to 90"	0.925	0.2639	31	61	36	15	6	112
8	CMP FE	$/EA; Inches	C is the $639 + 25.3D - 359[\ln(D)]^2$	12" to 84"	0.942	75.42	23	36	37	5	12	112
9	Piep FE	$EA; Inches	ln(c) is the $1.73 + 0.282[\ln(D)]$	12" to 78"	0.948	0.2827	32	80	57	19	1	188
10	Pipe FE (Instld)	$/EA; Inches	C is the $22.6 + 0.171D^2$	12" to 66"	0.955	47.31	6	19	12	4	7	48
11	CMP Arch FE (Instld)	$/EA; Inches	ln(C) is the $3.41 + 0.0409D$	18"$_x$ to 72"$_x$	0.954	0.2278	6	4	11	9	2	32
12	Relaying pipe	$/LF; Inches	C is the $7.82 + 0.00524D^2$	5" to 90"	0.833	6.214	7	12	11	6	15	51
13	CMP	$/LF; Inches	ln(C) is the $1.28 + 0.150[\ln(D)]^2$	6" to 120"	0.922	0.2699	96	118	126	16	43	394
14	RCP arch	$/LF; Inches	ln(C) is the $1.06 + 0.185[\ln(D)]^2$	22"$_x$ to 88"$_x$	0.938	0.1825	55	57	17	12	8	148

Table 3.2 Pipe Culvert Cost Functions (continued)

Case No.	Type of Pipe	Unit	Equation	Data Limitation	R	Standard Error	Sample Size n I*	P*	U*	S*	CFM*	Total
15	Pipe arch FE	$/AE; Inches	C is the $302 + 0.329D^2 - 17.0D$	17"$_x$ to 81"$_x$	0.897	106.4	9	30	17	4	-	60
16	RCP	$/LF; Inches	C is the $7.55 + 0.0201D^2$	12" to 132"	0.966	11.12	118	154	104	32	29	429
17	Pipe FE (corrosion resist.)	$/EA; Inches	C is the $-32.9 + 0.237D^2$	18" to 66"	0.946	89.84	8	36	13	8	-	65
18	CSP Arch	$/LF; Inches	C is the $6.97 + 0.0138D^2$	18"$_x$ to 72"$_x$	0.940	6.846	4	6	6	-	13	29
19	Pipe (corr. resist.)	$/LF; Inches	ln(C) is the $1.94 + 0.0363D$	18" to 78"	0.898	0.2701	16	45	17	8	4	86
20	CMP Arch FE	$EA; Inches	ln(c) is the $3.44 + 0.0422D$	22"$_x$ to 72"$_x$	0.957	0.1819	7	3	12	-	2	24
21	CSP	$/LF; Inches	ln(C) is the $1.27 + 0.154[\ln(D)]^2$	6" to 90"	0.919	0.2883	24	14	10	-	21	69
22	RCP Arch FE	$/EA; Inches	ln(C) is the $3.47 + 0.164[\ln(D)]^2$	29"$_x$ to 88"$_x$	0.939	0.1620	18	8	6	-	2	34
23	RCP Arch (Instld)	$/LF; Inches	C is the $-16.7 + 1.31D$	22"$_x$ to 88"$_x$	0.925	8.639	-	7	4	8	-	19

*I - Interstate; P - Primary; U - Urban; S - Secondary; CFM - County/Farm

The column "Data Limitation" in Table 3.2 shows the lower and upper bounds of pipe size used in this study. It is believed that the developed cost functions can be extrapolated beyond the present data range to slightly larger culvert sizes without seriously damaging the validity of the functions for use in an LTEC analysis. The data set represents the culvert sizes that have been used for highway crossings in Wyoming over the past 20 years. Of course, the use of larger pipe sizes in the future is possible.

The unit cost of the embankment is available from Wyoming Construction (1965 - 1985) which was also adjusted to year 1977. This unit cost is to be multiplied by the total volume of embankment to obtain the total cost of the embankment. The volume of embankment can be estimated if the physical layout of the roadway crossing is specified (Figures 3.la and 3.1b).

3.2 BOX CULVERTS

Installation cost of box culverts primarily involves cost of culvert and embankment. The total cost of a box culvert can be estimated as

$$C_{box} = N\ L\ (U_c\ Q_c + U_s\ Q_s) \qquad (3.1)$$

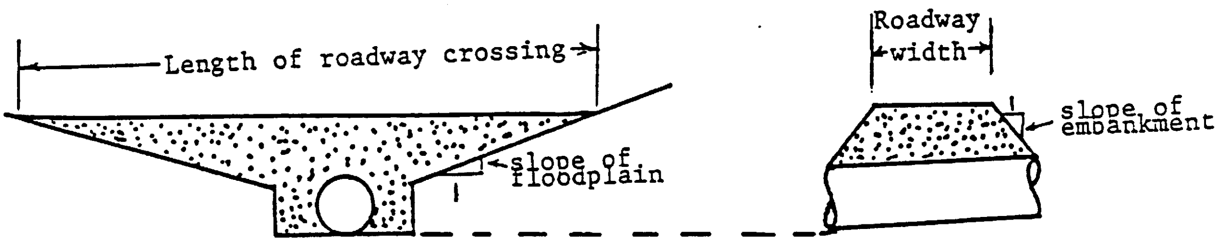
where C_{box} is the cost of a box culvert (\$), N is the number of barrels, L is the length of box culvert (ft.), U_c is the unit cost of concrete (\$/yd^3), Q_c is the quantity of concrete per unit length (yd^3/ft), U_s is the unit cost of reinforced steel (\$/lb), and Q_s is the quantity of reinforced steel per unit length (lb/ft). Variables Q_c and Q_s in Eq.(3.1) may potentially depend on the physical characteristics of the box culvert such as the width of barrel, height of culvert, and fill height. Fill height was found to have very little effect on estimating Q_c and Q_s and, consequently, was dropped from the equations. The two resulting equations for estimating Q_c and Q_s are

$$Q_c = -0.563 + 0.0764\ B + 0.189\ H \qquad (3.2)$$

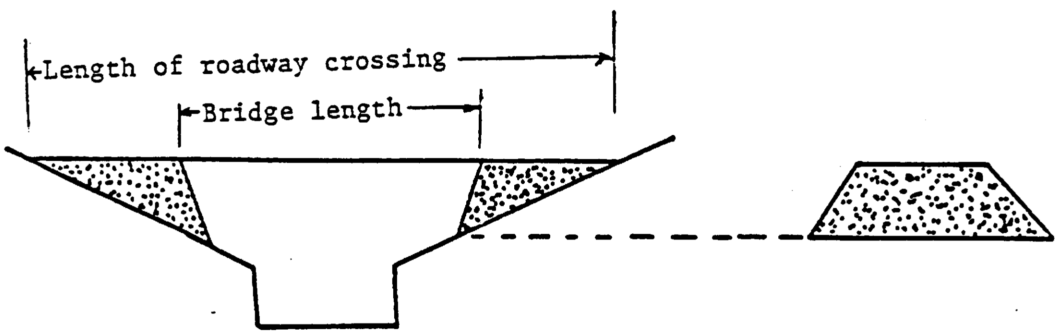
with a correlation coefficient of 0.89, and

$$Q_s = -5.87 + 2.55\ B\ H \qquad (3.3)$$

with a correlation coefficient of 0.95, in which B is the width of barrel (ft.) and H is the height of box culvert (ft.). The total cost for the roadway crossing can be estimated by adding the cost of embankment to the cost of the box culvert.



(a) Roadway Crossing with Culverts



(b) Roadway Crossing with Bridge

Figure 3.1 Schematic Diagrams of Roadway Crossings with Culverts and Bridges.

To estimate the cost associated with a box culvert having a capacity to accommodate the flood magnitude of a specified return period, variables such as N, L, B, H, roadway layout, and channel characteristics must be specified by the design engineer. However, it appears that in designing a box culvert, there are many possible combinations of N, W, and H which would yield essentially the same conveyance capacity. That is, the problem then becomes an optimization problem where the optimal N, W, and H leading to the minimum installation cost would be sought. Naturally, in the course of optimizing N, W and H, design specifications of the WDT on roadway geometry must be followed. In this study, a computer program LTEC.FOR was developed to implement the search of optimum box culvert geometry with the minimum first cost. Descriptions of the computer program LTEC.FOR are given in Chapter 8 of this report.

3.3 BRIDGES

To develop the first cost function for bridges, the dependent variable considered was the unit cost of a bridge per square foot of bridge deck. Independent variables potentially relevant are: length and type of bridge, type of substructure, clearance height of bridge, soil condition, and other variables, including wire enclosed riprap, removal of old bridge, reinforced concrete approach slabs. However, use of these variables is impractical for an LTEC analysis due to the fact that, when the LTEC design is performed, the details of the bridge design are normally unavailable except for the length and width of the bridge. It is unrealistic to develop a bridge cost function involving any design variables which are unknown or susceptible to changes in the later stage of design.

A preliminary investigation was performed to examine the relationship between unit cost of a bridge per square foot of bridge deck and relevant, known variables. The result of the correlation study based on 85 data points provided by the WDT was that the length of a bridge has a more important role than other variables in explaining the variation of unit cost of a bridge. However, the correlation coefficient is only around 50 percent. Later, more data were provided by the WDT with the intent of improving this original cost function. With 238 bridge data points included in a stepwise regression analysis, it was again found that the bridge length is the most important variable. The resulting regression equation is

$$U_{brdg} = 159 - 34.6 \ln(L) + 0.323 L - 0.000316 L^2 \tag{3.4}$$

with a correlation coefficient of 58 percent and standard error of $5.885/ft². The unit bridge cost versus bridge length for all 238 data points are shown in Figure 3.2. As can be seen, there is significant scatter in the data set. A series of trials were made by gradually deleting some outliers based on the magnitude of a standardized residual in an attempting to find the model structure that describes the data behavior. After sequentially deleting 96 'outliers', the final model had exactly the same structure as Eq.(3.4), but with a correlation coefficient of 0.914 and standard error of 1.885 $\$/ft^2$

Deletion of 96 data points represents a 40 percent reduction in the total number of data points. Although the regression equation associated with the reduced data set has a much higher correlation coefficient and smaller standard error, it can only be regarded as artificial and does not truly represent the behavior of the total data set. Low correlation coefficients results because there are many other important characteristics of bridges such as bridge type, geologic condition and substructure type that cannot be specified at the time when the LTEC analysis is performed. It is felt that the model derived on the basis of the total data set is more representative of the realistic design situation because the total data set lumps bridges of many different types and their individual characteristics. It perhaps would be desirable to develop cost functions for bridges of different characteristics as was done for pipe culverts. Again, however, different bridges still involve many variables that are not known in advance of the LTEC analysis, including the expected bridge type.

Examining Figure 3.2 closely, it appears that unit bridge cost per square foot has two distinct behaviors. That is, for bridges with a length shorter than some threshold value, the unit bridge cost decreases sharply as bridge length increases; when the bridge length is longer than this threshold value, the unit bridge cost increases only slightly with bridge length. A piece-wise linear cost function was developed using a pattern-search technique called the Hooke-Jeeves method (Hooke and Jeeves, 1961) to minimize the standard error of estimates. The resulting equation is

$$U_{brdg} = \begin{cases} 65 - 0.4813\ L, & L \leq 83' \\ 23.75 + 0.01875\ L, & L > 83' \end{cases} \tag{3.5}$$

with a standard error of 5.855 \$/ft which is slightly less than that for Eq. (3.4).

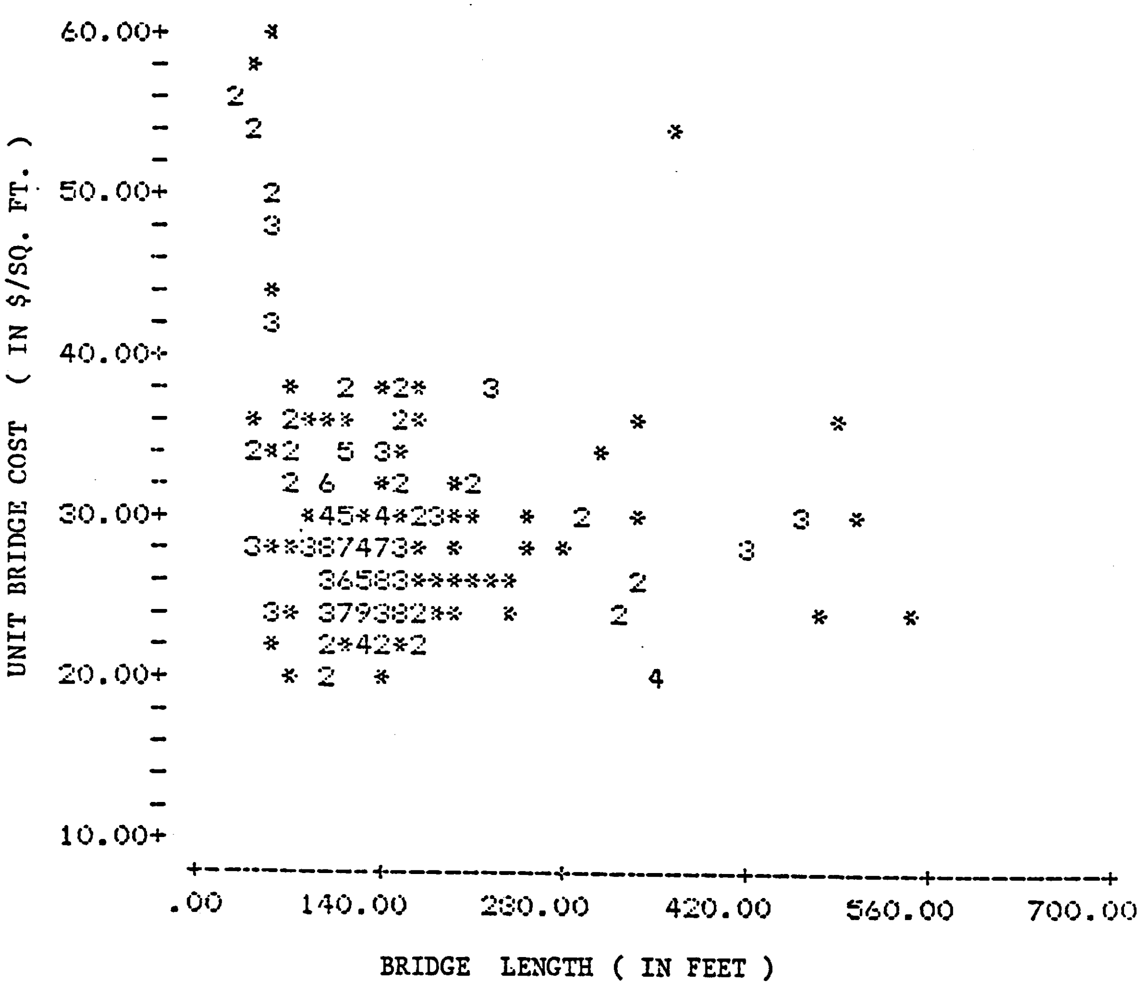


Figure 3.2 Scatter Plot of Unit Bridge Cost Versus Bridge Length

Although highly accurate cost functions for bridges could be derived, the function developed is considered sufficient for estimating the LTEC design frequency. The total cost of a roadway crossing using a bridge can be calculated by adding the cost of the embankment to the cost of the bridge structure (Figure 3.1b).

4.
IDENTIFICATION AND DEFINITION OF RELEVANT VARIABLES AND PARAMETERS IN THE LTEC DESIGN OF HIGHWAY DRAINAGE STRUCTURES

Since the LTEC design involves the evaluation of the first cost (i.e., structure and installation costs) and the second cost (i.e., flood related damage costs), the relevant variables and parameters associated with the first cost and the second cost were identified and are listed in Tables 4.1 and 4.2, respectively. Variables in this study were defined as those inputs which would vary from one site to another, while parameters were defined as constants which do not vary and are universally usable by all drainage structure sites. It should be noted that these lists of variables and parameters in Tables 4.1 and 4.2 are the modified version of a more extensive list extracted from published literature (Corry et al., 1980; Schneider and Wilson, 1980; Young and Childrey, 1974).

However, knowing that for new constructions the LTEC design must be performed during the early stage of planning, detailed information required for actual design is not always known in advance. Therefore, the list shown in Tables 4.1 and 4.2 was chosen on the basis of availability of information to a designer at the time when the LTEC design frequency is normally determined.

Table 4.1 Variables and Parameters Relevant in Evaluating the First Cost of Roadway Crossings.

Item	*PIPE CULVERTS*	*BOX CULVERTS*	*BRIDGES*
Parameters	Unit cost of culvert	Unit costs of concrete and steel	Unit cost of bridge
Variables	-Size of culvert -Length of culvert -Type of culvert	-Number of barrels -Length of barrel -Width per barrel -Quantity of concrete per unit length -Quantity of steel per unit length	-Length of bridge

Table 4.2 Damage Categories with Related Economic Variables and Site Characteristics

DAMAGE CATEGORY	ECONOMIC VARIABLES AND PARAMETERS	SITE CHARACTERISTICS
(1) *Floodplain Property Damage* - Losses to crops - Losses to buildings	- Types of crops - Economic values of crops - Types of buildings - Economic values of buildings	- Locations of crop fields - Locations of buildings - Physical layout of drainage structures - Roadway geometry - Flood characteristics - Stream valley cross-section - Slope of channel profile - Channel and floodplain roughness characteristics
(2) *Damage to Pavement & Embankment* - Pavement Damage - Embankment Damage	- Material cost for pavement - Material cost for embankment - Equipment costs - Man-hour costs - Repair rate for pavement and embankment	- Flood magnitude - Flood hydrograph - Overtopping duration - Depth of overtopping - Total area of pavement - Total volume of embankment - Types of drainage structure and layout - Roadway geometry - Soil properties of embankment
(3) *Traffic-Related Losses* - Increased travel cost due to detours - Lost time of vehicle occupants - Increased risk of accidents on detours - Increased risk of accidents on flooded highways	- Rate of repair - Operational cot of vehicle - Distribution of income for vehicle occupants - Cost of vehicle accident - Rate of accident	- Average daily traffic - Vehicle composition - Length of normal and detour paths - Flood hydrograph - Overtopping duration/depth - Repair duration - Expected detour length and vehicle speed during repair

5.
COLLECTION OF RELEVANT INFORMATION ON BASIN AND CHANNEL CHARACTERISTICS

The LTEC analysis of highway drainage structures requires integrated analysis of hydraulics and hydrology. Hydrologic analysis provides estimations of flood magnitude of various frequencies which serve as part of the input in the LTEC analysis. In this study, flood magnitudes of different return periods in the LTEC analysis are primarily estimated by (a) regional regression equations developed by the USGS using either the basin characteristics method or the channel geometry method, or (b) a flood-frequency relationship provided by the hydraulic engineers using other methods. According to three previous analyses (Lowham, 1976, 1982; Craig and Rankle, 1978) performed by the USGS for the regional flood frequency relations in Wyoming, the independent variables used were drainage area, maximum basin relief, and a precipitation index for mountainous areas (watershed characteristics method) or channel characteristics (channel geometry method). In a recent study of stream characteristics in Wyoming (Druse et al., 1988), the entire State of Wyoming was classified into three hydrologic regions: mountainous region, plains region, and high desert region. Regional flood-frequency relationships were established by two methods: channel geometry method and basin characteristics method. Independent variables used in the regional flood-frequency relationships in the three hydrologic regions by the two methods are listed in Table 5.1. When the hydraulic engineer selects another predictive method, it is necessary to define the flood magnitudes for the 2-, 5-, 10-, 25-, 50-, 100-, and 200-year events.

Evaluation of annual expected flood damage for a proposed roadway crossing requires knowing the backwater profile upstream of the crossing site when subject to a flood of a certain return period. This, in turn, depends on a number of hydraulic characteristics of the stream and roadway geometry. Geometry of channel cross-sections at about 250 actual pipe/box culverts and bridge sites were extracted from the drainage surveys and the Plan and Profiles of Proposed State Highways which were provided by the WDT.

Table 5.1 Regional Flood Frequency Equations for the State of Wyoming.

Regions	Basin Characteristics Method	Channel Geometry Method
Mountainous	Q_T = f(A, ELEV) or Q_T = f(A, PR)	Q_T = f(W)
Plains	Q_T = f(A, SB, GF)	Q_T = f(W, GF)
High Desert	Q_T = f(A, PR, GF)	Q_T = f(W, GF)

Note:
Q_T = annual peak flow with T-yr return period (cfs)
A = contributing drainage basin area (sq. miles)
ELEV = mean basin elevation (ft)
PR = average annual precipitation (inches)
SB = drainage basin slope (ft/mile)
GF = geographic factor
W = main-channel width (ft)

Elementary hydraulic parameters considered include (1) top width of the main channel as defined by Druse et al. (1988), (2) top width/average depth ratio, (3) average slope of the channel bottom, and (4) slopes of the floodplain (left and right) transverse to the flow direction. The original data base extracted from the drainage surveys and Plan and Profiles may not be representative enough to cover the wide range of channel characteristics which may be encountered by future highway projects. As a result, the data were expanded to consider many additional sites from the various sources of published literature which contained hydraulic information for streams in Wyoming (Lowham, 1976, 1982; Craig and Rankle, 1978). Any missing data which are not directly provided by the literature, particularly the slopes of the floodplain on both sides of the main channel perpendicular to the flow direction, were obtained from USGS 7.5-minute topographic maps measurements.

Summary of basin/channel characteristics considered as typical to Wyoming are shown in Table 5.2, including all the sources from which the data were obtained. Based on the data set, it was found that the great majority of streams can be classified as wide open channels indicated by that the top width/depth ratio exceeds 10. Knowing that wide open channels hydraulically behave like rectangular channels (Chow, 1959; Henderson, 1966), it was determined, for the purpose of simplifying the task of describing actual channel geometry, that an idealized channel cross-section as shown in Figure 5.1 could be used to perform hydraulic calculations.

It should be pointed out that the actual sites for bridges, box culverts, and pipe culverts available from the drainage surveys and Plan and Profiles was less than the sample size shown in Table 5.2. This is because sometimes there might be two or three cross-sectional profiles in the neighborhood of a given actual site. Therefore, each cross-sectional profile in the neighborhood of an actual site was measured regarding its channel characteristics and treated as an individual data point. The assumption made here was that a highway drainage structure (bridge, box culvert, or pipe culvert) could possibly have been located at one of the neighboring sites instead of the actual site and the sites would have similar physiographic basin characteristics. Otherwise, more information on basin/channel characteristics from the WDT would have been required.

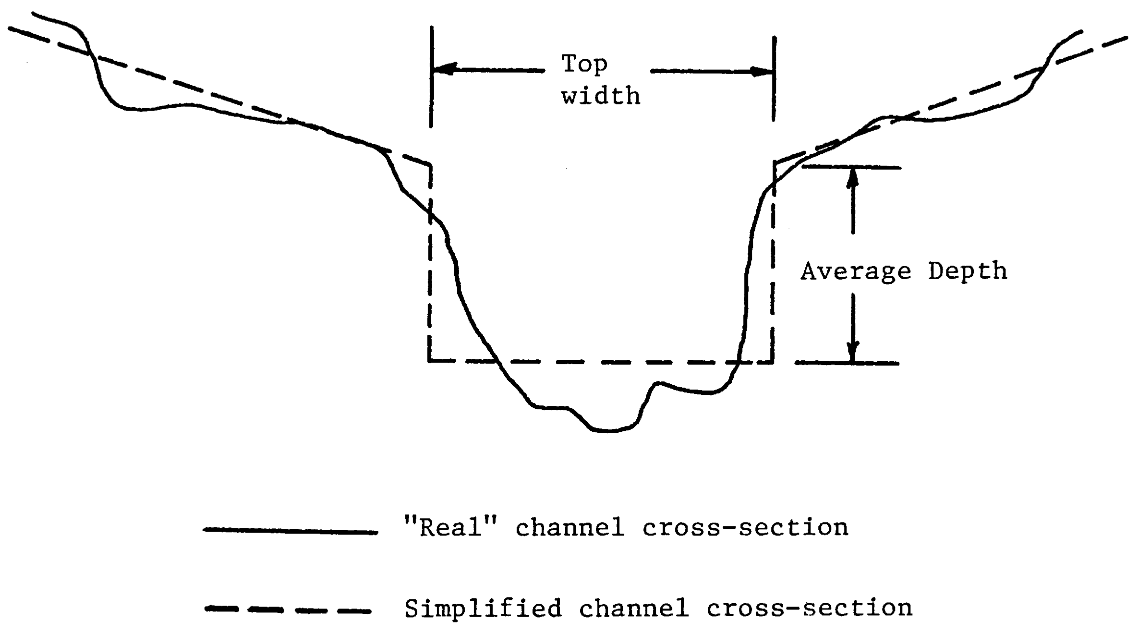


Figure 5.1 Idealization of Channel Cross-Section

Table 5.2 Simple Statistics for Hydraulic Characteristics in Wyoming.

Variable	Mean	Standard Deviation	Maximum Value	Minimum Value	at 75% Value	at 25% Value	Sample Size	Sources
Width of main channel	92.4	75.0	338.6	9.2	113.6	42.4	51	Green River Basin (3)
	36.7	30.0	180.0	2.0	48.7	15.0	152	Wyoming (5)
	124.0	100.4	566.0	20.0	146.2	59.5	102	Bridgy (7)
	51.2	35.1	150.0	8.0	60.0	28.0	60	Box culvert (7)
	53.1	53.4	290.0	6.0	66.0	19.0	92	Pipe culvert (7)
Ratio of top width to depth (ft/ft)	30.1	15.6	88.2	5.4	35.3	21.0	51	Green River Basin (3)
	10.05	7.30	53.75	1.50	13.72	4.92	152	Wyoming (5)
	15.8	10.8	66.7	3.20	22.2	7.7	102	Bridge (7)
	22.1	28.6	132.0	2.0	20.8	7.4	60	Box Culvert (7)
	30.3	30.7	175.0	5.2	38.2	12.7	92	Pipe culvert (7)
Main channel slope (ft/mi)	47.7	55.0	213.0	4.3	59.3	9.1	51	Green River Basin (3)
	139.5	103.0	543.0	8.0	197.7	66.8	152	Wyoming (5)
	31.8	34.6	142.0	2.4	33.2	10.6	100	Bridge (7)
	23.9	11.2	52.8	16.4	21.6	16.9	23	Box culvert (7)
	250	312	1584	4	299	79.0	94	Pipe culvert (7)
	605	191	929	240	733	436	22	USGS (4)
Maximum relief Rmax (ft)	403	175	752	5	545	317	22	USGS (4)
Drainage area (sq mi)	834	1887	9740	6	500	53	51	Green River Basin (3)
	222	541	5270	1	173	10	152	Wyoming (5)
	445	1008	7492	1	381	34	97	Bridge (7)
	33	105	464	0.270	5	1	50	Box culvert (7)
	0.181	0.334	2.0	0.00156	0.234	0.0172	94	Pipe culvert (7)
	3.36	2.86	10.80	0.69	5.20	1.37	22	USGS (4)
Floodplain slope Right side (ft/ft)	0.075	0.141	1.00	0.001	0.071	0.009	95	Bridge (7) (6)
	0.111	0.120	0.50	0.002	0.167	0.033	86	Box culvert (6)
	0.0685	0.0502	0.2500	0.0008	0.0909	0.0333	107	Pipe culvert (7)
Floodplain slope Left side (ft/ft)	0.0645	0.0972	0.5	0.001	0.0679	0.0096	94	Bridge (7) (6)
	0.097	0.118	0.5	0.005	0.111	0.027	86	Box culvert (6)
	0.0653	0.0441	0.250	0.0011	0.0833	0.0315	108	Pipe culvert (7)(6)

The channel width, W, must be recognized as that defined by Druse et al. (1988) where it is to be used to estimate the flood frequency relationship based on the channel-geometry method Generally, this is the top width for the low flow channel at the entrance or exit of a bendway where there is little evidence of bank erosion. this top width also corresponds to the mean arrival or dominant flood (about a 2-year flood) top width. The channel-geometry method is difficult to use where grassy swales are present.

To have a reliable assessment of floodplain slopes using the plan and profile sheets of the WDT, the floodplain slope was measured if the extent of the floodplain on both sides of the channel exceeded at least twice the top width of the main channel. With this criterion, floodplain slopes transverse to flow direction were only measurable at 37 bridge sites and none at the box culvert sites. As an alternative, floodplain slopes presented in the last two rows of Table 5.2 were obtained by measuring floodplain slopes from USGS 7.5-minute topographic maps. The intention was to obtain a total sample size of floodplain slopes of approximately 90 for each structure type. Table 5.3 indicates the number of floodplain slopes that are directly measured from WDT drainage surveys and from Plan and Profiles, and then indirectly synthesized from USGS topographic maps for different structures. The purpose of using synthesized data for floodplain slopes was to avoid retrieving additional data from the WDT microfilm files.

To expand the representative sample of floodplain slopes associated with different structure types in Wyoming, drainage basins of various sizes throughout Wyoming were selected and their floodplain slopes measured. All the sites selected in the synthesis process were considered as potential sites for future roadway crossings.

However, a question is raised by the foregoing synthesis procedure, that is: "For a selected basin, what type of structure is to be used for the roadway crossing? Pipe culvert, box culvert, or bridge?" To answer this question, the structure types and the corresponding basin/site characteristics were examined based on readily available data. The most easily available basin characteristic associated with the structure sites was the drainage basin area. Based on the information available from the drainage surveys and from Plan and Profiles, histograms (Figure 5.2) were constructed showing the distribution of the number of structures of a given type versus drainage area. It appears, from Figure 5.2, that the type of highway drainage structure was closely related to the

Table 5.3 Number of Data Points for Floodplain Slope.

Number of Data Points						Source of Data
Bridge		Box Culvert		Pipe Culvert		
R	L	R	L	R	L	
38	37	0	0	87	88	WHD
57	57	86	86	20	20	Topographic Map Wyoming
95	94	86	86	107	108	Total

Note: R - # of points of data on right side of river
L - # of points of data on left side of river

Table 5.4 Criteria for Structural Classification.

	Bridge	Box Culvert	Pipe Culvert
Area of Drainage Basins (sq. mi.)	> 15	0.5 to 50	< 3

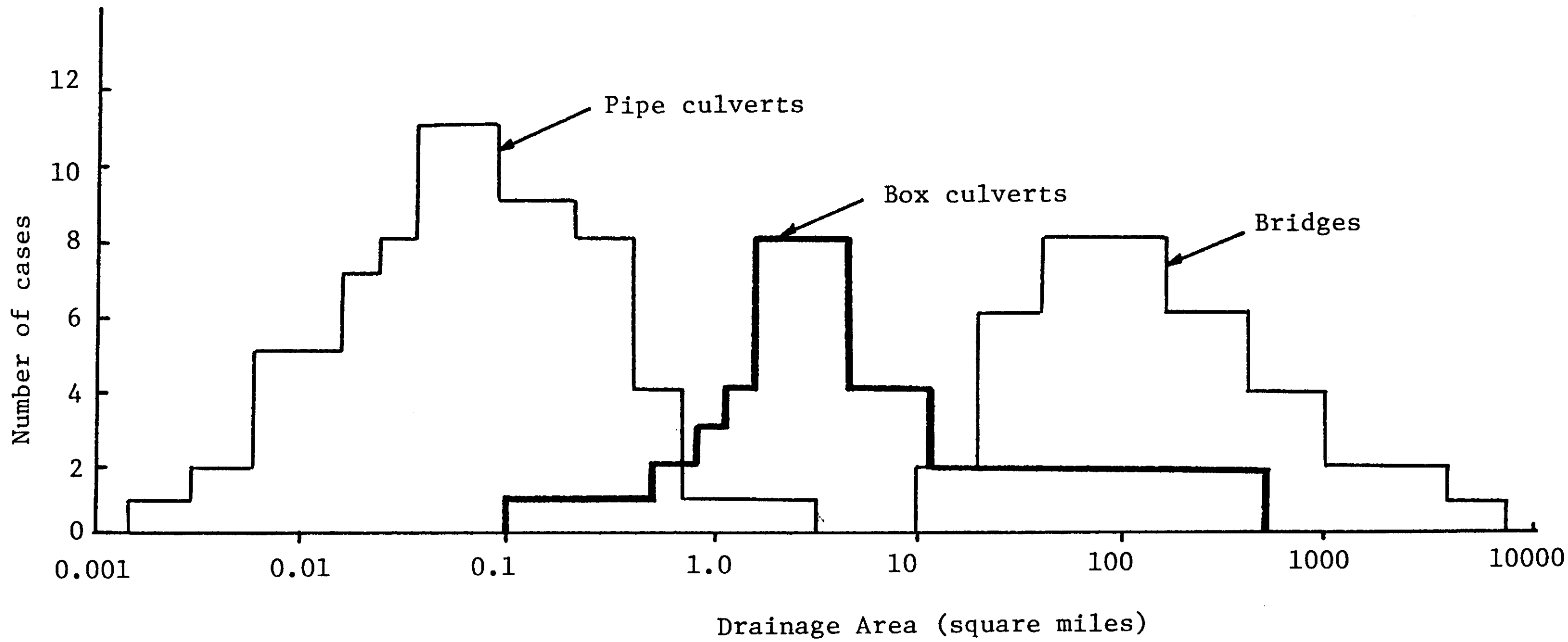


Figure 5.2 Histograms of Drainage Area Size for Bridges, Box Culverts, and Pipe Culverts.

corresponding drainage area. Although there is some overlapping with drainage area between pipe culverts and box culverts as well as box culverts and bridges, clear distinction is not difficult. Based on Figure 5.2, the criterion given in Table 5.4 was used as the basis for selecting sites for expanding the data base on floodplain slope for a given highway drainage structure type. For the sites with drainage basin areas falling in the overlapping region of two different structure types, it was assumed that hydraulically the two structure types are equally suitable with other site specific factors dictating the structure type selected as described.

As pointed out by the WDT staff, the determination of structure type depends on number of things such as drift, upstream property, grade line, low channel width, land use, and hydrologic region. Furthermore, a suggestion was given to use an index discharge such as mean annual discharge instead of the drainage area as described above. Although the original intention of using area-type criterion was to help select representative sites for the various structure types (so that information on floodplain slopes in the data base can be expanded through the synthesis procedure), an attempt to decide which structure type should be used based on an index discharge is possible. The justification for doing so is: having observed from the records that both culverts and bridges have been constructed in the overlap area, it can actually be assumed that, given a site with drainage area in the overlapping area, it is possible to use either a bridge or culvert at the given site depending on the unique site characteristics such as drift, ice, and land use characteristics. The algorithm developed for generating the synthetic data base does consider the two types of drainage structures that occur within this overlapping area.

Use of index discharge as suggested would be a better criterion because it contains physiographic/hydrologic information rather than just physiographic information alone (as is the case with using just drainage area). However, use of hydrologic variables as criterion would require that these variables be updated periodically as the data set is increased with time (mean annual discharge may change with, say, 10 more years of record). This may lead (but the probability is low) to a situation where structures built several years previously would not be consistent with present criterion. If this were to happen, consideration should be given to using some quantity that would be less variable over time.

6.
COLLECTION OF RELEVANT INFORMATION ON TANGIBLE ECONOMIC VARIABLES IN ASSESSING FLOOD DAMAGES

Flood damages and associated economic variables of roadway crossings include those from (1) floodplain property damage, (2) damage to pavement and embankment, and (3) traffic related losses.

6.1 DAMAGE TO FLOODPLAIN PROPERTIES

Damage to upstream floodplain properties caused by a highway crossing consists of two major damage categories: (a) damage to crops and (b) damage to buildings and their contents.

Crop damage can be estimated by the following equation

$$D_{crop} = \sum_{i=1}^{N} U_i A P_i Y_i Q_i \qquad \textbf{(6.1)}$$

in which U_i is the unit price of crop i (in \$/ton); A is the total floodplain area inundated (in acres); P_i is the percentage of flooded area planted with crop i; Y_i is the yield per acre of crop i (in tons/acre); and Q_i is the percentage of damage to crop i. The total area of floodplain inundated is a function of flood magnitude, hydraulic characteristics of the channel, and geometry of the highway crossing. Its determination requires hydraulic analysis of the backwater profile for a particular design of highway drainage structure under flood of a specified return period.

Crops typically found in Wyoming and their corresponding unit price and yield per acre for irrigated and non-irrigated lands can be obtained elsewhere (USDA, 1985) and are summarized in Table 6.1 for the year 1983. Crop yield information for irrigated land is tabulated in Table 6.2 for the year 1984. Comparison of Tables 6.1 and 6.2 indicates that average crop yield of irrigated land is higher than that of irrigated and non-irrigated lands together. It is more convenient to irrigate farm land located in the floodplain, unless farmers are prohibited from doing so due to legal restrictions. Therefore, it might be more

Table 6.1 Unit Price of Crops in Wyoming.

Crops	Yield (Y_i)*	Price (U_i)**	(Yi)*(Ui) dollars/acre
Other hay	1.20 ton/ac	66.5 $/ton	79.8
Oats	46.5	1.70	79.05
Wheat	26.5	3.30	87.45
Alfalfa hay	2.35 ton/ac	66.5 $/ton	156.28
Barley	62.7	3.20	200.64
Dry beans	1836 lbs/ac	14 $/100 lbs	257.04
Corn-grain	93.6 bush/ac	2.95 $/bush	276.12
Corn-silage	16.05 ton/ac	--	--
Sugar beets	2.34 ton/ac	34.28 $/ton	695.63

NOTE: * Values in yield (Yi) are the average of 10-year record (from 1975 to 1984 yield per harvested acre).
** Unit price of crop in 1984 dollars.
*** Data in 1983.

Table 6.2 Crop Yields for Irrigated Land in Wyoming (1983-1984).

Crop	Yield			Pct. Acreage (%)	(Y_i)*(U_i) $/acre	Unit of Yield
	1985	1984	Avg.			
Other hay	1.50	1.48	1.49	34.3	99.09	ton/acre
Oats	62.1	62.6	62.4	4.3	106.08	Bushels/acre
Wheat	54.9	54.0	54.5	17.7	179.85	Bushels/acre
Alfalfa hay	2.95	2.9	2.93	27.2	194.85	Ton/acre
Barley	72.6	71.5	72.05	7.9	230.56	Bushels/acre
Dry beans	1800	2050	1925	1.7	269.50	lb/acre
Corn	104	100	102.0	4.5	300.9	Bushels/acre
Sugar beets	19.2	20.0	19.6	2.4	670.32	Ton/acre

Note: Unit price using data in 1984.

reasonable to use information in Table 6.2 in assessing crop damages since thefloodplain area is most likely irrigated. Also, there would be little or no damage unless the crop were in the floodplain. Crop losses due to floodwater, basically, depend on the duration and depth of inundation. Representative percentages of damage to crops due to flooding are shown in Table 6.3 (Corry et al., 1980).

Due to the site specific nature of the variable P_i in Eq.(6.1), it is a part of the input that must be specified for each particular site under study. The quantities U_i, Y_i and Q_i for various crops are treated as the parameters. Their typical values, based on Tables 6.1 through 6.3, are built into the computer program, LTEC.FOR, as default-valued variables for the site-specific LTEC analysis unless otherwise specified. In the present study only one type of crop is generated for a given site.

Evaluation of damage to buildings in floodplain due to backwater effects requires information on the number of buildings in the floodplain, their locations, elevation, types, and values. Broadly speaking, building types typically found in floodplain are residential buildings with and without basements, commercial buildings, agricultural structures, commercial outdoor storage areas, and mobile homes. Tables 6.5 and 6.6 show the types of residential and commercial buildings. Flood damage to buildings in floodplain can be estimated by Eq. (6.2) as

$$D_{bldg} = \sum_{j=1}^{N} V_j \ P_j \qquad \textbf{(6.2)}$$

where N is the total number of buildings at risk in the floodplain; V_j is the estimated value of building j; and P_j is the percentage of damage to building j due to inundation. The variable P_j in Eq.(6.2) in general is a function of building type and inundation depth. Some general relations for P_j and inundation depth were available from the literature (Corry et al., 1980; Shah, 1985; Colorado Conservation Board, 1986) and are shown in Figures 6.1 through 6.3. No data have been collected specifically for Wyoming to develop similar curves. However, Figures 6.1 and 6.3 show the percent damage, rather than damage in monetary value, which would make them more suitable for use in this study. Recently, water depth-damage relations as used in 1987 for assessing flood insurance were obtained from Federal Emergency Management Agency (FEMA).

Table 6.3 Percent Damage to Crops (from Corry et al., 1980).

	% damage			
	≤ 24 hr inundation		≥ 24 hr inundation	
Crops	0-2 ft	2 ft	0-2ft	2 ft
Corn	54	88	75	100
Soybeans	92	150	150	100
Oats	67	97	81	100
Hay	60	82	70	97
Pasture	50	75	60	90
Winter Wheat	57	87	72	100

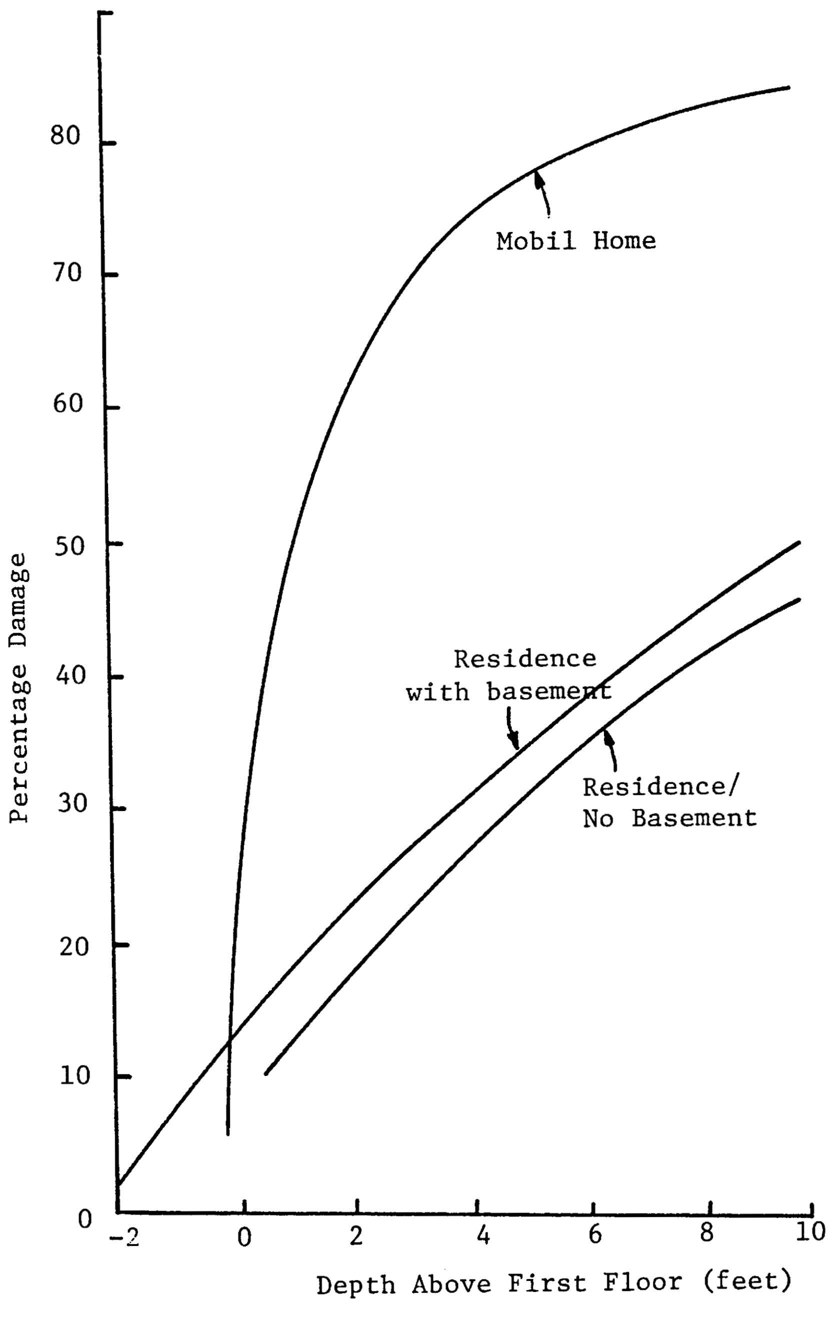


Figure 6.1 Percent Damage, Mixed Residences (Corry et al., 1980)

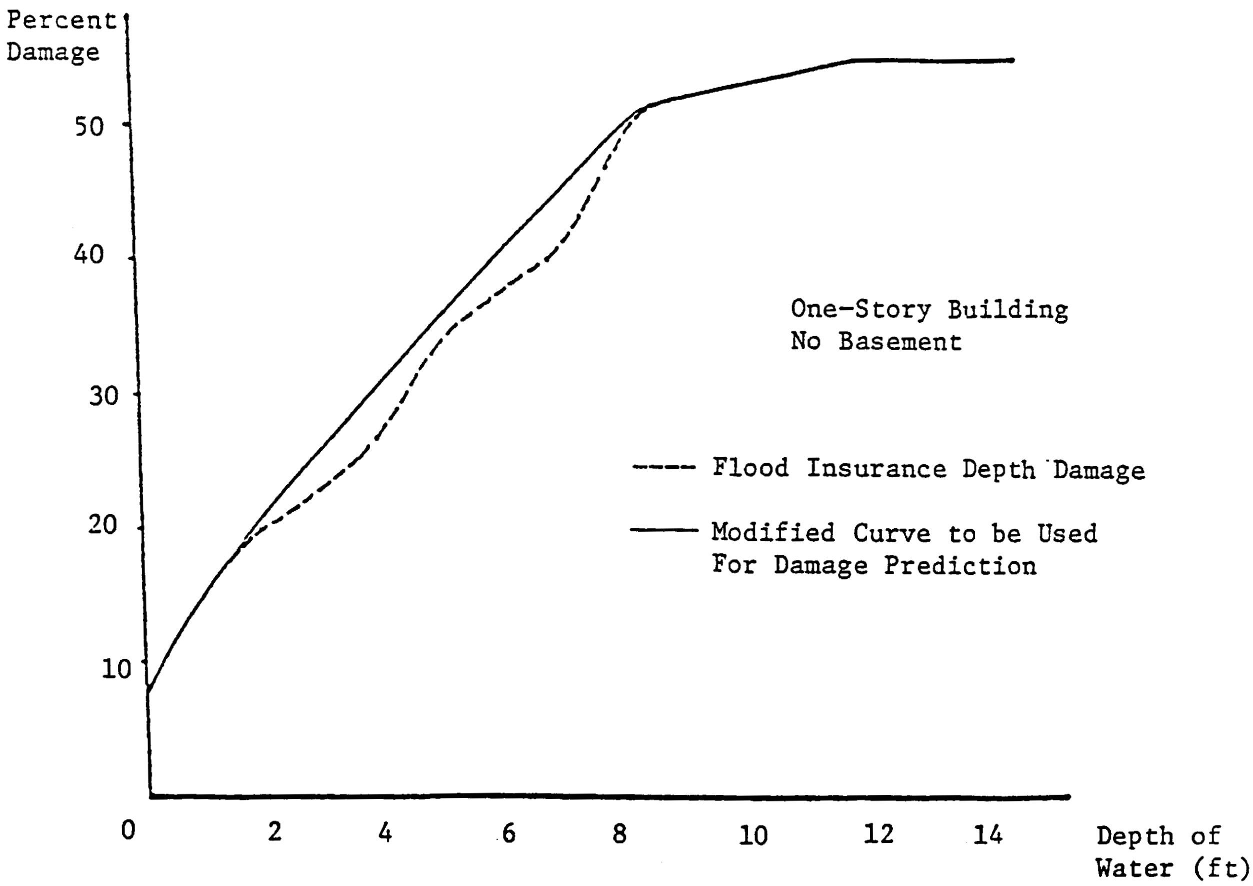


Figure 6.2 Typical Flood Damage Versus Depth of Inundation Curve (Shah, 1985)

Water depth above floor	Damage ratio, % of total value
-1	0
0	3
1	9
2	13
3	25
4	27
5	28
6	33
7	34
8	41
9	43
10	45
11	46
12	47
13	48
14	49
15	50

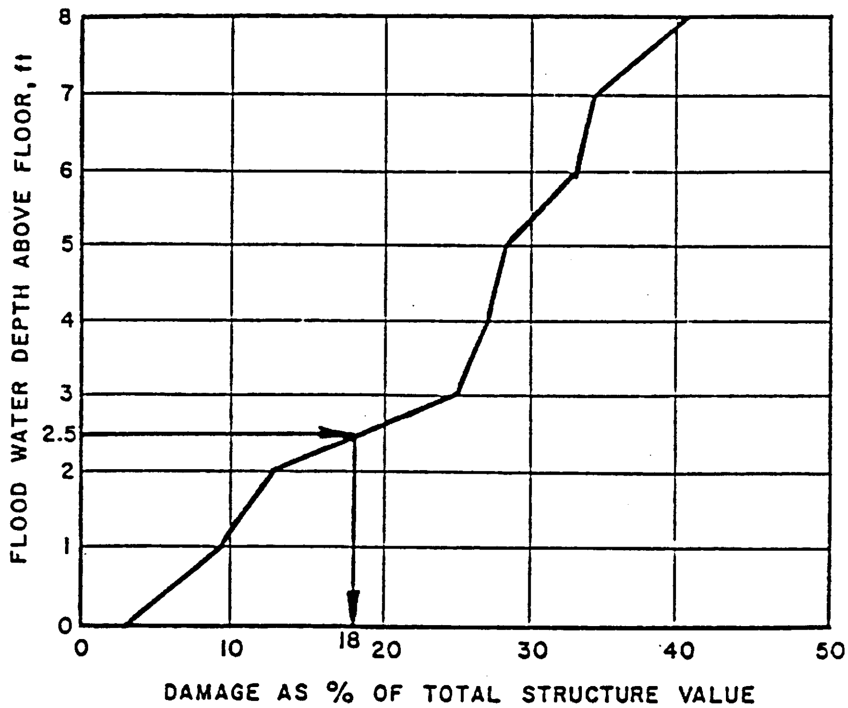


Figure 6.3 Flood Elevation Versus Damage to Structure (Colorado Conservation Board, 1986).

Tables 6.4 and 6.5 show the depth-percent damage values of building coverage and contents coverage, respectively, for various residential and commercial buildings. Tables6.4 and 6.5 represent the most current information on flood water depth-damage relations available. Since both tables are used nationwide for assessing flood damage, the WDT agreed that it would be acceptable to adopt them in this study. Using Tables 6.4 or 6.5, one is able to estimate damage to buildings by backwater effects once the information on the value of the building is determined. The computer program, LTEC.FOR, for the site specific LTEC analysis incorporates information contained in Tables 6.4 and 6.5.

It is generally difficult during highway design to know precisely the value of a building because it is dependent on its contents and the condition of the building itself. Therefore, it would be practical to leave the building value along with its type as an input variable to be specified by the user or designer.

To use Tables 6.4 and 6.5 and Eq.(6.2) for estimating flood damage to buildings requires the identification of the approximate elevation for the first floor flood entry point for each building at risk in the floodplain. This allows the determination of inundation depth above the first floor under various flood magnitudes.

A much more extensive and comprehensive list of flood damage or losses due to floods is provided by the Bureau of Reclamation (BuRec) (1986). BuRec Technical Memorandum No.7 (TM-7) provides a detailed listing of flood losses due to the failure of dams with consequences several orders of magnitude more severe than that of backwater caused by roadway crossings. The inclusion in the BuRec TM-7 of such items as employment and income losses, utilities, farm equipment, lost productive capacity of land, and many other items may not be entirely realistic for this study.

In summary, input variables for a site specific situation and information representative of statewide conditions in estimating floodplain property damage are listed in Table 6.7.

Table 6.4 Depth-Percent Damage Values for Building Coverage.

Water Depth (ft.)	Types of Residential Housing					
	One Floor W/O Bsmnt.	Two Floor W/O Bsmnt.	Two Floor W/ Bsmnt.	Split Level W/O Bsmnt.	Split Level W/ Bsmnt.	Mobile Home
-4						
-3						
-2			4.05		3.00	
-1			8.08		5.01	
0	7.46	5.05	10.85	3.01	6.02	8.24
1	13.55	9.01	15.15	8.99	15.68	44.34
2	20.61	13.06	20.76	13.00	18.84	63.26
3	26.85	18.00	23.44	24.98	21.92	73.31
4	28.76	19.98	27.83	26.97	26.94	78.48
5	29.91	21.98	32.74	27.99	31.93	79.75
6	40.70		37.73	32.99	34.95	80.86
7	42.82	25.98	43.64	34.00	35.95	81.98
8	43.98		48.61	40.99	43.96	
9	44.99		50.84	43.00	47.96	
10	46.32	37.98	52.88	44.99	49.96	
11	47.06		54.95		51.99	
12	48.26		56.90	47.00	53.98	
13	49.01		58.95		56.00	
14	49.98		59.97		57.99	
15	50.10				59.00	
16	50.10				60.00	
17	50.10					
18	50.10					

Table 6.5 Depth-Percent Damage Values for Contents Coverage

Water Depth (ft.)	Residential Contents: First Floor Only	Residential Contents: First Floor & Above	Residential Contents: Mobile Home	Commercial Contents: First Floor Only	Commercial Contents: First Floor & Above	Commercial Contents: Mobile Unit
-4						
-3						
-2						
-1						
0	11.20	7.32	3.25	10.20	7.17	3.03
1	22.84	10.38	26.58	17.42	9.75	26.96
2	31.39	17.96	49.12	23.53	17.72	49.92
3	34.09	22.54	64.08	29.37	22.62	64.89
4	36.70	28.14	70.35	35.21	28.34	70.89
5	40.54	33.06	75.60	40.05	33.15	75.89
6	44.88	38.92	77.68	45.01	39.26	77.97
7	49.86	43.91	78.80	49.99	44.03	78.98
8	54.77	49.79	80.73	55.03	50.04	80.99
9	59.88		82.88	59.98		82.99
10	59.83	57.93		60.01	57.98	
11						
12						
13						
14						
15						
16						
17						
18						

Table 6.6 Building Code Index.

Bldg Type	Description	Bldg Type	Description
Residential		*Commercial*	
1	One story w/o basement	34	Gas Company*
2	Two story w/o basement	35	Garage
3	Two story w/ basement	36	Greenhouse
4	Split level w/o basement	37	Grocery Store
5	Split level w/ basement	38	Grocery Store (Kwik)
6	Mobile home	39	Gift Shop
Commercial		40	Gun shop
1	Antique shop	41	Hall
2	Appliance shop	42	Hardware
3	Auto dealer	43	Hobby shop
4	Auto junkyard	44	Hotel
5	Auto parts	45	Jewelry
6	Auto repair	46	Laundry
7	Auto transmission service	47	Library
8	Auto muffler service	48	Liquor store
9	Bakery	49	Lumber yard
10	Bank	50	Meat market
11	Barber shop	51	Motel
12	Beauty shop	52	Music store
13	Boat store	53	Newspaper printing
14	Bowling alley	54	Nursing home
15	Book store	55	Nursery (plant)
16	Business (general)	56	Office building
17	Church	57	Plumbing supply
18	City hall	58	Police station
19	Cleaners	59	Post office
20	Clinic (medical)	60	Private club
21	Construction company	61	Real estate office
22	Country club	62	Radio station
23	Clothing	63	Restaurant
24	Dentist's office	64	Restaurant drive-in
25	Department store	65	School
26	Doctor's office	66	Tavern
27	Drug store	67	Theater
28	Fire Station	68	Transport company
29	Flooring and carpeting	69	Trailer Sales
30	Florist	70	Television repair
31	Food processor	71	Variety store
32	Funeral home	72	Warehouse
33	Furniture	73	Welding supply

* No data available for the percent damage of the contents.

Table 6.7 Economic Variables in Assessing Flood Damages to Upstream Properties.

	Crop Damage	Building Damage
Site-specific input variables	-Percentage of acreage distribution of various crops	-Numbers of buildings in floodplain at risk crops in floodplain -Values of buildings -Types of buildings -Elevation of doorway for each building
Statewide Representative Information	-Yield for crops (Table 6.2) -Unit price for crops (Table 6.2) -Percentage of damage for crops (Table 6.3)	-Percentage damage and inundation depth (Tables 6.4 and 6.5)

6.2 FLOOD DAMAGE TO PAVEMENT AND EMBANKMENT

When floodwater overtops roadway crossings, damage to pavement and embankment could occur due to erosion. In principle, losses of pavement and embankment due to a flood can be estimated as

$$D_{P/E} = \frac{E_w P_e C_e V_e}{48} + \frac{P_w P_p C_p A_p}{20} + MC \qquad \textbf{(6.3)}$$

in which $D_{P/E}$ is the economic loss of pavement and embankment; E_w is the embankment width (ft.); P_e is the percentage of embankment loss; C_w is the cost of the embankment ($/yd^3); V is the total volume of embankment subject to overflow (yd^3); P_w is the pavement width (ft); P_p is the percent of the pavement loss; C_p is the unit cost of pavement ($/yd^2); A_p is the total area of pavement subject to overflow (yd^2); and MC is the mobilization cost ($).

Variables in Eq.(6.3) relative to the physical layout of the roadway such as E_w, P_w, V_e and A_p are determined internally by the computer program, LTEC.FOR, using default values based on a design standard for various highway systems unless they are otherwise specified. Percentage of embankment loss and pavement loss information for different embankment surfaces under various overtopping conditions are available from Chen and Anderson (1987) which have been incorporated into LTEC.FOR. Costs for conservatively estimating embankment and pavement repair are available from the "Average Bid Price" (Wyoming Construction, 1980-1985) of the WDT. A list of parameters and variables for estimating damage to pavement and embankment is given in Table 6.8.

6.3 TRAFFIC RELATED LOSSES DUE TO FLOODING

Primarily, three components make up the total traffic related losses due to flooding: (a) increased vehicle running cost, (b) vehicle occupant time losses, and (c) accident costs related to the flooding.

Table 6.8 List of Parameters and Variables for Assessing Pavement and Embankment Damage.

Parameters	Parameters (To be computed)	Variables (To be specified by users)
-Unit cost of embankment	-Percentage of embankment loss	-Embankment width*
	-Length of embankment	
-Mobilization cost	-Volume of embankment	-Pavement width*
	-Percentage of loss	-Embankment height or grade line*
	-Total area of pavement subject to overflow	-Embankment soil type

* Can be determined by adopting standard design roadway geometry unless otherwise specified.

6.3.1 **Increased Vehicle Running Cost.** - This cost item results from taking a detour route rather than the normal route due to traffic interruption caused by overtopping floodwater and the following roadway restoration activity. The increased vehicle running cost can be estimated by

$$TL_{RC} = \frac{TD(ADTE)\ \Delta L\ U_{RC}}{24} \qquad \textbf{(6.4)}$$

where TL_{RC} is the traffic loss due to increased vehicle running cost ($); TD is the total delay time (in hours) which is the sum of overtopping duration; T_{ot} and roadway restoration time, T_r; ADTE is the equivalent average daily traffic (vehicle/day); ΔL is the increased distance of travel between the detour and normal routes (miles); and U_{RC} is the unit vehicle running cost ($/vehicle/mile).

When a vehicle is running on the road, the vehicle owner must pay taxes, insurance, maintenance, and fuel to operate the vehicle. Therefore, the unit vehicle running cost should include all these various cost considerations. A study has been made by the FHWA (1984) which shows the cost of owning and operating an automobile (Table 6.9). Data shown in Table 6.9 can be used as the basis for determining U_{RC} in Eq.(6.4).

Variable ΔL is the increased driving mileage due to the detour and must be specified by the designer. Information on average daily traffic (ATDE) in Wyoming were obtained from the WDT (1984). To compute the delay time, it is required to estimate overtopping duration and roadway restoration time. The overtopping duration depends on the highway drainage opening and the shape and magnitude of the flood hydrograph while the restoration time depends on the extent of flood damage to the pavement and embankment and the rate of repair. The roadway restoration time can be estimated as

$$T_r = \frac{24\ V_e P_e}{R_e} + \frac{24\ A_p P_p}{R_p} + M_t \qquad \textbf{(6.5)}$$

in which R_e and R_p are rates of embankment repair (yd^3/day) and pavement repair (yd^2/day), respectively; and M_t is the mobilization time (hrs). The other variables have been defined previously.

Table 6.9 Unit Cost of Owning and Operating Automobiles.

Vehicle Size	URC ($/vehicle/mile)
Large	0.3062
Intermediate	0.2784
Compact	0.2331
Subcompact	0.2271
Passenger van	0.3925

* The cost is obtained by averaging over a 12-year period for medium-priced vehicle operated in Baltimore area which was considered to be in the middle range.

6.3.2 **Time Loss of Vehicle Occupant.** - Information required for estimating the cost of time loss of a vehicle occupant, in general, is more difficult to obtain. To the investigators' knowledge, there are no immediate and direct data available for cost associated with the vehicle occupant(s) time (the average cost of a vehicle occupant in terms of cost due to the delay) and a typical carrier occupancy composition. If these data were available, then the cost associated with time loss of vehicle occupancy could be estimated as

$$TL_{VO} = \frac{(TD)\ (\Delta L)\ (ADTE)\ (OR)\ U_{OC}}{24\ S} \qquad \textbf{(6.6)}$$

in which TL_{VO} is the total cost of vehicle occupant time loss traveling on the detour (in \$); OR is the occupancy rate (persons/vehicle); U_{OC} is the unit cost per occupant (\$/person/hr); and S is an average vehicle speed (miles/hr) over the detour length. As a first approximation, the trucking business might be used with some modifications to obtain ballpark estimates for some of the above values.

6.3.3 **Increased Accident Cost.** - Based on the published statistics on traffic accidents in Wyoming (WHD, 1984), it is possible to deduce accident rate and cost associated with injury, death, and property damage due to detours. The increased accident cost can be estimated by

$$TL_{ACC} = \frac{(TD)\ (\Delta L)\ (ADTE)\ (DR)\ (AIF)}{24 \times 100} \qquad \textbf{(6.7)}$$

in which TL_{ACC} is the increased cost of an accident due to the detour (in \$); DR is the death rate (person/10^6 vehicle/miles); and AIF is the accident-injury factor defined as

$$AIF = (IR)\ (U_{inj}) + (DMR)\ (U_{damg}) \qquad (6.8)$$

where IR is the injury rate (injuries/death); U_{inj} is the unit cost per injury (\$/injury); DMR is the damage ratio (injuries/death); U_{damg} is the unit cost of damage (\$/ damage claimed). A list of parameters and variables for assessing traffic and accident-related costs is given in Table 6.10.

Table 6.10 List of Parameters and Variables for Assessing Traffic Related Costs.

Parameters	Parameters to be Computed	Input Variables
-Unit vehicle running cost	-Total delay time	-Increased travel distance
-Mobilization time traffic	-Overtopping time	-Average daily
-Occupancy rate	-Roadway restoration time	-Rate of embankment repair
-Unit cost of occupant	-Accident-injury factor	
-Vehicle speed		
-Death rate		
-Injury rate		
-Unit cost per injury		
-Damage ratio		
-Unit cost of damage		

In addition to the WHD (1983-1984), U.S. Department of Transportation (U.S. DOT, 1970) contains the results of a sample survey of policy reported injuries and fatalities due to automobile accidents in the 48 contiguous states and the District of Columbia. The study represents 500,000 fatalities and seriously injured persons and reports the following: "Average economic losses for seriously injured persons were $4,200. Average economic losses to fatality cases were $2,300, exclusive of lost earnings. Economic losses to families who had one or more seriously injured members or fatalities averaged $4,200 to date of interview plus $6,100 in future lost earnings." It should be noted that the dollar figures mentioned here are 1970 dollars. Adjustments were made to present day values with the realization that these costs are increasing substantially above the inflation rate of the dollar due to court decision awards in these types of cases.

7.
DEVELOPMENT OF HYDRAULIC RESPONSE EQUATIONS FOR HIGHWAY DRAINAGE STRUCTURES.

In the LTEC analysis of highway drainage structures, an optimization algorithm is used to identify the layout and hydraulic capacity of the structure and the corresponding design frequency with the least total annual expected cost. During the course of seeking the optimal design, the hydraulic responses have to be reevaluated each time when the structural configuration changes. Namely, hydraulic simulation programs such as CDS (Culvert Design System) (Wyoming State Highway Department, 1980) or WSPRO (Water Surface Profile computations) (Federal Highway Administration, currently being updated) has to be applied when ever the structural dimensions are altered. This implies a tremendous computational requirement to obtain the economic-LTEC design frequency for a given site condition. And yet, there are many site conditions to be considered in this study. The other disadvantage of using the complete hydraulic simulation models is that the models generate much information that are irrelevant to the LTEC design. Hence, a practical approach is required to accomplish the task. The approach used in this study was to develop simple yet accurate empirical equations for pertinent hydraulic responses of drainage structures for pipe and box culverts and bridge structures. The empirical equations are used, in lieu of the complete hydraulic simulation models such as CDS and WSPRO, to serve as the vehicle to predict the hydraulic responses of flow through or over highway drainage structures. This set of equations then were incorporated in the computer program LTEC.FOR for the LTEC analysis of highway drainage structures.

In the LTEC analysis of highway drainage structures, the pertinent hydraulic responses include: (1) overtopping duration, (2) average overtopping depth, (3) average headwater depth when overtopping occurs, (4) average tailwater depth when overtopping occurs, (5) maximum headwater depth, (6) inundation duration, and (7) average inundation depth. The first four variables are required to estimate damages associated with embankment erosion and traffic interruption. Variables 5-7 are used for calculating property damage associated with backwater effects.

The above hydraulic responses are related to various site conditions: (a) channel and floodplain geometries including channel width (see Druse et al., 1988), channel depth, and floodplain slopes in the transverse direction; (b) hydraulic characteristics of the channel including channel slope, Manning's roughness coefficient in the channel and floodplain; (c) roadway geometry including embankment height, embankment slope, and number of traffic lanes; (d) drainage structure properties such as number of barrels and culvert dimension; and (e) a hydrologic variable represented by the peak discharge and hydrograph.

The assumptions used to simulate the site conditions are: (a) rectangular channel cross-section, (b) a road width of 12 feet per lane; (c) slopes of channel and floodplain in longitudinal direction are identical; and (d) Manning's roughness coefficient does not vary with water depth.

7.1 PIPE CULVERTS

Statistical experimental designs were performed to generate 128 scenarios for site conditions based on the variable values shown in Table 7.1. The ranges of variables in Table 7.1 that define the site condition were based on the results of the data collected in Chapter 5. For each of the 128 site conditions generated, six peak discharges were used whose magnitudes and the corresponding volumes were determined by the regional regression equations developed by Lowham et al (1988). The shape of the hydrograph is assumed, for simplicity, to be triangular with its time-to-peak equal to 1/3 of the entire hydrograph time base. The culvert hydraulics simulator, CDS, was applied repeatedly for the 128 site conditions using its review option. The program CDS was modified such that it would compute and print the values of hydraulic responses of the culverts.

For the regression analysis, the data base consisted of 6 discharges times 128 site conditions = 768 cases, if no missing values were encountered. Each hydraulic response variable was used as the dependent variable which was regressed against independent variables defining the site conditions. Through numerous iterations, the final regression equations that were found to have sufficient accuracy are summarized below. Included are definitions of involved variables.

Table 7.1 Level of Values of Site Condition Variables for Pipe Culverts

Variable	Level of Variable Values
Channel Width (W)	10', 20', 40', 80' (in ft)
Channel Depth (D)	= W / (WD)[1] = (5, 20) (in ft)
Embankment Height (Hemb)	= (1.2 or 2.0) x Depth + 2.0' (in ft)
Left Floodplain Slope in Transverse Direction (Sl)	0.02, 0.05, 0.10, 0.18 (in ft/ft)
Right Floodplain Slope in the Transverse Direction (Sl)	0.02, 0.05, 0.10, 0.18 (in ft/ft)
Channel Slope (Sc)	75, 150, 350, 700 (in ft/mi)
Floodplain Roughness (np)	0.03, 0.06, 0.11, 0.22
Channel Roughness (nc)	0.03, 0.04, 0.06, 0.08
Number of Barrels (Nb)	1, 2
Embankment Slope (Semb)	2, 3, 5, 8 (in V:H=1:Semb)
Peak Discharge (Q)	100, 200, 400, 800, 1600, 3200, 6400, 12800 (in cfs)
Pipe Diameter (Diam)	= D_code[2](1,2,3,4) x min(W, Hemb-2')/4

1: WD = Width-Depth Ratio;
2: D_code = Diameter code having values of 1, 2, 3, and 4.

Dependent Variables:

(a) OVTPDUR = Overtop duration (in minutes).
(b) HWDEP = Avg. headwater depth when overtopping occurs (in ft).
(c) TWDEP = Avg. tailwater depth when overtopping occurs (in ft).
(d) HDMAX = Maximum headwater depth (in ft).
(e) DEPINUN = Depth of inundation (in ft).
(f) DURINUN = Duration of inundation (in min.)

Independent Variables;

(1) W = Width of channel (in ft) -- see Druse et al. (1988)
(2) D = Depth of channel (in ft)
(3) Hemb = Height of embankment (in ft)
(4) Sl = Slope of floodplain on the left (in ft/ft)
(5) Sr = Slope of floodplain on the right (in ft/ft)
(6) Sc = Slope of channel (in ft/ft)
(7) np = Manning's roughness coefficient for floodplain
(8) nc = Manning's roughness coefficient for channel
(9) Semb = Slope of embankment (V:H=1:Semb)
(10) Q = Peak discharge (in cfs)
(11) Nb = Number of barrels
(12) Nl = Number of lanes
(13) Diam = Pipe diameter (in ft) [for pipe culvert only]
(14) Wbox = Width of box culvert (in ft) [for box culverts]
(15) Hbox = Height of box culvert (in ft) [for box culverts]

(a) ln(OVTPDUR)

$$= 217+12.6 \ln(D)-99.9 \ln(Hemb)-13.5 \ln(Sl)+38.7 \ln(Sr)+34.7 \ln(Sc)-52.3 \ln(np) +27.0 \ln(nc)+18.9 \ln(Nb)-15.2 \ln(Semb)+15.0 \ln(Diam)-8.12 \ln(np)-2.75 \ln(Q)^2 -26.9 \ln(D) \ln(Nb)+17.4 \ln(Hemb) \ln(Sl)+16.6 \ln(Hemb) \ln(Q) -11.9 \ln(Hemb) \ln(Diam)-1.90 \ln(Sl) \ln(Q)+10.5 \ln(Sr) \ln(nc)+5.15 \ln(Sr) \ln(Semb) -3.96 \ln(Sc) \ln(np)-4.73 \ln(Sc) \ln(Q)+3.00 \ln(Semb) \ln(Q)$$

[se = 7.784, R^2 = 0.889, R^2_{adj} = 0.857]

(b) ln(HWDEP)

$$= -0.0045 - 0.00174\ LN(W) + 0.990\ \ln(Hemb) + 0.00331\ \ln(Sl) + 0.00418\ \ln(Sr) - 0.00441\ \ln(nc) + 0.00199\ \ln(Nb) + 0.00553\ \ln(Q) - 0.00168\ \ln(Diam)$$

[se = 0.009652, R^2 = 1.000, R^2_{adj} = 1.000]

(c) ln(TWDEP)

$$= -0.782 - 0.359\ \ln(W) + 0.139\ \ln(D) + 0.107\ \ln(Hemb) + 0.062\ \ln(Sl) - 0.238\ \ln(Sc) + 0.344\ \ln(np) + 0.107\ \ln(nc) + 0.100\ \ln(Nb) + 0.438\ \ln(Q) + 0.0527\ \ln(Diam)$$

[se = 0.2071, R^2 = 0.944, R^2_{adj} = 0.938]

(d) ln(HWMAX)

$$= -1.35 + 0.326\ \ln(W) + 0.526\ \ln(D) - 0.213\ \ln(Sl) - 0.0796\ \ln(Sc) - 0.155\ \ln(np) - 1.38\ \ln(Nb) + 0.304\ \ln(Q) - 0.428\ \ln(Diam) - 0.216\ \ln(Hemb)^2 - 0.0288\ \ln(Q)^2 - 0.0533\ \ln(Diam)^2 - 0.0453\ \ln(W)\ \ln(Q) - 0.183\ \ln(D)\ \ln(Nb) - 0.0594\ \ln(D)\ \ln(Q) + 0.228\ \ln(Hemb)\ \ln(Q) + 0.0277\ \ln(Sl)\ \ln(Q) - 0.0545\ \ln(Sr)\ \ln(np) - 0.276\ \ln(Sr)\ \ln(Nb) + 0.0908\ \ln(Nb)\ \ln(Q) + 0.0506\ \ln(Q)\ \ln(Diam)$$

[se = 0.1409, R^2 = 0.94, R^2_{adj} = 0.929]

(e) ln(DEPINUN)

$$= 0.453 - 0.0471\ \ln(W) + 0.292\ \ln(D) + 0.454\ \ln(Hemb) + 0.0147\ \ln(Sl) + 0.0843\ \ln(Sr) + 0.0521\ \ln(Sc) + 0.0242\ \ln(np) - 0.0456\ \ln(nc) + 0.0212\ \ln(Nb) + 0.0331\ \ln(Semb) + 0.105\ \ln(Q) - 0.0593\ \ln(Diam)$$

[se = 0.1145, R^2 = 0.961, R^2_{adj} = 0.956]

(f) ln(DURINUN)

$$= 4.08 + 0.788\ \ln(W) - 1.95\ \ln(Hemb) - 0.678\ \ln(Sl) + 0.429\ \ln(nc) + 0.140\ \ln(Semb) - 0.573\ \ln(Diam) + 0.235\ \ln(W)\ \ln(Sl) + 0.0695\ \ln(D)\ \ln(Sc) - 0.406\ \ln(Hemb)\ \ln(Sc) - 0.363\ \ln(Hemb)\ \ln(nc) - 0.473\ \ln(Hemb)\ \ln(Nb) + 0.120\ \ln(Hemb)\ \ln(Q) - 0.445\ \ln(Hemb)\ \ln(Diam) + 0.0634\ \ln(Sl)\ \ln(Sc) + 0.071\ \ln(Sr)\ \ln(Q) + 0.0948\ \ln(Sc)\ \ln(Q) - 0.321\ \ln(Nb)\ \ln(Semb) + 0.141\ \ln(Q)\ \ln(Diam) + 0.111\ \ln(Sr)^2$$

[se = 0.1787, R^2 = 0.917, R^2_{adj} = 0.895]

7.2 BOX CULVERTS

Similar to pipe culvert case, 128 site conditions were established through statistical experimental design. The level of values of basin/channel characteristics considered in the experimental design is shown in Table 7.2. Along with 6 discharges, there are a total of 768 cases from which hydraulic responses of box culverts were computed. The resulting regression equations of hydraulic responses, after numerous trial and errors, are given below.

(a) ln(OVTPDUR)

$$= 107+70.7 \ln(W)+7.12 \ln(D)-67.0 \ln(Hemb)+8.33 \ln(Sl)-7.78 \ln(Sr)+12.9 \ln(Sc)$$
$$-70.8 \ln(Nb) - 124 \ln(Hbox) - 62.5 \ln(Wbox) - 40.5 \ln(Nl)+22.4 \ln(Q)-1.34 \ln(Sl)^2$$
$$-39.6 \ln(Hbox)^2+15.4 \ln(W) \ln(Sc)+ 9.29 \ln(W) \ln(Hbox) - 7.25 \ln(Sl) \ln(Nl)$$
$$- 4.46 \ln(Sr) \ln(nc) - 20.5 \ln(Sc) \ln(Nb) - 19.2 \ln(Sc) \ln(Wbox)$$
$$+ 2.51 \ln(np) \ln(Semb) + 1.86 \ln(np) \ln(Wbox) + 5.03 \ln(nc) \ln(Wbox)$$
$$- 6.47 \ln(nc) \ln(Nl) - 2.40 \ln(nc) \ln(Q) + 8.09 \ln(Nb) \ln(Wbox)$$
$$- 11.0 \ln(Nb) \ln(Q) - 8.90 \ln(Semb) \ln(Hbox) + 4.86 \ln(Semb) \ln(Wbox)$$
$$+ 18.9 \ln(Hbox) \ln(Q) - 4.55 \ln(Wbox) \ln(Q)$$

[se = 8.17, R^2=0.812, R^2_{adj}=0.795]

(b) ln(HWDEP)

$$= 0.00273 + 0.00171 \ln(W) - 0.000716 \ln(D) + 0.991 \ln(Hemb)+ 0.00102 \ln(Sl)$$
$$+ 0.000961 \ln(Sr) + 0.000242 \ln(Sc)+ 0.000326 \ln(np) - 0.00103 \ln(Nb)$$
$$- 0.00056 \ln(Hbox)- 0.000703 \ln(Wbox) - 0.000441 \ln(Nl) + 0.00269 \ln(Q)$$

[se = 0.002568, R^2=1.000, R^2_{adj}=1.000]

(c) ln(TWDEP)

$$= 0.424 - 0.148 \ln(W) + 0.223 \ln(D) - 0.251 \ln(Hemb)+ 0.0886 \ln(Sl) + 0.102 \ln(Sr)$$
$$- 0.151 \ln(Sc) + 0.234 \ln(np)+ 0.100 \ln(nc) - 0.0404 \ln(Nb) - 0.01 \ln(Semb)$$
$$+ 0.248 \ln(Hbox)+ 0.306 \ln(Q)$$

[se = 0.09231, R^2=0.964, R^2_{adj}=0.963]

(d) ln(HWMAX)

$$= -0.065 - 0.0828 \ln(W) + 0.0787 \ln(D) + 0.97 \ln(Hemb) + 0.0381 \ln(Sl) - 0.192 \ln(Sr)$$
$$+ 0.0677 \ln(Sc) + 0.0326 \ln(np) - 0.0952 \ln(Nb)+ 0.0425 \ln(Semb) - 0.189 \ln(Hbox)$$
$$- 0.096 \ln(Wbox)+ 0.155 \ln(Q) + 0.0453 \ln(D)^2 - 0.143 \ln(Hemb)^2$$
$$- 0.0397 \ln(Sr)^2 + 0.00797 \ln(Q)^2$$

[se = 0.1319, R^2=0.943, R^2_{adj}=0.942]

Table 7.2 Level of Values of Site Condition Variables for Box Culverts

Variable	Level of Variable Values
Channel Width (W)*	10', 25', 60', 150' (in ft)
Channel Depth (D)	= W/(WD)[1] = (10, 25) (in ft)
Embankment Height (Hemb)	= (1.2 or 2.0) x Depth + 2.0' (in ft)
Left Floodplain Slope in Transverse Direction (Sl)	0.02, 0.05, 0.10, 0.18 (in ft/ft)
Right Floodplain Slope in Transverse Direction (Sl)	0.02, 0.05, 0.10, 0.18 (in ft/ft)
Channel Slope (Sc)	16, 24, 36, 54 (in ft/mi)
Floodplain Roughness (np)	0.03, 0.06, 0.11, 0.22
Channel Roughness (nc)	0.03, 0.04, 0.06, 0.08
Number of Barrels (Nb)	1, 2
Embankment Slope (Semb)	2, 3, 5, 8 (in V:H=1:Semb)
Peak Discharge (Q)	Six discharges using different return periods (in cfs)
Height of Box (Hbox)	= (Hemb-2)/a, where a=(1, 1.2, 2.4)
Width of Box (Wbox)	= f x W/Nb, where f=(0.8, 0.6, 0.4)

1: WD = Width-Depth Ratio;
* See Druse et al., 1988.

(e) ln(DEPINUN)

$$= 0.663 - 0.0851 \ln(W) + 0.22 \ln(D) + 0.296 \ln(Hemb) + 0.0587 \ln(Sl) + 0.0583 \ln(Sr) + 0.0703 \ln(Sc) + 0.0498 \ln(np) + 0.0395 \ln(nc) - 0.0959 \ln(Nb) + 0.0181 \ln(Semb) - 0.111 \ln(Hbox) - 0.0668 \ln(Wbox) + 0.251 \ln(Q)$$

[se = 0.09194, R^2=0.972, R^2_{adj}=0.972]

(f) ln(DURINUN)

$$= 475 + 24.8 \ln(W) + 107 \ln(Hemb) + 92.8 \ln(Sc) + 40.3 \ln(np) + 184 \ln(nc) - 88.3 \ln(Semb) - 104 \ln(Hbox) + 132 \ln(Wbox) + 62.7 \ln(Nl) - 76.7 \ln(Q) - 12.5 \ln(D)^2 - 38.0 \ln(Hemb)^2 + 7.21 \ln(np)^2 - 7.14 \ln(Q)^2 - 7.63 \ln(D) \ln(Sl) + 6.55 \ln(D) \ln(Sr) + 12.5 \ln(D) \ln(Sc) + 20.7 \ln(D) \ln(Wbox) + 47.6 \ln(Hemb) \ln(Sl) - 27.5 \ln(Hemb) \ln(Wbox) + 40.0 \ln(Hemb) \ln(Q) - 3.79 \ln(Sl) \ln(Sr) + 4.61 \ln(Sl) \ln(np) + 27.0 \ln(Sl) \ln(nc) - 3.63 \ln(Sl) \ln(Semb) - 33.0 \ln(Sr) \ln(Hbox) + 2.96 \ln(Sl) \ln(Wbox) + 15.5 \ln(Sl) \ln(Nl) + 8.37 \ln(Sr) \ln(Nb) + 6.99 \ln(Sr) \ln(Wbox) - 6.98 \ln(Sc) \ln(Q) + 25.0 \ln(Sc) \ln(nc) - 10.9 \ln(Sc) \ln(Semb) + 14.0 \ln(Sc) \ln(Wbox) - 13.1 \ln(Sc) \ln(Q) + 24.7 \ln(np) \ln(Nb) + 15.0 \ln(np) \ln(Wbox) - 5.45 \ln(np) \ln(Q) + 20.5 \ln(Nb) \ln(Semb) + 19.0 \ln(Semb) \ln(Nl)$$

[se = 15.28, R^2=0.878, R^2_{adj}=0.869]

7.3 BRIDGES

Statistical experimental designs were performed to generate 128 scenarios for site conditions based on the variable levels shown in Table 7.3. For each of the 128 site conditions generated, six peak discharges are used whose magnitudes were determined again by the regional regression equations (Druse et al., 1988). Since WSPRO does not have the capability to perform hydrograph routing, the shape of the hydrograph is not needed. The WDT staff pointed out that given the amount of temporary storage caused by a bridge in Wyoming, overlooking the flood hydrograph effect would not be significant oversight. The simulation program WSPRO was applied repeatedly for the 128 site conditions. The program was modified such that it would compute and print the values of hydraulic response of the bridge.

In regression analysis, the data base consists of 6 discharges time 128 site conditions = 768 cases for bridges, if no missing values are encountered. Out of 768 cases, there were 525 cases where the bridge hydraulics simulator "WSPRO" converged to a solution for the water profile computations. The values of

Table 7.3 Level of Values of Site Condition Variables for Bridges

Variable	Level of Variable Values
Channel Width (W)*	20, 60, 180, 540 (in ft)
Channel Depth (D)	= W/(WD)[1] = (3, 8, 20) (ft)
Embankment Height (Hemb)	= (3.0 or 6.0) x Depth (in ft)
Left Floodplain Slope in Transverse Direction (Sl)	0.001, 0.01, 0.07, 0.50 (in ft/ft)
Right Floodplain Slope in Transverse Direction (Sr)	0.001, 0.01, 0.07, 1.0 (in ft/ft)
Channel Slope (Sc)	2.5, 10, 35, 140 (in ft/mi)
Floodplain Roughness (np)	0.03, 0.06, 0.11, 0.22
Channel Roughness (nc)	0.03, 0.04, 0.06, 0.08
Abutment Slope (Sa)	2, 2.75, 3.25, 4 (in V:H=1:Sa)
Peak Discharge (Q)	Six discharges (in cfs)
Bridge Length (Lb)	= W x f(=2,3,4,5) (in ft)
Pier Width (Pw)	2.0, 2.5, 3.0, 3.5 (in ft)
Number of Lanes (Nl)	2, 4

1: WD = Width-Depth Ratio;
* See Druse et al., 1988.

hydraulic response variables determined by WSPRO for the 525 cases were used as the dependent variable which was regressed against independent variables defining the site conditions. The resulting regression equations with sufficient accuracy are summarized below. Included is a definition of the variables.

Dependent Variables:

(a) HWDEP = Avg. headwater depth when overtopping occurs (in ft).
(b) TWDEP = Avg. tailwater depth when overtopping occurs (in ft).
(c) HDMAX = Maximum headwater depth (in ft).
(d) OVTDEP = Avg. overtopping depth above the bridge deck (in ft).
(e) OVTVEL = Avg. overtopping flow velocity (in fps).
(f) WIDINUNL = Inundation width to the left (in ft).
(e) WIDINUNR = Inundation width to the right (in ft).

Independent Variables;

(1) W = Width of channel (in ft) -- See Druse et al., 1988.
(2) D = Depth of channel (in ft)
(3) Hemb = Height of embankment (in ft)
(4) Sl = Slope of floodplain on the left (in ft/ft)
(5) Sr = Slope of floodplain on the right (in ft/ft)
(6) Sc = Slope of channel (in ft/ft)
(7) np = Manning's roughness coefficient for floodplain
(8) nc = Manning's roughness coefficient for channel
(9) Sa = Slope of abutment (V:H=1:Semb)
(10) Lb = Bridge length (in ft)
(11) Wp = Pier Width (in ft)
(12) Nl = Number of lanes
(13) Q = Peak discharge (in cfs)

(a) ln(HWDEP)

$$\begin{aligned} &= 0.875 + 0.0319 \ln(W) + 0.0341 \ln(D) + 0.472 \ln(Hemb) - 0.0114 \ln(Sl) \\ &\quad - 0.0731 \ln(Sc) + 0.0661 \ln(np) + 0.267 \ln(nc) + 0.0305 \ln(Sa) \\ &\quad - 0.0987 \ln(Lb) + 0.0304 \ln(Wp) + 0.0605 \ln(Q) + 0.00613 \ln(D)^2 \\ &\quad + 0.0949 \ln(Hemb)^2 - 0.00238 \ln(Sl)^2 + 0.000684 \ln(Sr)^2 - 0.00582 \ln(Sc)^2 \\ &\quad + 0.0139 \ln(np)^2 + 0.0447 \ln(nc)^2 + 0.00679 \ln(Lb)^2 - 0.00335 \ln(Q)^2 \end{aligned}$$

[se =0.02999, R^2 =99.8%, R^2 (adj) = 99.7%]

(b) $\ln(TWDEP)$

$$= 2.84 - 0.443 \ln(Sr) + 0.286 \ln(np) + 0.506 \ln(Sa) - 1.01 \ln(Wp) - 1.29 \ln(Nl)$$
$$- 0.160 \ln(Q) + 0.134 \ln(nc)^2 - 0.0243 \ln(W) \ln(Sc) - 0.363 \ln(W) \ln(Sa)$$
$$- 0.155 \ln(D) \ln(Sl) + 0.209 \ln(D) \ln(Sa) - 0.983 \ln(D) \ln(Wp)$$
$$+ 0.192 \ln(Hemb) \ln(Sl) + 0.0250 \ln(Hemb) \ln(Sc) - 0.196 \ln(Hemb) \ln(nc)$$
$$+ 0.0310 \ln(Hemb) \ln(Lb) + 0.738 \ln(Hemb) \ln(Wp) + 0.131 \ln(Hemb) \ln(Nl)$$
$$+ 0.0274 \ln(Sl) \ln(Sc) + 0.0465 \ln(Sl) \ln(np) + 0.0720 \ln(Sl) \ln(Wp)$$
$$+ 0.0930 \ln(Sl) \ln(Nl) - 0.0302 \ln(Sr) \ln(np) - 0.157 \ln(Sr) \ln(nc)$$
$$- 0.0043 \ln(Sr) \ln(Sa) - 0.0232 \ln(Sr) \ln(Lb) - 0.131 \ln(Sr) \ln(Wp)$$
$$- 0.135 \ln(nc) \ln(Nl) + 0.0282 \ln(Q)^2 - 0.0043 \ln(Q) \ln(D)$$
$$- 0.0239 \ln(Q) \ln(Hemb) - 0.0102 \ln(Q) \ln(Sl) + 0.0159 \ln(Q) \ln(Sr)$$
$$+ 0.00705 \ln(Q) \ln(Sc) - 0.0130 \ln(Q) \ln(np) + 0.105 \ln(Q) \ln(nc)$$
$$+ 0.0823 \ln(Q) \ln(Sa) + 0.00043 \ln(Q) \ln(Lb) + 0.104 \ln(Q) \ln(Nl)$$

[s = 0.03606, R-sq = 99.2%, R-sq(adj) = 99.0%]

(c) $\ln(HWMAX)$

$$= - 0.799 + 0.214 \ln(W) - 0.595 \ln(D) + 0.776 \ln(Hemb) - 0.112 \ln(Sr) + 0.231 \ln(Sc)$$
$$+ 0.669 \ln(np) + 2.02 \ln(Sa) - 0.580 \ln(Lb) + 2.22 \ln(Nl) + 0.409 \ln(Q)$$
$$- 0.0617 \ln(W)^2 - 0.0105 \ln(Sl)^2 + 0.104 \ln(np)^2 + 0.0464 \ln(Lb)^2$$
$$- 0.108 \ln(W) \ln(Hemb) - 0.0035 \ln(W) \ln(np) + 0.478 \ln(W) \ln(Nl)$$
$$- 0.0670 \ln(D) \ln(Sl) + 0.0422 \ln(Hemb) \ln(Sl) - 0.0255 \ln(Hemb) \ln(Sr)$$
$$+ 0.0605 \ln(Hemb) \ln(np) - 0.0603 \ln(Hemb) \ln(Nl) + 0.0119 \ln(Sl) \ln(Sc)$$
$$+ 0.0446 \ln(Sl) \ln(nc) + 0.0251 \ln(Sl) \ln(Lb) + 0.0203 \ln(Sl) \ln(Nl)$$
$$+ 0.0122 \ln(Sr) \ln(Lb) - 0.00098 \ln(Sr) \ln(Nl) + 0.0377 \ln(Sc) \ln(np)$$
$$- 0.0345 \ln(Sc) \ln(nc) + 0.145 \ln(Sc) \ln(Sa) - 0.124 \ln(Sc) \ln(Lb)$$
$$- 0.168 \ln(Sc) \ln(Wp) + 0.0790 \ln(np) \ln(Nl) - 0.158 \ln(nc) \ln(Sa)$$
$$+ 0.119 \ln(nc) \ln(Lb) - 0.446 \ln(nc) \ln(Wp) + 0.261 \ln(nc) \ln(Nl)$$
$$- 0.834 \ln(Sa) \ln(Wp) - 0.743 \ln(Sa) \ln(Nl) - 0.186 \ln(Lb) \ln(Wp) - 0.256 \ln(Lb) \ln(Nl)$$
$$- 0.237 \ln(Wp) \ln(Nl) + 0.0685 \ln(Q) \ln(D) - 0.00446 \ln(Q) \ln(Sl)$$
$$+ 0.0259 \ln(Q) \ln(Sc) - 0.0182 \ln(Q) \ln(np) - 0.0010 \ln(Q) \ln(nc)$$
$$+ 0.0124 \ln(Q) \ln(Sa) - 0.0633 \ln(Q) \ln(Nl)$$

[se = 0.1129, R^2 = 97.4%, R^2 (adj) = 97.1%]

(d) $\ln(OVTDEP)$

$$= - 4.38 - 0.506 \ln(W) - 0.304 \ln(D) + 0.215 \ln(Sl) + 0.273 \ln(Sr) - 0.380 \ln(Sc) + 1.24 \ln(np)$$
$$- 0.43 \ln(nc) + 5.86 \ln(Sa) + 1.04 \ln(Wp) - 0.0519 \ln(Sl)^2 - 0.0463 \ln(Sr)^2$$
$$+ 0.0994 \ln(Hemb) \ln(Sr) + 0.0300 \ln(Sl) \ln(Sr) + 0.0141 \ln(Sr) \ln(nc)$$
$$- 0.0793 \ln(Sl) \ln(Wp) + 1.71 \ln(nc) \ln(Sa) + 0.373 \ln(Lb) \ln(Wp) + 0.0344 \ln(Q)^2$$
$$+ 0.101 \ln(Q) \ln(W) - 0.0315 \ln(Q) \ln(Sl) - 0.0331 \ln(Q) \ln(Sr) + 0.0408 \ln(Q) \ln(Sc)$$
$$- 0.118 \ln(Q)\, np - 0.161 \ln(Q) \ln(nc) - 0.109 \ln(Q) \ln(Lb) - 0.372 \ln(Q) \ln(Wp)$$

[se = 0.2644, R^2 = 94.9%, R^2 (adj) = 93.9%]

(e) $\ln(OVTVEL)$

$$= 11.4 - 2.58 \ln(Hemb) - 0.191 \ln(Sl) + 1.32 \ln(Sr) + 0.924 \ln(Sc) + 0.522 \ln(np) +7.59 \ln(nc)+3.33 \ln(Lb)+1.62 \ln(Wp)+1.17 \ln(Nl)+0.315 \ln(D)^2-0.787 \ln(Hemb)^2 -0.0599 \ln(Sl)^2 +1.05 \ln(nc)^2-1.94 \ln(Sa)^2 + 0.259 \ln(W) \ln(D)-0.715 \ln(D) \ln(nc) +0.624 \ln(Hemb) \ln(nc)- 0.0435 \ln(Sl) \ln(Sc) + 0.152 \ln(Sl) \ln(nc) +0.408 \ln(Sr) \ln(nc)+0.282 \ln(Sr) \ln(Wp)-0.139 \ln(Sc) \ln(np)+0.239 \ln(Sc) \ln(nc) -0.729 \ln(Sc) \ln(Sa)+0.0806 \ln(Sc) \ln(Wp)+0.215 \ln(np) \ln(Wp)+ 0.618 \ln(nc) \ln(Lb) -0.990 \ln(Sa) \ln(Lb) + 0.605 \ln(Sa) \ln(Wp) + 1.93 \ln(Sa) \ln(Nl) - 0.759 \ln(Lb) \ln(Nl) -0.0773 \ln(Q)^2 - 0.294 \ln(Q) \ln(D) + 0.650 \ln(Q) \ln(Hemb) + 0.00968 \ln(Q) \ln(Sl) -0.0259 \ln(Q) \ln(Sr)+0.0092 \ln(Q) \ln(Sc)-0.199 \ln(Q) \ln(np)-0.130 \ln(Q) \ln(nc) +0.178 \ln(Q) \ln(Sa)$$

[se = 0.09972, R^2 = 97.6%, R^2 (adj) = 96.9%]

(f) $\ln(WIDINUNL)$

$$= - 0.03-3.25 \ln(W)+0.738 \ln(D) - 0.583 \ln(Sl) - 0.534 \ln(Sr) - 1.04 \ln(Sc) - 0.740 \ln(np) - 3.58 \ln(nc) - 7.36 \ln(Sa) - 1.36 \ln(Lb) + 6.55 \ln(Wp) + 1.07 \ln(Nl) - 0.172 \ln(D)^2 + 0.0444 \ln(Sl)^2 + 0.0449 \ln(Sr)^2 - 0.188 \ln(Sc)^2 - 0.184 \ln(np)^2 - 0.534 \ln(W) \ln(Sc) + 0.201 \ln(D) \ln(Sl) + 0.183 \ln(D) \ln(Sc) - 2.10 \ln(D) \ln(nc) - 5.02 \ln(D) \ln(Sa) - 0.297 \ln(Hemb) \ln(D) + 0.531 \ln(Hemb) \ln(np) + 2.02 \ln(Hemb) \ln(nc) + 4.99 \ln(Hemb) \ln(Sa) - 0.729 \ln(Hemb) \ln(Lb) - 0.0422 \ln(Sl) \ln(Sr) + 0.107 \ln(Sl) \ln(Sc) - 0.0845 \ln(Sl) \ln(np) + 0.191 \ln(Sl) \ln(Lb)- 0.131 \ln(Sr) \ln(np) + 0.152 \ln(Sr) \ln(Lb) - 0.336 \ln(Sr) \ln(Nl)- 0.130 \ln(Sc) \ln(np) - 0.113 \ln(Sc) \ln(nc) - 0.624 \ln(np) \ln(Sa)+ 0.602 \ln(np) \ln(Wp) - 0.484 \ln(np) \ln(Nl) + 2.60 \ln(nc) \ln(Wp) + 0.806 \ln(nc) \ln(Nl) - 0.326 \ln(Lb) \ln(Nl) - 0.254 \ln(Q)^2- 0.044 \ln(Q) \ln(W) + 0.518 \ln(Q) \ln(Hemb) - 0.0363 \ln(Q) \ln(Sl)- 0.0260 \ln(Q) \ln(Sr) + 0.0499 \ln(Q) \ln(Sc) - 0.342 \ln(Q) \ln(np)- 0.240 \ln(Q) \ln(nc) + 0.492 \ln(Q) \ln(Lb) + 0.211 \ln(Q) \ln(Wp)$$

[se = 0.4799, R^2 = 97.0%, R^2 (adj) = 96.5%]

(g) $\ln(WIDINUNR)$

$$= - 25.3-4.57 \ln(W)+0.516 \ln(Hemb)-0.474 \ln(Sr)-0.972 \ln(Sc)- 4.47 \ln(np) - 5.22 \ln(nc) +12.6 \ln(Sa)+0.853 \ln(Lb)+3.99 \ln(Nl)+1.15 \ln(Q)+0.491 \ln(Hemb)^2 + 0.148 \ln(Sr)^2 - 0.138 \ln(Sc)^2 - 0.461 \ln(np)^2 - 0.392 \ln(W) \ln(Sr) - 0.347 \ln(W) \ln(Sc) -0.550 \ln(D) \ln(Hemb)+0.0912 \ln(D) \ln(Sl) + 0.344 \ln(D) \ln(Sr) + 0.386 \ln(D) \ln(Sc) - 0.459 \ln(D) \ln(nc) + 1.50 \ln(D) \ln(Wp) + 1.70 \ln(D) \ln(Nl) - 0.467 \ln(Hemb) \ln(Sr) +0.278 \ln(Hemb) \ln(nc) - 0.594 \ln(Hemb) \ln(Lb) - 2.07 \ln(Hemb) \ln(Wp) - 2.28 \ln(Hemb) \ln(Nl)- 0.0306 \ln(Sl) \ln(Sr)+ 0.0638 \ln(Sl) \ln(Sc) - 0.135 \ln(Sl) \ln(np) - 0.0139 \ln(Sr) \ln(np)+ 0.550 \ln(Sr) \ln(Lb)+ 0.258 \ln(Sr) \ln(Wp) - 0.259 \ln(Sr) \ln(Nl) - 0.214 \ln(Sc) \ln(np) + 0.256 \ln(Sc) \ln(Sa) - 0.449 \ln(Sc) \ln(Nl) - 0.406 \ln(np) \ln(nc) + 0.258 \ln(np) \ln(Sa) + 2.51 \ln(nc) \ln(Sa)+ 1.71 \ln(nc) \ln(Nl) - 0.369 \ln(Sa) \ln(Lb) + 1.31 \ln(Wp) \ln(Nl) - 0.238 \ln(Q)^2 + 0.493 \ln(Q) \ln(Hemb) - 0.0413 \ln(Q) \ln(Sl) - 0.194 \ln(Q) \ln(np) + 0.371 \ln(Q) \ln(Lb) + 0.134 \ln(Q) \ln(Wp)$$

[se = 0.4908, R^2 = 97.2%, R^2 (adj) = 96.8%]

8.
DETERMINATION OF AT-SITE LTEC DESIGN FREQUENCY

In this study, a fortran program, LTEC.FOR, was developed to determine the at-site configuration of roadway crossing structures with the minimum first cost, to compute the associated annual expected flood damage, and to identify the LTEC design return period. The program is used as the working tool for computing information on the LTEC design frequency under various site conditions in the generated data base. Descriptions of generating site conditions in the data base are given in Chapter 13.

The program LTEC.FOR allows the designer to specify a flood-frequency relationship, or a regional flood-frequency relationship developed by Druse et al (1988) using either the channel geometry or basin characteristic methods. The program, LTEC.FOR, has four major components: (1) a "structural costs component" consisting of the cost functions for bridges, box culverts, and pipe culverts; (2) a "hydraulic responses component" defining the hydraulic responses of flood of a specified return period when passing roadway crossing structures; (3) a "flood damage functions component" containing subroutines for calculating damages from flood of a specified return period to buildings, crops, pavement and embankment, and traffic interruption; and (4) an "optimization component" using an optimum-seeking algorithm that identifies the configuration of roadway crossing with minimum construction cost (i.e., first cost) for a specified flood subject to design constraints. Details of the components of program LTEC.FOR are described in the following sections.

8.1 PROGRAM INPUTS

Inputs to program LTEC.FOR are the site conditions and the associated economic data that affect the total cost of the roadway structure under consideration. The required inputs for site condition and for computing flood related damages are listed in Tables 8.1 and 8.2, respectively. Similarly, inputs relating to structures and for controlling the optimization algorithm are shown in Tables 8.3 and 8.4, respectively.

Table 8.1 Inputs Required by program LTEC.FOR for a Given Site Condition

VARIABLE	DESCRIPTIONS
IST	Structure type; 1 - Bridge; 2 - Box Culvert; 3 - Pipe Culvert.
IREGION	Hydrologic region in Wyoming: 1 : Mountainous region; 2 : Plains region; 3 : High desert region.
IMODEL	Flood frequency equation to be used for computing peak discharges of different return periods; 0 : User supply his/her frequency relation; 1 : Use channel-geometry method; 2 : Use basin characteristics method.
INI	Initial solution index: 0 : No initial solutions will be given; they are computed in subroutine 'SIZING'; 1 : User specifies the initial solutions.
W *	Top width of main channel (in ft)
D	Depth of main channel (in ft)
Sl	Average slope of floodplain on the left (in ft/ft)
Sr	Average slope of floodplain on the right (in ft/ft)
Sc	Average slope of channel (in ft/ft)
Np	Manning's roughness coefficient for floodplain
Nc	Manning's roughness coefficient for channel
DA	Drainage area (sq. mi.)
PR	Mean annual precipitation depth (in)
GF	Geographic factor

* See Druse et al., 1988.

Table 8.2 Input Required by LTEC.FOR for Computing Flood Damage Costs

VARIABLE	DESCRIPTIONS
BUILDINGS DATA:	
NRES	Number of residential buildings susceptible for flood damage;
NCOM	Number of commercial buildings susceptible for flood damage;
LOCATION	1 : Urban ; 2 : Rural
INDEXBR(I)	Type of residential building (6 types, Table 6.5)
INDEXBC(I)	Type of commercial building (73 Types, Table 6.6)
ELEVBR(I)	Elevation of residential building I, (ft);
ELEVBC(I)	Elevation of commercial building I, (ft);
VALUER(I)	Estimated value of residential building I, in($1000)
VALUEC(I)	Estimated value of commercial building I, in($1000)
CROPS DATA:	
NCRO	Number of crop types on the site (10 types, Table 6.2)
INDXI(I)	Irrigation types for crop I:
INDXC(I)	Type of crops;
ELEVC(I)	Average elevation of crop I, (ft);
PP(I)	Percentage of planting area of type I crop.
TRAFFIC DATA:	
ATSITE	Index for the type of detour: 0 - Detour is away from the crossing site; 1 - Detour is at the crossing site.
DELL	Increased distance of travel between the detour and normal routes, (miles);
P(I)	Percentage of daily traffic of vehicle size I, sum of P(I) = 1; (4 sized are considered presently).
RREP	Rate of repair for embankment and pavement, (cu yd/day);
TM	Mobilization time, (hrs);
OR(I)	Occupancy rate of I size of vehicle, (persons/vehicle);
UOC	Unit cost of occupancy, ($/person/hr);
ASVD	Average vehicle speed, (miles/hr);
AR	Accident ratio, (accident/100 million vehicle mile);
ADTE	Equivalent average daily traffic, (vehicle/day);
UDAMG	Unit cost of damage, ($/damage claimed);
PAVEMENT AND EMBANKMENT DATA:	
INDXF	Type of flood;
INDXS	Type of embankment base soil (3 types);
INDXSC	Index of embankment surface condition; 1 = Non-paved; 2 = Paved
INDXV	Type of vegetal cover (3 types).

Table 8.3 Input Required by LTEC.FOR for Structural and Economic Aspects

VARIABLE	DESCRIPTIONS
NL	Number of lanes
FREEBRD	Required freeboard (in ft)
WP	Proposed pier width (in ft); for bridge only.
COVERDEP	Minimum soil cover; for box and pipe culverts.
INDEXP	Index for pipe culvert types.
RDWID	Roadway total width including width of traffic lanes, medium, and shoulders. If RDWID=0, the following road specifications must be given. (For culverts only).
BRIWID	Bridge width including width of traffic lanes, and shoulders. If RDWID=0, the following road specifications must be given. (For bridges only).
WLANE	Width of traffic lanes (in feet).
THICKPV	Thickness of pavement (in inches).
WSHODR	Width of shoulders (in feet).
WMEDIUM	Width of medium (in feet).
RATE	Interest rate
LIFE	Expected project life (in years)

Table 8.4 Inputs Required by LTEC.FOR for Optimization Subroutine

VARIABLE	DESCRIPTIONS
ITMAX	Maximum number of times the objective function is called.
NREDU	Maximum number of times the initial step size is to be reduced.
EPSY	Error in objective function to be reached before program terminates.
ALPHA	Factor for extending the size of the initial steps, ALPHA is greater than or equal to 1.0
BETA	Factor for reducing the size of the initial steps, 0.0< BETA < 1.0
IPRINT	Print control. IPRINT=0 results in no intermediate output; IPRINT=1 results in output on each iteration.

8.2 THE OPTIMIZATION COMPONENT

The decision variables considered in the program LTEC.FOR are: (1) for bridges - bridge length, embankment height, and abutment slope; (2) for box culverts - embankment slope, box height, box width, and number of barrels; (3) for pipe culverts - embankment slope, pipe diameter, and number of barrels. Although circular pipe culverts are considered in the program to determine pipe culvert layouts, the result can be extended to include arch pipes with equivalent diameter as the circular pipes.

There are two ways to specify the top width of the roadway. The first is to specify the total width of roadway including width of traffic lanes, median, and shoulders. Alternatively, users can input traffic lane number and widths of lane, median and shoulders based on which the program computes the top width of the embankment. Therefore, once the embankment slope (a decision variable) for a culvert is determined, the length of barrels and the volume of embankment is computed according to Figure 3.1.

The constraints considered in LTEC.FOR primarily include minimum soil cover thickness, freeboard (a safety factor if one so desires), and lower and upper bounds on embankment height, bridge length, width and height of box culvert, and diameter of pipe culverts. These bounds are specified according to the range of values used in the experimental design (Chapter 7) from which hydraulic responses of flow passing the roadway crossings are generated. In addition, the bridge length must be greater than the channel width. For a feasible solution (with all the decision variables satisfying the constraints), the total first cost of the structure is computed.

Once the minimum first cost structural configuration is determined, the associated second cost relating to flood damages is computed using Eq.(2.5). The flood magnitudes of different return periods are estimated by a set of regional regression equations applicable to the State of Wyoming developed by the USGS for the WDT (Druse et al., 1988), or by entering a flood-frequency relationship unique to a site. In the program LTEC.FOR, users can select the regional flood frequency method (channel geometry method or basin characteristics method) by which flood magnitudes of different return periods are computed. In using the channel-geometry regional flood-frequency equations, users are warned that, above a certain channel width, a smaller flow magnitude would occur as the return period increases which is incorrect. A similar situation could occur when basin-characteristic regional flood frequency equations are applied outside their intended range of use. Tables 8.5 and 8.6, respectively, show the valid range and relationship between independent variables for the channel-geometry and basin-characteristics methods to ensure that the regional frequency equations yield flood magnitude that would increase with return period. Refer to Table 8.5 as an example. Applying channel-geometry method to mountainous region, the resulting magnitude of 500-year flood will be less than that of 200-year flood if channel width is greater than 13 feet. When the value of this upper limit is small, the user must be cautious about the applicability of the regional equations. Except for some return periods in the mountainous region, the channel-geometry method should produce consistency results for the other two regions for channel width that one would encounter in Wyoming.

The algorithm employed to determine the highway drainage structure with the least construction cost utilizes the Hooke-Jeeves pattern search procedure (Hooke and Jeeves, 1961). The procedure is based on the philosophy that any set of moves which have been successful in obtaining lower cost design on earlier searches will be worth trying again. The method starts cautiously with short excursions from a starting solution point (defined by the decision variables). The step size grows with repeated success indicated by improving the objective function value (reducing the first cost). Subsequent failure indicates that shorter steps are in order, and if a change in direction is required, the technique will start over again with a new pattern. In the vicinity of the optimum, the search step size becomes very small to avoid overlooking any promising directions. The search procedure continues until the convergence criterion is satisfied.

8.3 STRUCTURAL COST COMPONENT

Three types of highway drainage structure are considered, namely, bridges, box culverts, and pipe culverts. The subroutines for calculating the corresponding costs are BRI_FC for bridges, BOX_FC for box culverts, and PIP_FC for pipe culverts. The cost functions used in these subroutines are based on those given in Chapter 3. In each of the subroutines, the volume of embankment and the corresponding cost are also computed. The total structural cost is then the sum of the two cost items. Note that cost functions for the three types of drainage structures developed in Chapter 3 are for 1977 values. Adjustment factor is needed to bring the 1977 values to the present condition.

Table 8.5 Valid Range of Channel Width for Regional Flood Frequency Equations By Channel-Geometry Method

Return Period	Mountainous Region	Plains Region	High Desert Region
2 yrs			
	1,364'	5.9'x10^{10}	13,601,148'
5 yrs			
	1,234'	3.7'x10^{7}	1,134,183'
10 yrs			
	693'	1.9'x10^{12}	29,637'
25 yrs			
	1,411'	9.8'x10^{7}	3,773'
50 yrs			
	6,582'	3.5'x10^{14}	15,391'
100 yrs			
	54,574'	3.2'x10^{6}	6,308'
200 yrs			
	13'	6.7'x10^{15}	1,717'
500 yrs			

Note: The channel widths given above are the upper limits above which the discharge of a given return period is lower than that of the next higher return period.

Table 8.6 Required Valid Relationship Between Independent Variables for Regional Flood Frequency Equations By Basin-Characteristic Method

Return Period	Mountainous Region	Plains Region	High Desert Region
2 yrs			
	$A^{0.02}\ PR^{0.35} < 4.6275$	$SB^{-0.09} < 1.5422$	$A^{0.03V}\ PR^{-0.21} < 1.5916$
5 yrs			
	$A^{0.01}\ PR^{0.19} < 2.2671$	$A^{0.01U}\ SB^{-0.05} < 1.2073$	$A^{0.01V}\ PR^{-0.09} < 1.3019$
10 yrs			
	$A^{0.01}\ PR^{0.19} < 2.5233$	$SB^{-0.05} < 1.2250$	$A^{0.02V}\ PR^{-0.08} < 1.4059$
25 yrs			
	$PR^{0.13} < 1.7630$	$A^{0.01U}\ SB^{-0.04} < 1.1889$	$A^{0.01V}\ PR^{-0.04} < 1.2473$
50 yrs			
	$A^{0.01}\ PR^{0.12} < 1.7100$	$SB^{-0.02} < 1.1608$	$A^{0.01V}\ PR^{-0.03} < 1.2438$
100 yrs			
	$A^{0.01}\ PR^{0.13} < 1.7960$	$A^{0.01U}\ SB^{-0.01} < 1.4000$	$PR^{-0.02} < 1.1960$
200 yrs			
	$A^{0.01}\ PR^{0.149} < 1.8601$	$SB^{-0.01} < 1.3461$	$A^{0.01V}\ PR^{-0.02} < 1.3082$
500 yrs			

Note: A = Drainage area (in square miles);
PR = Average annual precipitation (in inches);
SB = Slope of the basin (in ft/mile);
U = $A^{-0.05}$;
V = $A^{-0.03}$.

8.4 HYDRAULIC RESPONSE COMPONENT

To evaluate the second cost associated with various flood damages due to the presence of roadway crossing structures, hydraulic responses such as backwater effect, overtopping depth and duration, etc. must be known. Information for these types of flood damage can be obtained by applying hydraulic simulation models such as CDS for culverts and WSPRO for the water surface profile due to bridges/culverts. Although the incorporation of such detailed hydraulic simulation models into the optimization framework is technically possible, its required computational effort is beyond the scope of the study. As an alternative, hydraulic responses under different hydrological conditions, channel properties, and commonly encountered configurations of roadway crossing structures are obtained through repeated applications of appropriate simulation models. The set of empirical hydraulic response equations described in Chapter 7 were developed and were used in the program LTEC.FOR as a substitute for the complete hydraulic simulation models, CDS and WSPRO.

The program LTEC.FOR contains three subroutines, namely, BRI_EQ, BOX_EQ, and PIP_EQ; each contains hydraulic responses for bridges, box culverts, and pipe culverts, respectively. The hydraulic responses pertinent to the study are:(a) HWDEP - average headwater depth when overtopping occurs (in ft.), (b) TWDEP -average tailwater depth when overtopping occurs (in ft.), (c) OVTDEP - average overtopping depth above the roadway surface (in ft.), (d) OVTVEL - average overtopping flow velocity (in fps), (e) WIDINUNL - inundation width on the left bank (in ft.), and (f) WIDINUNR - inundation width on the right bank (in ft.).

For the given site condition, flow rate, and design solution with regard to roadway configuration (i.e., embankment height, embankment slope, drainage structural opening), the maximum headwater depth without overtopping is first calculated by subroutine BRIHWMAX or BOXHWMAX or PIPHWNO to test the solution feasibility. That is, the minimum elevation difference between embankment height and maximum water depth must be as large as the specified freeboard (safety factor). If this and other feasibility conditions are satisfied, the program computes those hydraulic responses mentioned above to be used for evaluating flood related damages.

8.5 FLOOD DAMAGE FUNCTIONS COMPONENT

Flood related damage items presently considered in program LTEC.FOR include damages to residential and commercial buildings, crops, road embankment and pavement, and traffic interruption. In subroutine DAMBLDG, six (6) types of residential buildings (Table 6.4) and seventy three (73) types of commercial buildings (Table 6.6) are considered. The damage percentage, which is a function of inundation depth, in terms of building values of different types are internally specified in the subroutine.

The subroutine DAMCROP considers eight (8) economic crop types (Table 6.2) typically found in the State of Wyoming on irrigated and non-irrigated lands including desert and range lands . The internal parameters include crop yield per acre, unit price, and damage percentage (function of inundation duration) for the various types of crops which are based on data shown in Section 6.1 of this report.

The subroutine DAMTRAF calculates the traffic related damages due to roadway overtopping such as costs of passenger time on a detour route and the expected cost due to an accident. The data required for this subroutine are listed in Table 8.2. Some of this information may be available with reasonable accuracy while many other parameters may not be easily assessed.

Finally, the subroutine DAMEP evaluates the damage costs to embankment and pavement induced by erosion from flow overtopping the road crossing structures. The subroutine extracts information from the recent study on embankment erosion by Chen and Anderson (1987). It considers two flow types (free and non-free flows), three types of embankment base soil (non-cohesive, high-cohesive, and low-cohesive), two types of embankment surface condition (non-paved and paved), and three types of vegetative cover (without vegetal cover, weeping lovegrass, and crabgrass). The volume of soil eroded due to overtopping can be calculated from the headwater and tailwater depths, and the factors indicated above.

9.
FACTORS AND MECHANISMS FOR DETERMINING EXTENDED-LTEC DESIGN FREQUENCY

The purpose of a highway is to serve the public. This service can be summarized from 23CFR 650A (formally FHWA's "Location and Hydraulic Design of Encroachments on Floodplain", Federal Highway Program Manual, Volume 6, Chapter 7, Section 3, Subsection 2) which states: "It is the policy of the Federal Highway Administration that in the development of a project, a systematic interdisciplinary approach be used to **assess engineering considerations and beneficial and adverse social, economic**, environmental, and other effects; that efforts be made in developing projects to improve the relationship between man and his environment, and to preserve the natural beauty of the countryside and natural and cultural resources; that project development involve consultation with local, state and federal agencies, and the public; **that decisions be made in the best overall** public interest based on a balanced consideration of the need for fast, safe and **efficient transportation, public services, and social, economic, and environmental effects**, and national environmental goals." With present technology, many of these factors are intangible and would have to be considered intuitively or subjectively. This research shows how to quantify some of these more important intangible factors.

Determination of an appropriate design frequency for highway drainage structures is an important element in the overall decision-making process. In addition to economic costs of the project, there are other aspects to consider such as the effect of drift and ice, environmental impact, public convenience, and legal liability of the state highway agency which are intangible and might be equally if not more important in the decision-making process. Therefore, determination of an appropriate design frequency requires inclusion of many important tangible as well as intangible factors so that the balanced decision advocated by the FHWA and others can be achieved.

9.1 FACTORS AFFECTING THE DESIGN FREQUENCY

Numerous factors can enter into the decision-making process when selecting an appropriate design frequency for highway drainage structures. There are tangible factors including drainage structure cost and flood related damages, and various intangible factors including public service, legal ramifications, maintenance budgets, availability of funds, and other factors such as environmental and hydraulic effects. Specifically, we consider in this study the two tangible factors (namely, construction costs and expected flood related damage costs) and three intangible factors (namely, maintenance frequency, litigation potential, and public service). In this section, we discuss various factors, in a more broad context, that could affect the selection of appropriate design frequency for highway drainage structures design.

9.1.1 **Costs of Drainage Structures** - Drainage structure cost is one of the main items in the conventional LTEC analysis shown in Eq.(2.1) of Chapter 2. A drainage structure with higher capacity and serviceability would, in general, be larger and would impose a heavier financial burden on the public. A highway agency, like any public agency, must perform numerous tasks related to road planning, construction, design, maintenance, rehabilitation, and others under budget constraint. Committing excessive costs to a certain drainage structure for unnecessary capacity would preclude funds for other tasks. How to strike a balance so that public funds are most effectively and efficiently used is the challenge to the decision-makers and hydraulics engineers.

9.1.2 **Costs Related Flood Damages** - Flood related cost is another important element in the conventional LTEC analysis procedure. Roadway crossing structures encroach on the natural waterway and could alter the hydraulics of flow. Therefore, potential damage or inconvenience could be brought to the adjacent property owners. Although the construction of roadways provides many positive impacts to the region, the structures are not completely failure-free. A flood in excess of the selected design flood could interrupt traffic as well as cause damage to the structure and adjacent property.

Flood related damages of a highway drainage structure are closely dependent on the hydraulic capacity of the structure which, in turn, affects the cost of the structure. Referring to Figure 2.1, the LTEC analysis considers the tradeoff of the two cost items in attempting to arriving the most economically efficient design. In a urban area where flood related damage could be extensive, decision-makers would tend to adopt a higher standard for drainage structure performance. On the other hand, in an area where flood related damage is minor or insignificant, such as in an un-inhabitated rural area, it is usually sensible to adopt a lower standard for drainage structure.

9.1.3 **Environmental and Hydraulic Effects.** - Construction of drainage structures for highway crossings frequently require encroaching on the natural floodplain. In general, the presence of roadway crossings with encroachment may result in a change in hydraulic characteristics such as flow distribution, flow velocity, and sediment transport capacity. Stream response to changes in these characteristics may be confined to the local area or may extend miles upstream and downstream of the site.

At this time, it is difficult to quantitatively and definitively relate the design frequency to the potential hydraulic effects on a stream system. Heuristically, increases in the design return period of a highway drainage structure, in general, represents less encroachment on the floodplain and, therefore, less disturbance to the natural hydraulic characteristics of flow.

Encroachment on the floodplain commonly does not affect the hydraulics of a stream during a normal low flow period. Effect on hydraulics becomes more pronounced under high flow conditions when hydraulic encroachment acts as a constriction in the flow path. The presence of an encroachment tends to increase the flow velocity in the vicinity of a structure site which increases the ability of the flow to erode the stream bank and bed. Therefore, after a major flood event, the stream somewhere downstream of a highway drainage structure site designed with a low return interval may become braided and unstable. Good discussions of general response of a stream system to the presence of a roadway crossing can be found elsewhere (AASHTO, 1991, 1992; FHWA, 1987). Table 9.1 summarizes the effect of bridges on meandering dynamically stable channels (Farraday and Charlton, 1983). Where the channel is in the transition range between a stable or braided regime, the structure may cause a threshold to be exceeded and force a channel to become unstable and braided. Where the channel is already unstable and braided, the hazards to the structure may be significantly increased, but the environmental hazards will not materially change.

Impact of roadway crossings on the environment primarily arises from the potential increase in sediment concentration as the result of change in hydraulic characteristics. Highway drainage structures designed with a lower return period are more susceptible to being overtopped by major floods. When roadways are overtopped by floods, large quantities of embankment material may be eroded and carried into the stream. Too much excess sediment entering a stream might have, at least temporarily, destructive effects on fish and wildlife habitat. There could be other changes in stream systems induced by the roadway crossing that might have some impact, for better or worse, on the aquatic ecosystem.

As stated above, assessment of hydraulic effects and environmental impacts associated with different design return intervals can at best be made through subjective and personal judgement. If a stream over which a roadway crossing is to be constructed does not contain any environmentally sensitive reaches, then the decision can be made mainly on tangible factors and perhaps other intangible factors. On the other hand, for the present, care must be exercised in subjectively judging the effects of the drainage structure on the ecological system and overall stream system.

9.1.4 **Public Service.** - This is a term devised for the purpose of this research which broadly covers the general serviceability performance of roadways to the public. It includes primarily the notion that traffic interruption should only occur due to extraordinary circumstances such as from very large floods. The perceived seriousness of the situation may largely depend on the traffic volume, traffic delay incurred, availability of alternative routes, and overall importance of the route, including the provision of emergency and rescue (Section 5 of Chapter 2, AASHTO, 1992).

Although the tangible aspect of traffic interruption can be estimated as described in Section 6.3 of Chapter 6, there are intangible aspects of the serviceability of a highway which cannot be measured in terms of monetary value. These aspects may include physiologic feeling of highway users, level of service to which the highway users have become accustomed, and importance of the route to national defense and to the economic well-being of a community if traffic interruption occurs.

Simplistically, the public serviceability of a highway at a roadway crossing can be measured by its ability to provide continuous service to the public without being interrupted by flooding. Clearly this measure is closely related to the design return interval used for drainage structures. The larger the design return period for a drainage structure, the less frequent will the traffic be interrupted by flooding which naturally would have a higher serviceability and cause less inconvenience, both tangible and intangible, to the traveling public.

9.1.5 **Legal Litigation.** - State highway departments must design roadway crossings with extreme care to best serve the general public. However, sometimes the engineers and/or highway department may be involved in legal litigation. In general, legal litigation could arise from many possible causes. The legal section in the Model Drainage Manual and Highway Drainage Guidelines (AASHTO, 1991, 1992) provides a brief yet comprehensive discussion of various laws and regulations affecting highway drainage design.

Even if a highway engineer carefully practices drainage design for roadway crossings with all the legal ramifications in mind, litigation may still result for the perceived negligent design of a roadway drainage structure. This would generally occur after a major storm event which causes flood damage to properties or creates a hazardous condition at roadway crossings that endangered the life of the highway user.

Among many things, the design frequency selected for a highway drainage structure more or less measures the likelihood of a transportation department getting involved in litigation regarding its drainage design policy. Intuitively, use of a larger return period would result in less chance of being involved in litigation for a transportation department which, as a practical matter, could be desirable from the highway department's point of view. Conversely, attempting to avoid litigation by designing for very large return periods at all drainage sites would generally be very costly for the public.

9.1.6 **Other Factors.** - In addition to the four intangible factors mentioned above that may have significant impact on the determination of design frequency for highway drainage structures, the following intangible factors may also be added to the list: potential loss of life, national defense highway, and impact on local economy and environments. These additional factors were extracted from Table 1 of AASHTO (1992).

In summary, the list of intangible factors mentioned in this section are only meant to be tentative for the purpose of discussion and consideration in devising a reasonable and prudent methodology for extending a design frequency determined by using tangible factors with the LTEC analysis procedure. All these intangible factors are non-commensurable and, most of them, are in conflict with the economical consideration of drainage structure design. Consideration of all or some of these factors would provide a much more complete picture of the problem than the conventional LTEC analysis procedure which considers only the quantifiable economic aspect of the problem. Use of a multiple-attribute approach enhances more realistic decision-making and the selection of a design frequency so determined will be more acceptable in practice and defensible during litigation or negotiation with others.

9.2 MECHANISMS FOR MULTIPLE-ATTRIBUTE DECISION-MAKING

There are methods with various degrees of sophistication for multiple-attribute decision-making (MADM). A simple yet quite effective method called the "simple additive weighing (SAW) technique" was employed in this study to quantify intangibles for determining the extended-LTEC design frequency. This technique involves an analysis of an information matrix consisting of a decision-maker's subjective evaluation of their preference by assigning ratings to each of the attributes involved for a number of alternatives under consideration. A typical information matrix for a MADM problem is shown in Figure 9.1. The relative merit of each alternative is judged on the basis of its final rating computed as

$$F_i = \frac{\sum_{j=1}^{N} R_{ij} W_j}{\sum_{j=1}^{N} W_j}, \quad for\ i=1,2,\ldots,M \qquad \textbf{(9.1)}$$

in which F_i is the final rating for alternative i; R_{ij} is the rating for alternative i with respect to attribute j; W_i is the weight for attribute j representing the relative importance of attribute j; N and M are, respectively, the total number of alternatives and attributes.

Figure 9.1 Information Matrix for the SAW Method

ALTERNATIVES	FACTORS (ATTRIBUTES) Factor 1	Factor 2	...	Factor j	...	Factor N
Alt-1	R_{11}	R_{12}	...	R_{1j}	...	R_{1N}
Alt-2	R_{21}	R_{22}	...	R_{2j}	...	R_{2N}
.	.	.	...	.	...	.
.	.	.	...	.	...	.
.	.	.	...	.	...	.
Alt-i	R_{i1}	R_{i2}	...	R_{ij}	...	R_{iN}
.	.	.	...	.	...	.
.	.	.	...	.	...	.
.	.	.	...	.	...	.
Alt-M	R_{M1}	R_{M2}	...	R_{Mj}	...	R_{MN}
RELATIVE IMPORTANCE	W_1	W_2	...	W_j	...	W_N

It was possible to use MADM to extend the traditional LTEC analysis to include the intangible factors. In relating to the problem of determining an extended-LTEC design frequency, the attributes are the economic (tangible) factors and those intangible factors discussed in the previous sub-section. The alternatives are the various design frequencies to be considered by design engineers and/or policy makers of a transportation department. In determining the list of alternative design frequencies to investigate, one should use the economic-LTEC analysis frequency as the lower bound. Consideration of additional intangible attributes (factors) such as environmental would generally lead to the use of a larger design frequency. Determination of the list of return periods in excess of the economic LTEC frequency to be investigated is rather arbitrary. At present, the 500-yr event is commonly used as an upper limit for highway bridge scour considerations and some FEMA floodplain studies.

9.3 ISSUES IN MADM DECISION-MAKING FOR EXTENDED-LTEC ANALYSIS

Determination of an extended-LTEC design frequency using the MADM approach is a plausible and viable way of problem solving. There is no study known to the investigators that has systematically and quantitatively examined the multi-dimensional aspects of the LTEC analysis. This could be a new area of challenge in the LTEC analysis for highway drainage structures or risk-based design philosophy. However, several important issues need to be considered for implementing the proposed technique:

(a) Who is (or are) the decision-maker(s)? - Administrators in a highway department may have different views than that of engineers with regard to the relative importance of attributes. Therefore, depending on who is "playing the game", the conclusions are bound to vary from one "player" to another. Since the study is aimed at determining a unified and consistent drainage design policy for a transportation department, it is logical to consider the entire transportation department, as a whole, to be the sole decision-maker. The simple additive weight technique described above is suitable to a single decision-maker. The theories and techniques in game theory are developed for cases of multiple decision-makers who have conflicting views and interests in attributes. The nature of the problem in game theory is negotiation, which is not the case with this study.

(b) What are the attributes to be considered? - Based on the list of factors mentioned above which might have an impact on the selection of design frequency, the investigators and the WDT staff decided on a viable list of attributes for implementing the proposed technique.

(c) How to design a procedure for an operation survey? - This issue mainly concerns the designing of a set of questionnaires under various conditions for which decision-maker's judgments on weights and ratings are to be asked. The challenging part is to devise a questionnaire set that is easily and intuitively understandable for all participants to be involved in the survey. Furthermore, a need to determine who will be the participants is required.

(d) How to synthesize and analyze survey results? - Results of a survey showing various participants' judgments on weights and ratings will be varied. Even for a single decision-maker (or participant), it is not difficult to imagine that they might not be able to assign an exact value to each of the weights or ratings. Consequently, it would be more realistic and reasonable to allow the decision-maker to assign lower, upper and most likely values for the weights and ratings to reflect the degree of uncertainty in their preference and judgement.

10.
DESIGN OF SURVEY QUESTIONNAIRE

After extensive interaction with WDT personnel, a survey questionnaire was formulated and sent to various highway agencies throughout the nation. The complete survey questionnaire is attached as Appendix A.1.

The survey questionnaire consists of four (4) parts.

Part 1. - Respondent Background Information

This part of questionnaire is concerned with respondent's current position, background, and employer and was completed by all respondents.

Part 2. - Rating the Relative Importance of Factors Affecting Drainage Design.

Seven factors, both tangible and intangible, were considered in the questionnaire. Each respondent was requested to rate the seven factors using verbal rating as well as a numerical rating. All respondents were requested to complete this part of the survey.

Part 3. - Rating of Design Return Period Versus Intangible Factors.

Among the seven factors considered in Part 2, three intangible factors, i.e., (1) maintenance frequency, (2) litigation potential, and (3) public service were rated against various design return periods under various site conditions. The site condition was classified based on location, drainage structure type, average daily traffic, detour length, fill height, and flood plain land use. A total of seventy two (72) categories were in the questionnaire. Only the highway engineers, hydraulics engineers, and bridge structural engineers were requested to complete this part of the questionnaire. Each respondent was given six randomly chosen site conditions; three in an urban setting and three in a rural setting to rate.

Part 4. - Rating of Economic Desirability of Selecting a Non-optimal Design Return Period.

Only hydraulics engineers and bridge structural engineers were requested to complete this part of the questionnaire. Each respondent was requested to use both numerical and verbal ratings to rate the desirability of various non-optimal return periods. Associated with these non-optimal return periods are the percentages of incremental total annual expected cost in excess of the optimal cost of the LTEC design frequency. Each respondent was given three cases out of a total of six optimal return periods of 2-, 5-, 10-, 25-, 50-, and 100-year.

While the survey form was being finalized, letters were sent by Mr. A. Mainard Wacker of the WDT to various agencies and individuals inviting their participation in the survey. Thirty six (36) requests for survey forms were received and a total of 192 respondents returned the questionnaire with only two respondents leaving their questionnaire unanswered. The distribution of respondents' position and employer are shown in Table 10.1. Each questionnaire received was indexed and information contained in Part 1 of survey questionnaire were attached to the data base prepared for each part of the survey. Appendix A.2 lists respondents's position, employer, and their verbal and numerical ratings for the seven factors considered. The data obtained from this questionnaire was provided to all respondents completing the questionnaire as a courtesy for their participation.

Table 10.1 Distribution of Survey Respondents' Position and Employer

(a) By Employer:

Federal Government	33
State Government	152
County Government	3
City Government	0
Consulting Engineers	3
Unknown Identity	1
Total	192

(b) By Position:

Highway Engineers	44
Hydraulic Engineers	47
Bridge Structural Eng.	30
Branch Heads	32
Administrative Staff	14
Chief Engineers	2
Others	22
Unknown Identity	1
Total	192

11.
ANALYSES OF SURVEY RESULTS

11.1 ANALYSIS AND SUMMARY OF PART-2 SURVEY RESULTS (Rating the Rative Importance of Factors Affecting Drainage Design).

The objective of the Part 2 survey was to evaluate the relative importance of several tangible and intangible factors in highway drainage structure designs. Seven factors were considered in Part 2 of the survey and they are: (1) drainage structure cost, (2) flood related damage costs, (3) maintenance frequency, (4) litigation potential, (5) public service, (6) loss of human life, and (7) hydrologic uncertainties in the design. The analyses were performed primarily with a statistical package SPSS (Statistical Package for Social Sciences, 1988).

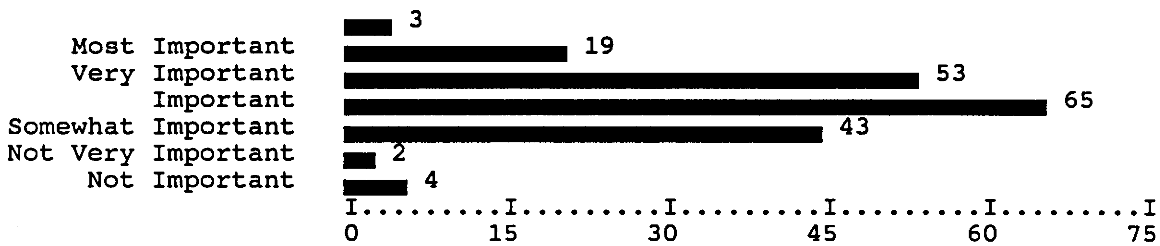
11.1.1 Summary of Opinion for Different Factors (All Respondents) - This subsection shows the relative frequencies and histograms of both verbal and numerical ratings using answers from all respondents. From Figures 11.1(a)-(g) and Figures 11.2(a)-(g), it is interesting to observe that, for each factor under consideration, there are always a few responses that are very different from the majority of the responses. Looking back at the original survey data, we cannot identify those individuals who are consistently responsible for such responses.

From Figures 11.1(a)-(b), the rating 'IMPORTANT (I)' was given most frequently by the respondents to all factors except to 'Flood Related Damage Costs' and 'Loss Of Human Life'. A great majority of respondents considered the loss of human life as the 'MOST IMPORTANT (MI)' factor in highway drainage structure design and flood related damage costs as being a 'VERY IMPORTANT (VI)' factor.

The numerical ratings shown by Figures 11.2(a)-(g) do not indicate such consistency as shown in the verbal ratings. It is probably because respondents had more choices in the numerical rating scale than in the verbal rating. Figures 11.2(a)-(g) show the basic statistics such as the mean and standard deviation, for each factor under consideration. One sees that the factor 'Hydrologic Uncertainty' has the lowest mean numerical rating while the factor of 'Loss Of Human Life' has the highest mean numerical rating. The factor 'Flood Related Damage Cost' has the second highest mean value. The remaining factors are close.

(a) DRAINAGE STRUCTURE COST

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	19	10.1	10.1	11.7
Very Important	VI	53	28.0	28.0	39.7
Important	I	65	34.4	34.4	74.1
Somewhat Important	SI	43	22.8	22.8	96.9
Not Very Important	NVI	2	1.1	1.1	98.0
Not Important	NI	4	2.1	2.1	100.0
	TOTAL	189	100.0	100.0	



(b) FLOOD DAMAGE COST

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	23	12.2	12.2	13.8
Very Important	VI	94	49.7	49.7	63.5
Important	I	34	18.0	18.0	81.5
Somewhat Important	SI	31	16.4	16.4	97.9
Not Very Important	NVI	1	.5	.5	98.4
Not Important	NI	2	1.1	1.1	99.5
Not-At-All Important	NA	1	.5	.5	100.0
	TOTAL	189	100.0	100.0	

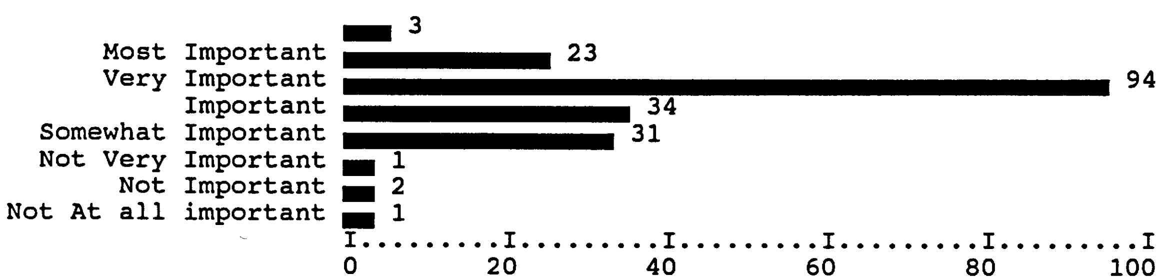
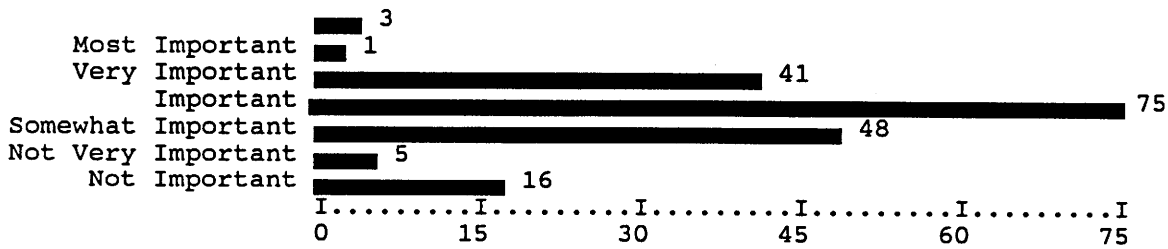


Figure 11.1 Relative Frequency and Histograms of Verbal Rating on the Various Factors by All Respondents

(c) MAINTENANCE FREQUENCY

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	1	.5	.5	2.1
Very Important	VI	41	21.7	21.7	23.8
Important	I	75	39.7	39.7	63.5
Somewhat Important	SI	48	25.4	25.4	88.9
Not Very Important	NVI	5	2.6	2.6	91.5
Not Important	NI	16	8.5	8.5	100.0
	TOTAL	189	100.0	100.0	



(d) LITIGATION POTENTIAL

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	7	3.7	3.7	5.3
Very Important	VI	52	27.5	27.5	32.8
Important	I	70	37.0	37.0	69.8
Somewhat Important	SI	35	18.5	18.5	88.3
Not Very Important	NVI	8	4.2	4.2	92.5
Not Important	NI	14	7.4	7.4	100.0
	TOTAL	189	100.0	100.0	

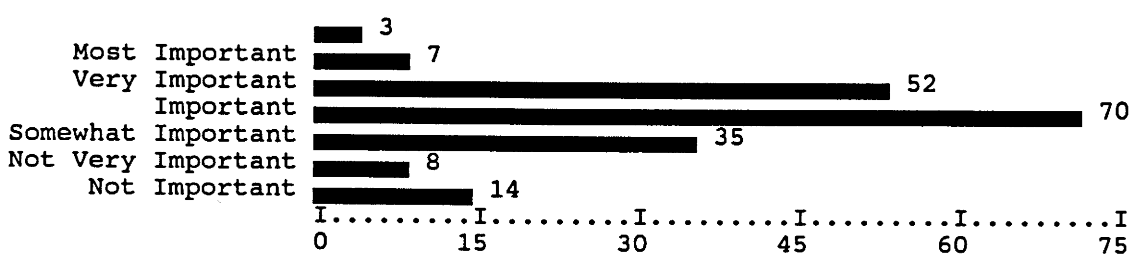
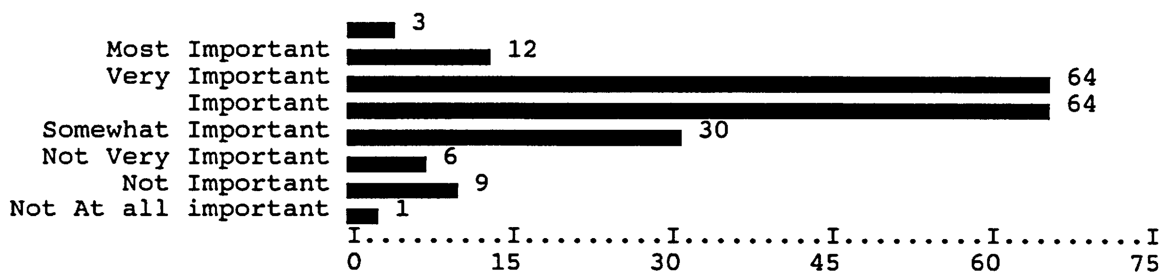


Figure 11.1 Relative Frequency and Histograms of Verbal Rating on the Various Factors by All Respondents (Continued)

(e) PUBLIC SERVICE

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	12	6.3	6.3	7.9
Very Important	VI	64	33.9	33.9	41.8
Important	I	64	33.9	33.9	75.7
Somewhat Important	SI	30	15.9	15.9	91.6
Not Very Important	NVI	6	3.2	3.2	94.8
Not Important	NI	9	4.8	4.8	99.6
Not-At-All Important	NA	1	.5	.5	100.0
	TOTAL	189	100.0	100.0	



(f) LOSS OF HUMAN LIFE

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	117	61.9	61.9	63.5
Very Important	VI	39	20.6	20.6	84.1
Important	I	18	9.5	9.5	93.6
Somewhat Important	SI	6	3.2	3.2	96.8
Not Very Important	NVI	2	1.1	1.1	97.9
Not Important	NI	3	1.6	1.6	99.5
Not-At-All Important	NA	1	.5	.5	100.0
	TOTAL	189	100.0	100.0	

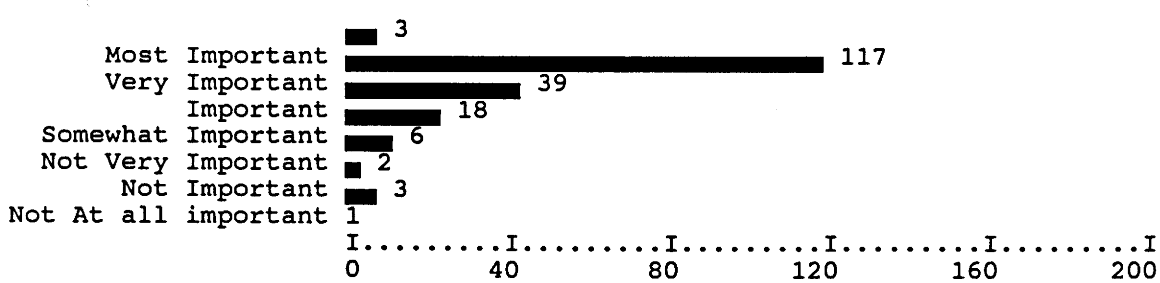


Figure 11.1 Relative Frequency and Histograms of Verbal Rating on the Various Factors by All Respondents (Continued)

(g) HYDROLOGIC UNCERTAINTY

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
		3	1.6	1.6	1.6
Most Important	MI	3	1.6	1.6	3.2
Very Important	VI	14	7.4	7.4	10.6
Important	I	87	46.0	46.0	56.6
Somewhat Important	SI	46	24.3	24.3	80.9
Not Very Important	NVI	9	4.8	4.8	85.7
Not Important	NI	25	13.2	13.2	98.9
Not-At-All Important	NA	2	1.1	1.1	100.0
	TOTAL	189	100.0	100.0	

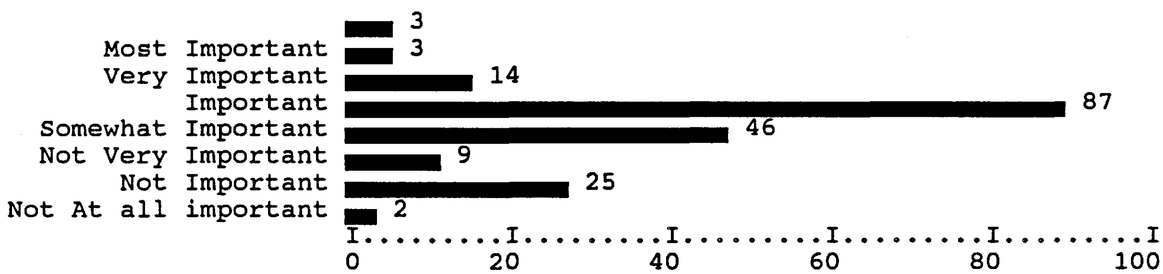


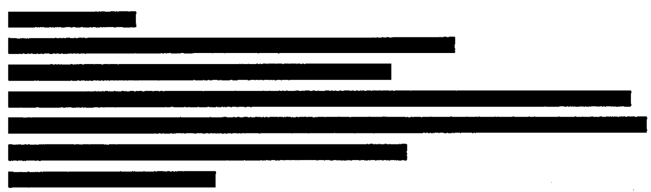
Figure 11.1 Relative Frequency and Histograms of Verbal Rating on the Various Factors by All Respondents (Continued)

Label	Mean	Std Dev	Min	Max	N
DRAINAGE STRUCTURE COST	7.01	1.79	1	10	182
COSTS RELATED TO FLOOD DAMAGE	7.55	1.68	2	10	182
MAINTENANCE FREQUENCY	6.14	1.61	2	9	182
LITIGATION POTENTIAL	6.38	1.90	2	10	182
PUBLIC SERVICE/CONVENIENCE	6.65	1.94	1	10	182
RISK FOR LOSS OF HUMAN LIFE	8.85	2.06	1	10	182
HYDROLOGIC UNCERTAINTIES	5.41	1.94	0	10	182

(a) <u>DRAINAGE STRUCTURAL COST</u>

```
Mean        7.0055  Std Err     .1330  Min       1.0000  Skewness   -.4606
Median      7.0000  Variance   3.2210  Max      10.0000  S E Skew    .1801
5% Trim     7.0611  Std Dev    1.7947  Range     9.0000  Kurtosis    .0771
```

```
Frequency
    5.00 Extremes    (1), (2), (3)
    8.00        4  *
   28.00        5  *
   24.00        6  *
   39.00        7  *
   40.00        8  *
   25.00        9  *
   13.00       10  *
```



(b) <u>COSTS RELATED TO FLOOD DAMAGE</u>

```
Mean        7.5549  Std Err     .1245  Min       2.0000  Skewness   -.8772
Median      8.0000  Variance   2.8229  Max      10.0000  S E Skew    .1801
5% Trim     7.6593  Std Dev    1.6802  Range     8.0000  Kurtosis    .8274
```

```
Frequency
   10.00 Extremes    (2), (3), (4)
   12.00        5  *
   17.00        6  *
   36.00        7  *
   53.00        8  *
   36.00        9  *
   18.00       10  *
```

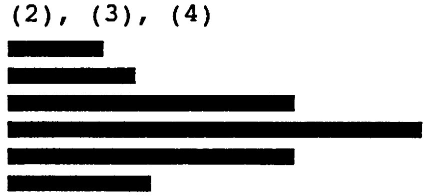


Figure 11.2 Numerical Ratings for Various Factors in Highway Drainage Structure Designs by *All* Respondents.

(c) MAINTENANCE FREQUENCY

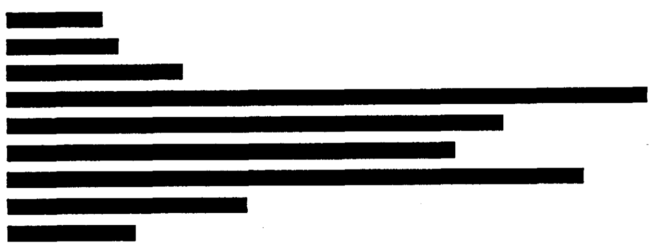
Mean	6.1374	Std Err	.1191	Min	2.0000	Skewness	-.1939
Median	6.0000	Variance	2.5832	Max	9.0000	S E Skew	.1801
5% Trim	6.1703	Std Dev	1.6072	Range	7.0000	Kurtosis	-.4887

Frequency			
3.00	Extremes		(2)
6.00	3	*	
17.00	4	*	
41.00	5	*	
40.00	6	*	
30.00	7	*	
35.00	8	*	
10.00	9	*	

(d) LITIGATION POTENTIAL

Mean	6.3846	Std Err	.1406	Min	2.0000	Skewness	-.1880
Median	6.0000	Variance	3.5971	Max	10.0000	S E Skew	.1801
5% Trim	6.4151	Std Dev	1.8966	Range	8.0000	Kurtosis	-.4209

Frequency		
6.00	2	*
7.00	3	*
11.00	4	*
40.00	5	*
31.00	6	*
28.00	7	*
36.00	8	*
15.00	9	*
8.00	10	*



(e) PUBLIC SERVICE/CONVENIENCE

Mean	6.6538	Std Err	.1438	Min	1.0000	Skewness	-.4882
Median	7.0000	Variance	3.7635	Max	10.0000	S E Skew	.1801
5% Trim	6.7143	Std Dev	1.9400	Range	9.0000	Kurtosis	-.1621

Frequency		
1.00	1	*
5.00	2	*
6.00	3	*
13.00	4	*
25.00	5	*
26.00	6	*
38.00	7	*
38.00	8	*
21.00	9	*
9.00	10	*

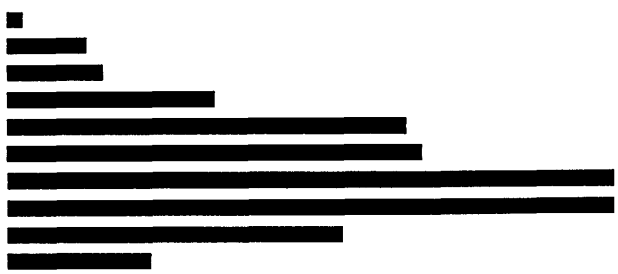


Figure 11.2 Numerical Ratings for Various Factors in Highway Drainage Structure Designs by *All* Respondents. (Continued)

(f) RISK FOR LOSS OF HUMAN LIFE

```
Mean        8.8462  Std Err      .1525  Min       1.0000  Skewness   -2.2676
Median     10.0000  Variance    4.2303  Max      10.0000  S E Skew     .1801
5% Trim     9.1612  Std Dev     2.0568  Range     9.0000  Kurtosis    4.8805
```

```
Frequency
   15.00 Extremes     (1), (2), (3), (4), (5)
    8.00        6  *
    3.00        7  *
   20.00        8  *
   26.00        9  *
  110.00       10  *
```

(g) HYDROLOGIC UNCERTAINTIES

```
Mean        5.4066  Std Err      .1437  Min        .0000  Skewness    -.1562
Median      5.0000  Variance    3.7564  Max      10.0000  S E Skew     .1801
5% Trim     5.4274  Std Dev     1.9381  Range    10.0000  Kurtosis     .5152
```

```
Frequency
    3.00        0  .
    3.00        1  .
    6.00        2  .
   14.00        3  .
   23.00        4  .
   50.00        5  .
   32.00        6  .
   28.00        7  .
   16.00        8  .
    1.00        9  .
    6.00       10  .
```

Figure 11.2 Numerical Ratings for Various Factors in Highway Drainage Structure Designs by *All* Respondents. (Continued)

11.1.2 Comparison of Opinion for Different Factors by Position (All Respondents) - It is of interest to examine any differences in opinion toward the various factors by respondents holding different employment positions. Tables 11.1(a)-(g) are cross-tabulations of verbal rating versus position for different factors considered in this survey. These cross-tabulation tables should be read row-wide. There are two numbers in each cell; the number on the top is the number of respondents, holding the position indicated for that row, choose a particular rating for that column. The second number represents the row percentages. For example, refer to Table 11.1(a) for the factor "DRAINAGE STRUCTURE COST". To illustrate: out of a total of 44 highway engineers (see first row), the distribution of verbal ratings by them is 2, 15, 15, 10, 1, and 1 for "MOST IMPORTANT", "VERY IMPORTANT", "IMPORTANT", "SOMEWHAT IMPORTANT (SI)", "NOT-VERY IMPORTANT (NVI)", and "NOT IMPORTANT (NI)", respectively. These correspond to the row percentages of 4.5%, 34.1%, 34.1%, 22.7%, 2.3%, and 2.3%, respectively. The differences in opinion by respondents holding different positions in highway agencies toward each factor can be observed by comparing the row percentages among different rows.

A formal statistical test on the difference in opinion toward a particular factor by *all* respondents of different positions can be made by using the numerical rating. The means and standard deviations of numerical ratings for the relative importance of seven factors by all respondents holding different position are tabulated in Table 11.2. A test procedure, called one-way analysis of variance, was applied with the objective to examine the equality of the average numerical ratings among different groups of respondents holding different positions. That is, the hypothesis test problem considered can be stated as

H_o : Mean ratings by all positions are equal ($\mu_1 = \mu_2 = \ldots = \mu_6$).

versus

H_a : Not all mean ratings by all positions are equal.

Three multiple-range test procedures from the SPSS were applied including Duncan procedure, modified LSD procedure, and Student-Newman-Keuls procedure. The significance levels chosen were 0.01 for Duncan procedure and 0.05 for the remaining two procedures.

Except for the factor "HYDROLOGIC UNCERTAINTIES IN DESIGN", it was found that no two positions rated significantly differently for all other factors. Both Duncan procedure and modified LSD procedure indicated that the average rating for factor "HYDROLOGIC UNCERTAINTIES IN DESIGNS" by chief engineers were significantly lower than those by highway/hydraulic engineers. The Student-Newman-Keuls procedure indicated that chief engineers' rating on "HYDROLOGIC UNCERTAINTIES IN DESIGN" is significantly lower than those given by all other positions. Note that there are only two respondents in the position as the chief engineers and both opinions are consistent giving "NI - Not Important" to this factor (see Table 11.1(g)).

Table 11.1 Cross-tabulations of Verbal Ratings on the Various Factors by Respondents Holding Different Positions.

(a) DRAINAGE STRUCTURE COST

POSITION (Row Count / Row Pct)	VERBAL RATINGS MI	VI	I	SI	NVI	NI	Row Total
HIGHWAY ENGINEER	2 4.5	15 34.1	15 34.1	10 22.7	1 2.3	1 2.3	44 23.4
HYDRAULIC ENG.	6 13.3	13 28.9	15 33.3	7 15.6		3 6.7	45 23.9
BRIDGE ENGINEERS	1 3.3	13 43.3	7 23.3	7 23.3	1 3.3		30 16.0
BRANCH HEADS	5 16.1	4 12.9	11 35.5	11 35.5			31 16.5
ADM. STAFF	3 21.4	1 7.1	8 57.1	2 14.3			14 7.4
CHIEF ENGINEERS		1 50.0	1 50.0				1.1
OTHERS	2 9.1	6 27.3	8 36.4	6 27.3			22 11.7
Column Total	19 10.1	53 28.2	65 34.6	43 22.9	2 1.1	4 2.1	188 100.0

(b) FLOOD RELATED DAMAGE COST

POSITION \ Row Count Row Pct	VERBAL RATINGS MI	 VI	 I	 SI	 NVI	 NI	 NA	Row Total
HIGHWAY ENGINEER	9 20.5	20 45.5	9 20.5	4 9.1		1 2.3	1 2.3	44 23.4
HYDRAULIC ENG.	7 15.6	24 53.3	7 15.6	6 13.3				45 23.9
BRIDGE ENGINEERS	2 6.7	15 50.0	5 16.7	6 20.0		1 3.3		30 16.0
BRANCH HEADS	3 9.7	18 58.1	5 16.1	4 12.9	1 3.2			31 16.5
ADM. STAFF	2 14.3	6 42.9	2 14.3	4 28.6				14 7.4
CHIEF ENGINEERS		1 50.0	1 50.0					2 1.1
OTHERS		10 45.5	5 22.7	7 31.8				22 11.7
Column Total	23 12.2	94 50.0	34 18.1	31 16.5	1 .5	2 1.1	1 .5	188 100.0

(c) MAINTENANCE FREQUENCY

POSITION \ Row Count Row Pct	MI	VI	I	SI	NVI	NI	Row Total
HIGHWAY ENGINEER		4 9.1	19 43.2	14 31.8	2 4.5	5 11.4	44 23.4
HYDRAULIC ENG.		12 26.7	18 40.0	9 20.0	2 4.4	3 6.7	45 23.9
BRIDGE ENGINEERS	1 3.3	6 20.0	11 36.7	9 30.0		2 6.7	30 16.0
BRANCH HEADS		9 29.0	13 41.9	5 16.1	1 3.2	3 9.7	31 16.5
ADM. STAFF		3 21.4	5 35.7	4 28.6		2 14.3	14 7.4
CHIEF ENGINEERS			1 50.0	1 50.0			1.1
OTHERS		7 31.8	8 36.4	6 27.3		1 4.5	22 11.7
Column Total	1 .5	41 21.8	75 39.9	48 25.5	5 2.7	16 8.5	188 100.0

(d) LITIGATION POTENTIAL

POSITION (Row Count / Row Pct)	VERBAL RATINGS MI	VI	I	SI	NVI	NI	Row Total
HIGHWAY ENGINEER	1 2.3	11 25.0	15 34.1	16 36.4	1 2.3		44 23.4
HYDRAULIC ENG.	2 4.4	17 37.8	15 33.3	6 13.3	1 2.2	3 6.7	45 23.9
BRIDGE ENGINEERS	1 3.3	6 20.0	12 40.0	7 23.3	1 3.3	2 6.7	30 16.0
BRANCH HEADS	2 6.5	9 29.0	12 38.7	1 3.2	3 9.7	4 12.9	31 16.5
ADM. STAFF		4 28.6	5 35.7	2 14.3	1 7.1	2 14.3	14 7.4
CHIEF ENGINEERS			1 50.0			1 50.0	1.1
OTHERS	1 4.5	5 22.7	10 45.5	3 13.6	1 4.5	2 9.1	22 11.7
Column Total	7 3.7	52 27.7	70 37.2	35 18.6	8 4.3	14 7.4	188 100.0

(e) PUBLIC SERVICE

POSITION (Row Count / Row Pct)	MI	VI	I	SI	NVI	NI	NA	Row Total
HIGHWAY ENGINEERS	1 2.3	7 15.9	21 47.7	11 25.0		3 6.8	1 2.3	44 23.4
HYDRAUL. ENG.	5 11.1	19 42.2	11 24.4	7 15.6		2 4.4		45 23.9
BRIDGE ENGINEERS	2 6.7	14 46.7	8 26.7	1 3.3	2 6.7	2 6.7		30 16.0
BRANCH HEADS	3 9.7	11 35.5	12 38.7	3 9.7	1 3.2	1 3.2		31 16.5
ADM. STAFF	1 7.1	4 28.6	5 35.7	3 21.4	1 7.1			14 7.4
CHIEF ENGINEERS		1 50.0		1 50.0				2 1.1
OTHERS		8 36.4	7 31.8	4 18.2	2 9.1	1 4.5		22 11.7
Column Total	12 6.4	64 34.0	64 34.0	30 16.0	6 3.2	9 4.8	1 .5	188 100.0

(f) LOSS OF HUMAN LIFE

POSITION (Row Count / Row Pct)	VERBAL RATINGS MI	VI	I	SI	NVI	NI	NA	Row Total
HIGHWAY ENGINEERS	16 36.4	18 40.9	7 15.9	1 2.3		1 2.3	1 2.3	44 23.4
HYDRAULIC ENG.	34 75.6	7 15.6	1 2.2	1 2.2	1 2.2			45 23.9
BRIDGE ENGINEERS	20 66.7	3 10.0	3 10.0	1 3.3	1 3.3	1 3.3		30 16.0
BRANCH HEADS	19 61.3	5 16.1	5 16.1	1 3.2		1 3.2		31 16.5
ADM. STAFF	11 78.6	1 7.1	1 7.1	1 7.1				14 7.4
CHIEF ENGINEERS	1 50.0	1 50.0						2 1.1
OTHERS	16 72.7	4 18.2	1 4.5	1 4.5				22 11.7
Column Total	117 62.2	39 20.7	18 9.6	6 3.2	2 1.1	3 1.6	1 .5	188 100.0

(g) HYDROLOGIC UNCERTAINTY

POSITION (Row Count / Row Pct)	MI	VI	I	SI	NVI	NI	NA	Row Total
HIGHWAY ENGINEER	1 2.3	5 11.4	24 54.5	10 22.7	1 2.3	3 6.8		44 23.4
HYDRAULIC ENGINE	2 4.4	2 4.4	17 37.8	15 33.3	2 4.4	5 11.1	1 2.2	45 23.9
BRIDGE ENGINEERS		1 3.3	12 40.0	9 30.0	2 6.7	5 16.7		30 16.0
BRANCH HEADS		3 9.7	17 54.8	5 16.1	2 6.5	3 9.7	1 3.2	31 16.5
ADM. STAFF		2 14.3	5 35.7	2 14.3	1 7.1	4 28.6		14 7.4
CHIEF ENGINEER						2 100.0		2 1.1
OTHERS		1 4.5	12 54.5	5 22.7	1 4.5	3 13.6		22 11.7
Column Total	3 1.6	14 7.4	87 46.3	46 24.5	9 4.8	25 13.3	2 1.1	188 100.0

Table 11.2 Means and Standard Deviations of Numerical Ratings for Relative Importance of Different Factors by *All* Respondents Holding Different Positions.

Position	Struc. Cost		Flood Damage		Maint. Freq.	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
Highway Engr.	6.841	1.756	7.568	1.933	5.727	1.557
Hydraul. Engr.	7.245	2.013	8.022	1.465	6.289	1.824
Bridge Engr.	7.035	1.615	7.345	1.540	6.207	1.485
Branch Heads	7.097	1.489	7.452	1.761	5.968	1.642
Adm. Staff	6.857	2.031	7.786	1.119	6.072	1.374
Chief Engr.	4.000	5.657	6.000	1.414	6.500	0.707

Position	Litigation		Public Srvc.		Human Life	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
Highway Engr.	6.546	1.530	6.227	1.775	8.568	1.793
Hydraul. Engr.	6.866	1.825	7.355	1.644	9.422	1.517
Bridge Engr.	6.276	1.823	7.172	2.022	8.586	2.556
Branch Heads	6.033	2.228	6.419	2.107	8.323	2.555
Adm. Staff	5.929	2.017	6.714	1.685	9.571	0.690
Chief Engr.	5.000	2.828	7.500	0.707	9.000	1.414

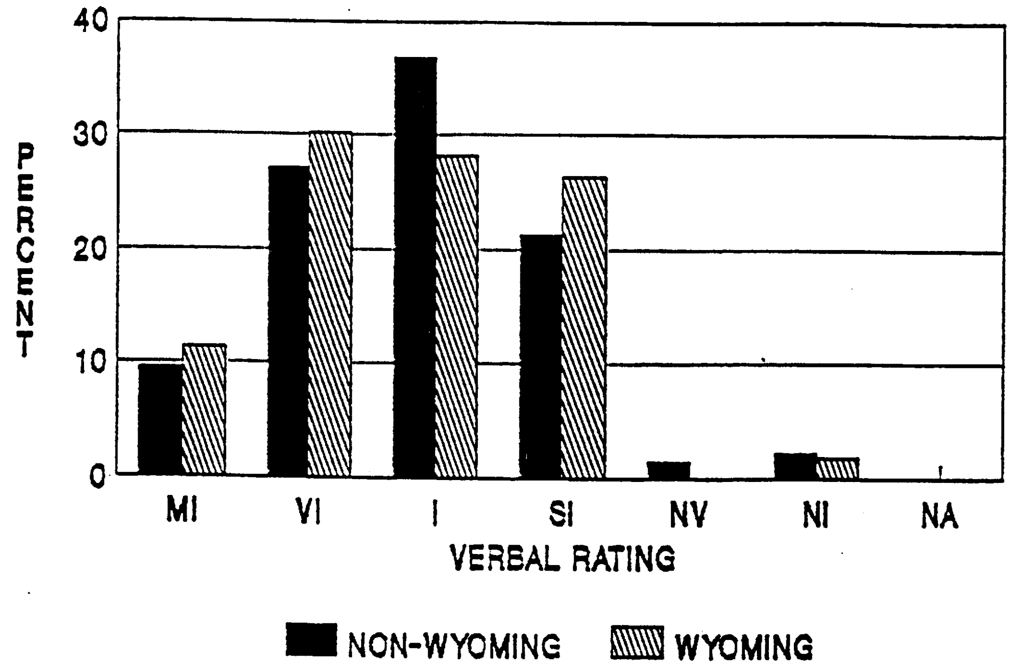
Position	Hydrol. Unc.	
	Mean	Stdev
Highway Engr.	5.750	1.780
Hydraul. Engr.	5.645	1.876
Bridge Engr.	5.207	1.698
Branch Heads	5.193	2.097
Adm. Staff	4.929	2.129
Chief Engr.	1.500	2.212

11.1.3 Comparison of Opinion Between Wyoming and Non-Wyoming Respondents Holding Different Positions - The third item being looked at is to see if there exists any difference in opinion between Wyoming and non-Wyoming respondents on the rating of the factors under consideration in this study. For visual display, Figures 11.3(a)-(g) show the percentages of verbal rating by the respondents between the two categories. There is little difference between the two categories that can be visually identified.

Statistically, a test on the difference in opinion between the Wyoming and non-Wyoming groups can be made by the so-called two-sample T-test using the values of numerical rating. A schematic diagram of two-sample test of the means is shown in Figure 11.5. The results of such test on the various factors for respondents holding different positions are shown in Tables 11.3(a)-(f). In this test, the null hypothesis (H_0) is that the true mean ratings between two groups under consideration are identical, that is, H_0: $\mu_1 = \mu_2$, with μ_1 and μ_2 being the means ratings of the two groups, respectively. The alternative hypothesis, (H_a), is that the mean ratings of the two groups under consideration are not equal, that is H_0: $\mu_1 \neq \mu_2$. The p-value indicates the chance that the true but unknown mean ratings of the two groups would be different based on the sample mean ratings. A smaller p-value indicates a stronger disparity between the null hypothesis ($\mu_1 = \mu_2$) and the sample data. In general, a significance level of 0.01 or 0.05 is used in the test below which the null hypothesis is rejected. Among the different positions and factors between the two groups, only the rating on the factor "PUBLIC SERVICE" by branch heads are statistically significantly different. All the other positions yielded very much the same rating for all factors. This indicates that, except as noted for the branch head's rating of "PUBLIC SERVICE", the Wyoming and non-Wyoming respondents in highway agencies are very much consistent in their views on the relative importance of the various factors considered in highway drainage structure designs.

Tables 11.4-11.7 list the values of relevant statistics for comparing the difference in mean numerical ratings between respondents holding different positions. Tables 11.4 and 11.5 are for Wyoming respondents under the assumptions of equal variance and unequal variances between groups, respectively. Tables 11.6 and 11.7 are for non-Wyoming respondents. Comparisons between chief engineers/ administrators and other ranks were not made because there is only one data observation in the category of chief engineers/administrator which makes statistical analysis impossible.

(a) DRAINAGE STRUCTURE COST



(b) FLOOD RELATED DAMAGE COSTS

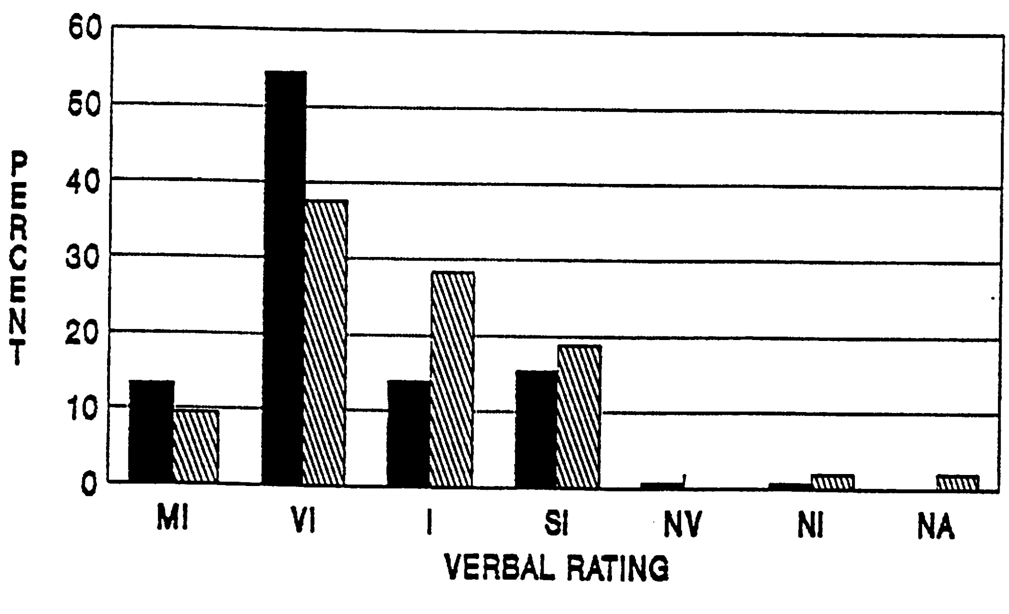
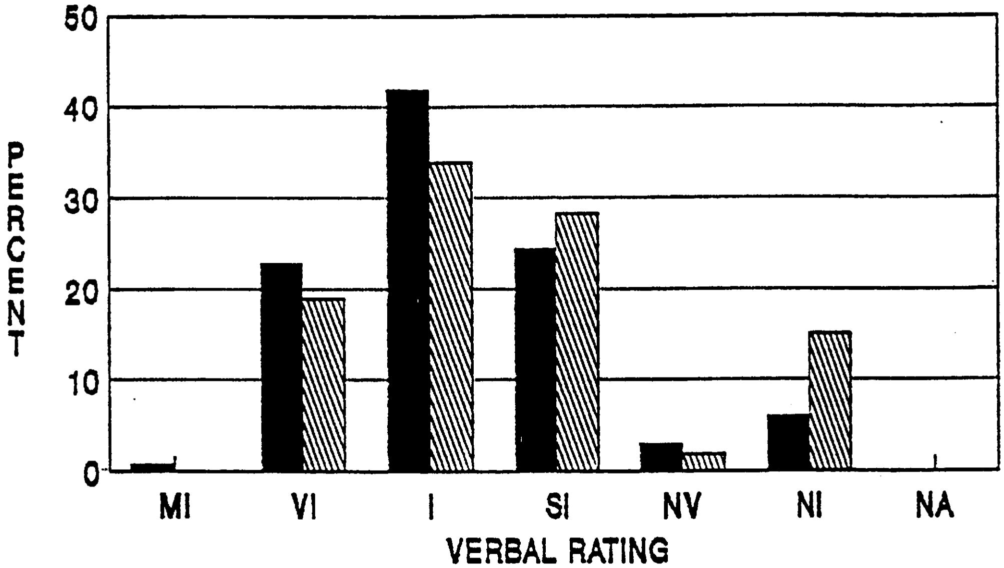


Figure 11.3 Comparison of Verbal Ratings Between Wyoming and Non-Wyoming Respondents.

(c) MAINTENANCE FREQUENCY



(d) LITIGATION POTENTIAL

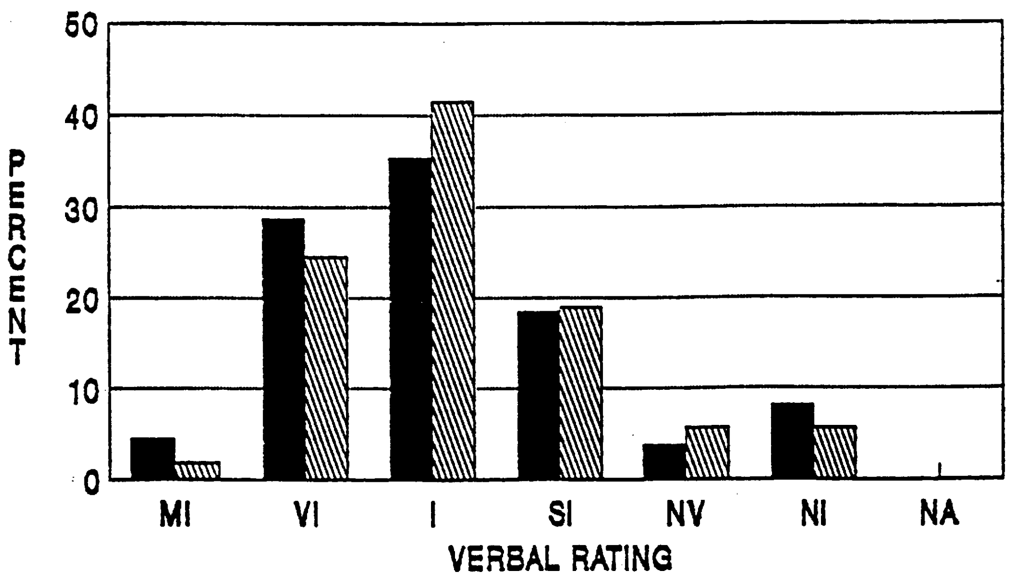
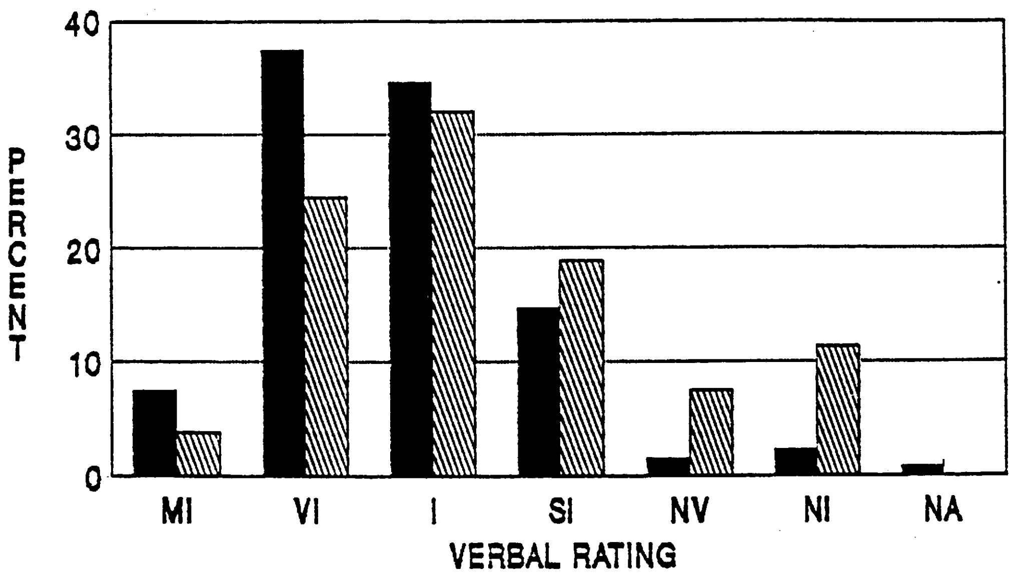


Figure 11.3 Comparison of Verbal Ratings Between Wyoming and Non-Wyoming Respondents. (Continued)

(e) PUBLIC SERVICE



(f) LOSS OF HUMAN LIFE

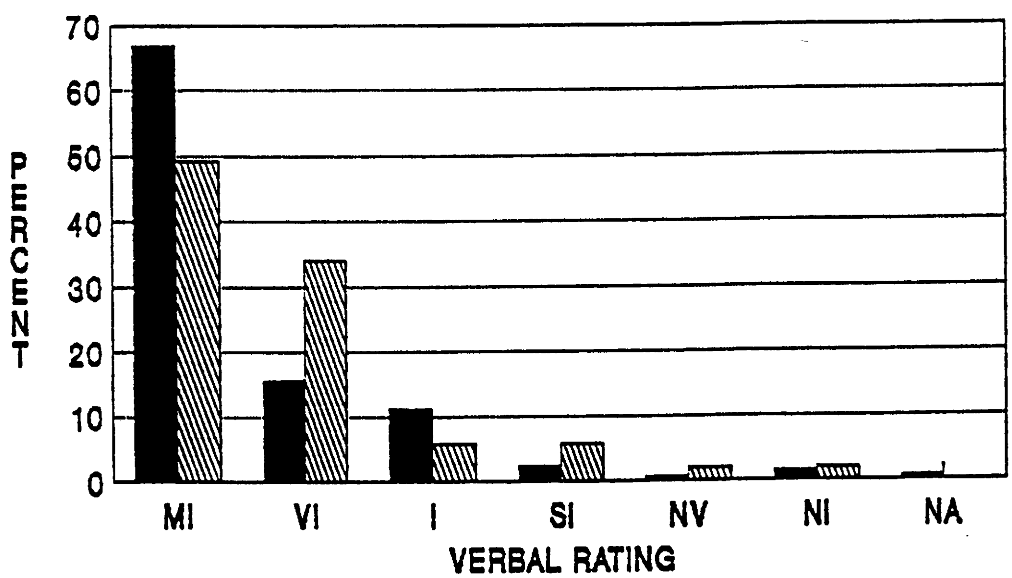


Figure 11.3 Comparison of Verbal Ratings Between Wyoming and Non-Wyoming Respondents. (Continued)

(g) <u>HYDROLOGIC UNCERTAINTY</u>

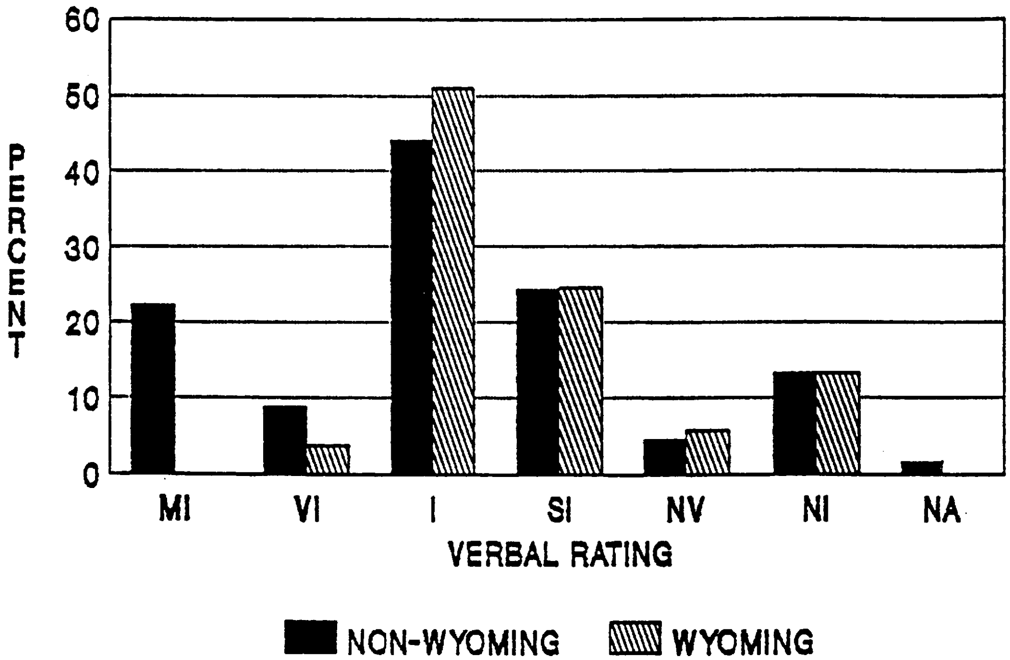
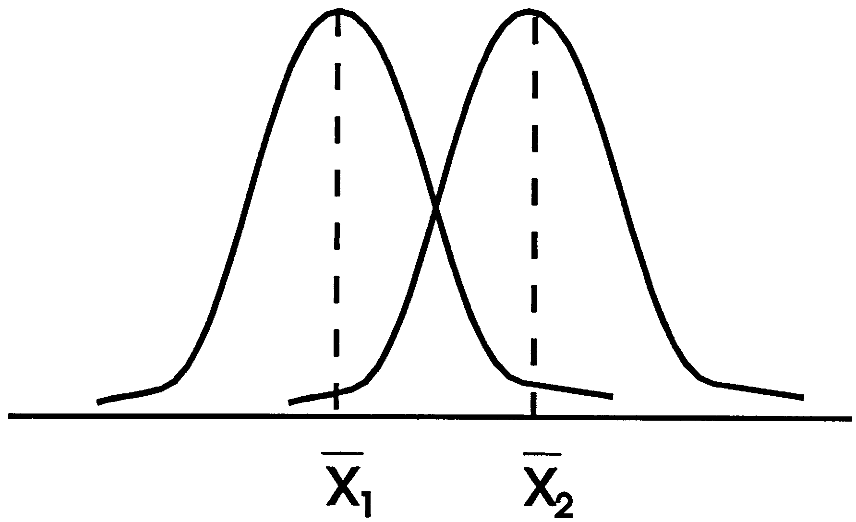
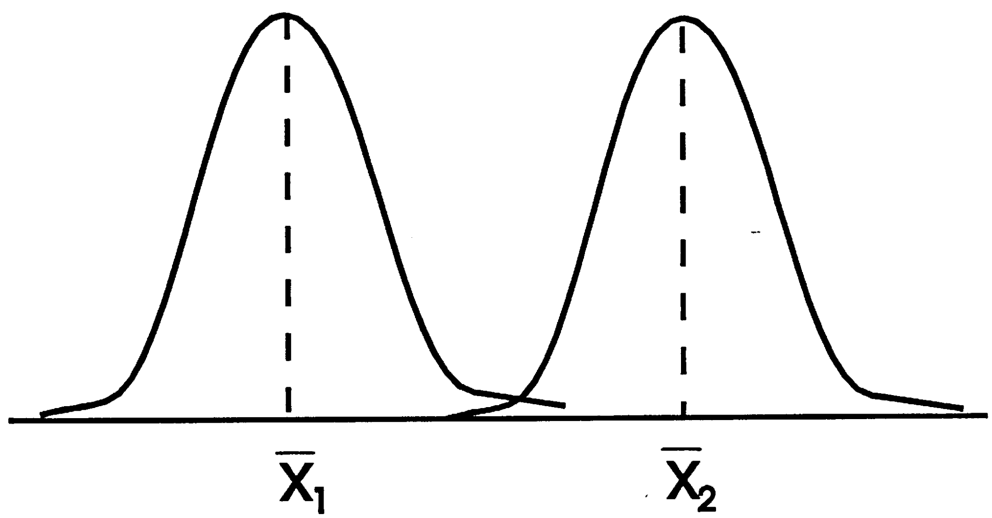


Figure 11.3 Comparison of Verbal Ratings Between Wyoming and Non-Wyoming Respondents. (Continued)



(a) Difference Between the Two Means Is Not Significant



(b) Difference Between the Two Means Is Significant

Figure 11.4 Schematic Diagram for Two-Sample T-Test.

Table 11.3(a) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Highway Engineers* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	7.158(19)[3]		6.600(25)[3]
	Stand. Dev.	1.642		1.871
	p-value[1]		0.308	
	p-value[2]		0.300	
FLOOD RELATED DAMAGE COSTS	Mean	7.316		7.760
	Stand. Dev.	2.136		1.809
	p-value[1]		0.460	
	p-value[2]		0.471	
MAINT. FREQ.	Mean	5.842		5.640
	Stand. Dev.	1.642		1.524
	p-value[1]		0.676	
	p-value[2]		0.679	
LITIGATION POTENTIAL	Mean	6.632		6.480
	Stand. Dev.	1.342		1.686
	p-value[1]		0.749	
	p-value[2]		0.742	
PUBLIC SERVICE	Mean	6.316		6.160
	Stand. Dev.	1.529		1.972
	p-value[1]		0.777	
	p-value[2]		0.769	
LOSS OF HUMAN LIFE	Mean	8.842		8.360
	Stand. Dev.	1.167		2.177
	p-value[1]		0.388	
	p-value[2]		0.352	
HYDROLO. UNCERT.	Mean	5.263		6.120
	Stand. Dev.	1.661		1.900
	p-value[1]		0.126	
	p-value[2]		0.119	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.

Table 11.3(b) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Hydraulics Engineers* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	7.250 (4)[3]		7.244 (41)[3]
	Stand. Dev.	2.630		1.985
	p-value[1]		0.995	
	p-value[2]		0.997	
FLOOD RELATED DAMAGE COSTS	Mean	7.000		8.122
	Stand. Dev.	3.162		1.269
	p-value[1]		0.156	
	p-value[2]		0.531	
MAINT. FREQ.	Mean	5.500		6.366
	Stand. Dev.	2.646		1.771
	p-value[1]		0.376	
	p-value[2]		0.564	
LITIGATION POTENTIAL	Mean	6.500		6.902
	Stand. Dev.	1.915		1.841
	p-value[1]		0.679	
	p-value[2]		0.710	
PUBLIC SERVICE	Mean	5.750		7.512
	Stand. Dev.	3.304		1.468
	p-value[1]		0.049*	
	p-value[2]		0.366	
LOSS OF HUMAN LIFE	Mean	8.500		9.512
	Stand. Dev.	1.732		1.519
	p-value[1]		0.215	
	p-value[2]		0.332	
HYDROLO. UNCERT.	Mean	4.750		5.732
	Stand. Dev.	1.708		1.911
	p-value[1]		0.329	
	p-value[2]		0.342	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.
* : The means are significantly different at 5% level.

Table 11.3(c) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Bridge Engineers* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	7.600(5)[3]		6.917(24)[3]
	Stand. Dev.	0.548		1.767
	p-value[1]		0.405	
	p-value[2]		0.131	
FLOOD RELATED DAMAGE COSTS	Mean	7.200		7.375
	Stand. Dev.	1.304		1.610
	p-value[1]		0.822	
	p-value[2]		0.801	
MAINT. FREQ.	Mean	5.800		6.292
	Stand. Dev.	1.924		1.429
	p-value[1]		0.514	
	p-value[2]		0.612	
LITIGATION POTENTIAL	Mean	5.600		6.417
	Stand. Dev.	2.302		1.767
	p-value[1]		0.379	
	p-value[2]		0.488	
PUBLIC SERVICE	Mean	6.200		7.375
	Stand. Dev.	2.490		1.974
	p-value[1]		0.256	
	p-value[2]		0.366	
LOSS OF HUMAN LIFE	Mean	8.000		8.708
	Stand. Dev.	3.464		2.422
	p-value[1]		0.584	
	p-value[2]		0.682	
HYDROLO. UNCERT.	Mean	5.200		5.208
	Stand. Dev.	1.304		1.793
	p-value[1]		0.992	
	p-value[2]		0.991	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.

Table 11.3(d) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Branch Heads* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	8.500(2)[3]		7.000(29)[3]
	Stand. Dev.	0.707		1.535
	p-value[1]		0.186	
	p-value[2]		0.138	
FLOOD RELATED DAMAGE COSTS	Mean	8.000		7.414
	Stand. Dev.	0.000		1.823
	p-value[1]		NC[4]	
	p-value[2]		NC	
MAINT. FREQ.	Mean	6.000		5.966
	Stand. Dev.	1.414		1.679
	p-value[1]		0.978	
	p-value[2]		0.978	
LITIGATION POTENTIAL	Mean	6.000		6.035
	Stand. Dev.	1.414		2.291
	p-value[1]		0.984	
	p-value[2]		0.979	
PUBLIC SERVICE	Mean	9.500		6.207
	Stand. Dev.	0.707		2.177
	p-value[1]		0.044*	
	p-value[2]		0.019*	
LOSS OF HUMAN LIFE	Mean	9.000		8.276
	Stand. Dev.	1.414		2.631
	p-value[1]		0.706	
	p-value[2]		0.599	
HYDROLO. UNCERT.	Mean	4.500		5.241
	Stand. Dev.	0.707		2.166
	p-value[1]		0.638	
	p-value[2]		0.341	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.
4 : Not Computable.
* : The means are significantly different at 5% level.

Table 11.3(e) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Administrative Staff Engineers* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	7.000(3)[3]		6.818(11)[3]
	Stand. Dev.	2.646		1.991
	p-value[1]		0.897	
	p-value[2]		0.920	
FLOOD RELATED DAMAGE COSTS	Mean	7.667		7.818
	Stand. Dev.	0.577		1.250
	p-value[1]		0.845	
	p-value[2]		0.771	
MAINT. FREQ.	Mean	5.000		6.364
	Stand. Dev.	1.000		1.502
	p-value[1]		0.169	
	p-value[2]		0.124	
LITIGATION POTENTIAL	Mean	6.000		5.909
	Stand. Dev.	1.000		2.256
	p-value[1]		0.948	
	p-value[2]		0.921	
PUBLIC SERVICE	Mean	6.000		6.909
	Stand. Dev.	1.732		1.758
	p-value[1]		0.442	
	p-value[2]		0.477	
LOSS OF HUMAN LIFE	Mean	9.000		9.727
	Stand. Dev.	1.000		0.647
	p-value[1]		0.146	
	p-value[2]		0.334	
HYDROLO. UNCERT.	Mean	5.000		4.909
	Stand. Dev.	2.646		2.119
	p-value[1]		0.951	
	p-value[2]		0.960	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.

Table 11.3(f) Comparison of Mean Ratings Between Wyoming and Non-Wyoming *Chief Engineers or Administrators* for Various Factors

FACTOR	STATISTICS	WYOMING		NON-WYOMING
DRAINAGE STRUC. COST	Mean	8.0000(1)[3]		4.000(1)[3]
	Stand. Dev.	0.000		0.000
	p-value[1]		NC[4]	
	p-value[2]		NC	
FLOOD RELATED DAMAGE COSTS	Mean	5.000		7.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	
MAINT. FREQ.	Mean	7.000		6.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	
LITIGATION POTENTIAL	Mean	3.000		7.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	
PUBLIC SERVICE	Mean	7.000		8.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	
LOSS OF HUMAN LIFE	Mean	8.000		10.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	
HYDROLO. UNCERT.	Mean	3.000		0.000
	Stand. Dev.	0.000		0.000
	p-value[1]		NC	
	p-value[2]		NC	

Note: 1 : 2-tail probability using pooled variance estimate.
2 : 2-tail probability using separate variance estimate.
3 : numbers in () are sample sizes.
4 : Not Computable.

As can be seen from the p-values in Tables 11.4-11.5, Wyoming respondents with different positions gave rather consistent ratings on the relative importance for all factors except, again, for "PUBLIC SERVICE". From Tables 11.3, the average rating for "PUBLIC SERVICE" given by branch heads from Wyoming is significantly higher than that given by their colleagues in other positions. On the other hand, ratings of relative importance by non-Wyoming respondents are less uniform and consistent as those by Wyoming respondents. From Tables 11.6-11.7, it is observed that, for all factors considered, there are some differences that are statistically significant between respondents holding different positions.

Table 11.4 Comparisons of Ratings of Relative Importance of Each Factor for *WYOMING* Respondents With Different Positions (Under Equal Variance Condition).

(a) FACTOR 1 - DRAINAGE STRUCTURE COST

FACTOR 1	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.913	0.560	0.273	0.872
Hydraul. Engineers		0.772	0.569	0.880
Bridge Engineers			0.079	0.117
Branch Heads				0.053

(b) FACTOR 2 - FLOOD RELATED DAMAGE COSTS

FACTOR 2	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.774	0.906		0.783
Hydraul. Engineers		0.890		0.739
Bridge Engineers				0.573

(c) FACTOR 3 - MAINTENANCE FREQUENCY

FACTOR 3	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.687	0.956	0.896	0.395
Hydraul. Engineers		0.804	0.818	0.765
Bridge Engineers			0.896	0.514
Branch Heads				0.292

(d) FACTOR 4 - LITIGATION POTENTIAL

FACTOR 4	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.849	0.105	0.523	0.434
Hydraul. Engineers		0.322	0.751	0.681
Bridge Engineers			0.827	0.782
Branch Heads				1.000

(e) FACTOR 5 - PUBLIC SERVICE

FACTOR 5	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.475	0.869	0.010	0.730
Hydraul. Engineers		0.766	0.212	0.904
Bridge Engineers			0.139	0.898
Branch Heads				0.000*

* Ratings are different at 1% significance level.

(f) FACTOR 6 - LOSS OF HUMAN LIFE

FACTOR 6	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.571	0.127	0.854	0.821
Hydraul. Engineers		0.534	0.726	0.650
Bridge Engineers			0.719	0.648
Branch Heads				1.000

(g) FACTOR 7 - HYDROLOGICAL UNCERTAINTY

FACTOR 7	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.551	0.934	0.533	0.791
Hydraul. Engineers		0.569	0.858	0.816
Bridge Engineers			0.510	0.807
Branch Heads				0.292

Table 11.5 Comparisons of Ratings of Relative Importance of Each Factor for *WYOMING* Respondents With Different Positions (Under Unequal Variance Condition).

(a) FACTOR 1 - DRAINAGE STRUCTURE COST

FACTOR 1	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.952	0.337	0.135	0.937
Hydraul. Engineers		0.818	0.441	0.908
Bridge Engineers			0.388	0.774
Branch Heads				0.481

(b) FACTOR 2 - FLOOD RELATED DAMAGE COSTS

FACTOR 2	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.863	0.882		0.564
Hydraul. Engineers		0.914		0.717
Bridge Engineers				0.517

(c) FACTOR 3 - MAINTENANCE FREQUENCY

FACTOR 3	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.823	0.966	0.971	0.299
Hydraul. Engineers		0.858	0.785	0.752
Bridge Engineers			0.899	0.472
Branch Heads				0.622

(d) FACTOR 4 - LITIGATION POTENTIAL

FACTOR 4	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.905	0.389	0.945	0.418
Hydraul. Engineers		0.544	0.758	0.679
Bridge Engineers			0.805	0.748
Branch Heads				1.000

(e) FACTOR 5 - PUBLIC SERVICE

FACTOR 5	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.767	0.926	0.012**	0.807
Hydraul. Engineers		0.831	0.104	0.904
Bridge Engineers			0.043**	0.899
Branch Heads				0.078

** Ratings are different at 5% significance level.

(f) FACTOR 6 - LOSS OF HUMAN LIFE

FACTOR 6	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.735	0.626	1.000	0.830
Hydraul. Engineers		0.789	0.756	0.656
Bridge Engineers			0.617	0.576
Branch Heads				1.000

(g) FACTOR 7 - HYDROLOGICAL UNCERTAINTY

FACTOR 7	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.617	0.930	0.369	0.896
Hydraul. Engineers		0.682	0.817	0.899
Bridge Engineers			0.427	0.919
Branch Heads				0.803

Table 11.6 Comparisons of Ratings of Relative Importance of Each Factor for *NON-WYOMING* Respondents With Different Positions (Under Equal Variance Condition).

(a) FACTOR 1 - DRAINAGE STRUCTURE COST

FACTOR 1	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.030**	0.411	0.254	0.704
Hydraul. Engineers		0.424	0.511	0.483
Bridge Engineers			0.801	0.855
Branch Heads				0.699

** Ratings are different at 5% significance level.

(b) FACTOR 2 - FLOOD RELATED DAMAGE COSTS

FACTOR 2	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.202	0.303	0.307	0.917
Hydraul. Engineers		0.006*	0.004*	0.434
Bridge Engineers			0.896	0.372
Branch Heads				0.470

* Ratings are different at 1% significance level.

(c) FACTOR 3 - MAINTENANCE FREQUENCY

FACTOR 3	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.003*	0.042**	0.254	0.127
Hydraul. Engineers		0.839	0.229	0.997
Bridge Engineers			0.224	0.869
Branch Heads				0.440

* Ratings are different at 1% significance level.
** Ratings are different at 5% significance level.

(d) FACTOR 4 - LITIGATION POTENTIAL

FACTOR 4	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.112	0.856	0.161	0.273
Hydraul. Engineers		0.203	0.014	0.082
Bridge Engineers			0.249	0.351
Branch Heads				0.857

(e) FACTOR 5 - PUBLIC SERVICE

FACTOR 5	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.000*	0.004*	0.898	0.220
Hydraul. Engineers		0.650	0.000*	0.182
Bridge Engineers			0.002*	0.443
Branch Heads				0.295

* Ratings are different at 1% significance level.

(f) FACTOR 6 - LOSS OF HUMAN LIFE

FACTOR 6	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.001*	0.438	0.836	0.047**
Hydraul. Engineers		0.012*	0.000**	0.643
Bridge Engineers			0.340	0.176
Branch Heads				0.078

* Ratings are different at 1% significance level.
** Ratings are different at 5% significance level.

(g) FACTOR 7 - HYDROLOGICAL UNCERTAINTY

FACTOR 7	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.193	0.023**	0.016**	0.044**
Hydraul. Engineers		0.185	0.172	0.162
Bridge Engineers			0.921	0.587
Branch Heads				0.617

** Ratings are different at 5% significance level.

Table 11.7 Comparisons of Ratings of Relative Importance of Each Factor for *NON-WYOMING* Respondents With Different Positions (Under Unequal Variance Condition).

(a) FACTOR 1 - DRAINAGE STRUCTURE COST

FACTOR 1	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.191	0.545	0.399	0.762
Hydraul. Engineers		0.495	0.564	0.538
Bridge Engineers			0.858	0.889
Branch Heads				0.788

(b) FACTOR 2 - FLOOD RELATED DAMAGE COSTS

FACTOR 2	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.386	0.435	0.488	0.912
Hydraul. Engineers		0.059	0.078	0.486
Bridge Engineers			0.934	0.384
Branch Heads				0.432

(c) FACTOR 3 - MAINTENANCE FREQUENCY

FACTOR 3	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.083	0.129	0.458	0.200
Hydraul. Engineers		0.855	0.341	0.997
Bridge Engineers			0.449	0.895
Branch Heads				0.478

(d) FACTOR 4 - LITIGATION POTENTIAL

FACTOR 4	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.345	0.899	0.416	0.464
Hydraul. Engineers		0.298	0.097	0.201
Bridge Engineers			0.497	0.519
Branch Heads				0.877

(e) FACTOR 5 - PUBLIC SERVICE

FACTOR 5	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.005*	0.036**	0.934	0.270
Hydraul. Engineers		0.769	0.007*	0.314
Bridge Engineers			0.046**	0.491
Branch Heads				0.304

* Ratings are different at 1% significance level.
** Ratings are different at 5% significance level.

(f) FACTOR 6 - LOSS OF HUMAN LIFE

FACTOR 6	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.026**	0.600	0.898	0.007*
Hydraul. Engineers		0.152	0.028**	0.488
Bridge Engineers			0.537	0.065
Branch Heads				0.009*

* Ratings are different at 1% significance level.
** Ratings are different at 5% significance level.

(g) FACTOR 7 - HYDROLOGICAL UNCERTAINTY

FACTOR 7	Hydraul. Engineers	Bridge Engineers	Branch Heads	Admin. Staff
Highway Engineers	0.426	0.090	0.118	0.121
Hydraul. Engineers		0.272	0.331	0.262
Bridge Engineers			0.952	0.690
Branch Heads				0.665

11.1.4 Analysis of Correspondence Between Verbal and Numerical Ratings for Relative Importance - The verbal ratings for relative importance in the survey questionnaire was divided into seven classes ranging from "MOST IMPORTANT" to "NOT-AT-ALL-IMPORTANT". The relative frequencies for each verbal rating are summarized in Figure 11.5(a)-(f). No numerical rating was made for the "NOT-AT-ALL IMPORTANT" class. For each verbal rating, there always exist some cases whose numerical ratings are drastically different from the norm. A close check with the questionnaire sheets corresponding to these cases did not identify any particular pattern or individual producing such ratings.

One possible explanation for the occurrence of such unusual ratings could be attributed to the fine classification of verbal ratings resulting in difficulty on a respondents' part to make discernable distinction among the ratings. This fine classification of verbal ratings also resulted in the relative frequencies of some of the verbal ratings being difficult to interpret and explain. For example, Figure 11.6(a) shows a drop in number of cases for numerical rating '9'. Under a 'normal' condition, one would expect that the relative frequency for "MOST IMPORTANT" category would be the highest for '10' then taper off as the numerical rating decreases. This also happened for the "SOMEWHAT IMPORTANT" category.

For this reason, three categories including "VERY IMPORTANT", "IMPORTANT", and "LESS IMPORTANT" were selected. It was felt the collapse of the original seven verbal classes into three would better serve the practical purpose of modeling the respondents' ratings for relative importance. Without loosing valuable data from the survey questionnaires, the original classes of "MOST IMPORTANT" and "VERY IMPORTANT" were combined into the new class of "VERY IMPORTANT", "IMPORTANT" and "SOMEWHAT IMPORTANT" were collapsed into "IMPORTANT", and the remaining classes were combined into the class of "LESS IMPORTANT". The relative frequencies resulting from collapsing of the original verbal ratings are shown in Figure 11.6(a)-(c). As can be seen, the frequency diagrams behave more regular as one would expect.

Value	Frequency	Percent	Valid Percent	Cum Percent
1.00	3	1.6	1.6	1.6
8.00	23	12.6	12.6	14.2
9.00	3	1.6	1.6	15.8
10.00	153	84.1	84.1	100.0
TOTAL	182	100.0	100.0	

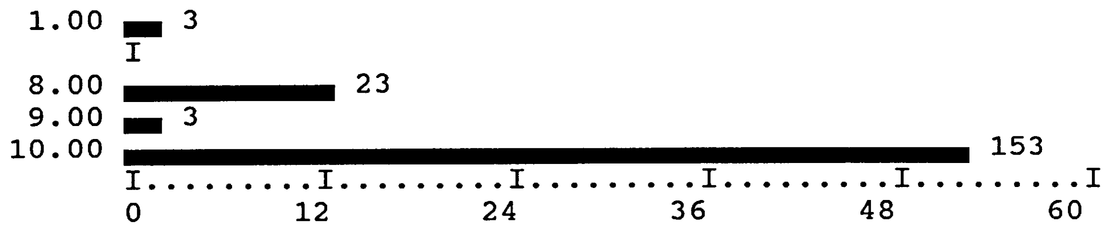


Figure 11.5(a) Summary for Verbal Rating 'MI' With All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
1.00	2	.6	.6	.6
2.00	3	.8	.8	1.4
3.00	1	.3	.3	1.7
5.00	1	.3	.3	2.0
6.00	13	3.6	3.6	5.6
7.00	43	12.0	12.0	17.6
8.00	105	29.4	29.4	95.2
9.00	172	48.2	48.2	65.8
10.00	17	4.8	4.8	100.0
TOTAL	357	100.0	100.0	

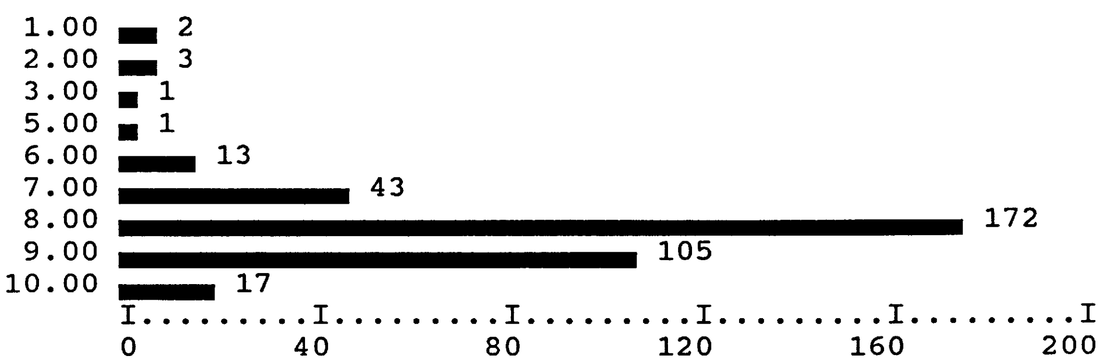


Figure 11.5(b) Summary for Verbal Rating 'VI' With All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
2.00	4	1.0	1.0	1.0
3.00	9	2.2	2.2	3.2
4.00	34	8.2	8.2	11.4
5.00	91	22.0	22.0	73.6
6.00	166	40.2	40.2	51.6
7.00	74	17.9	17.9	91.5
8.00	29	7.0	7.0	98.5
9.00	5	1.2	1.2	99.7
10.00	1	.2	.2	100.0
TOTAL	413	100.0	100.0	

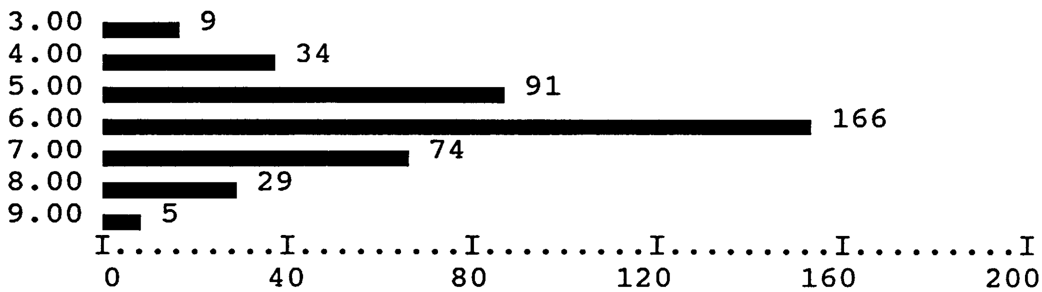


Figure 11.5(c) Summary for Verbal Rating ' I ' With All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
3.00	2	.8	.8	.8
4.00	10	4.2	4.2	5.0
5.00	74	31.0	31.0	46.9
6.00	26	10.9	10.9	15.9
7.00	87	36.4	36.4	83.3
8.00	37	15.5	15.5	98.7
9.00	3	1.3	1.3	100.0
TOTAL	239	100.0	100.0	

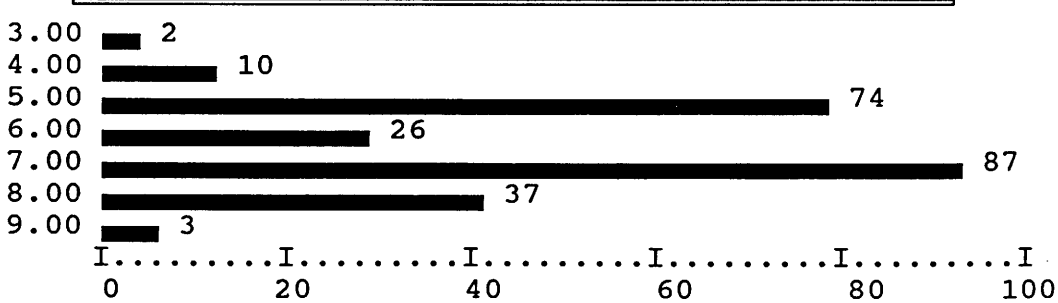


Figure 11.5(d) Summary for Verbal Rating 'SI' With All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
1.00	3	7.9	7.9	7.9
2.00	14	36.8	36.8	44.7
3.00	7	18.4	18.4	63.1
4.00	5	13.5	13.5	76.6
5.00	7	18.4	18.4	95.0
6.00	1	2.6	2.6	97.6
7.00	1	2.6	2.6	100.0
TOTAL	38	100.0	100.0	

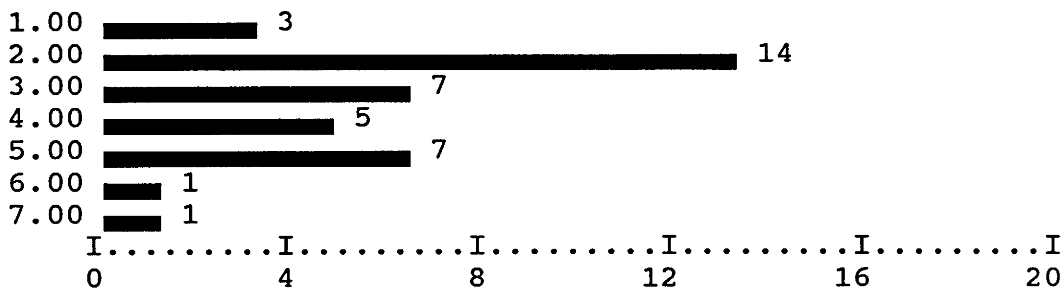


Figure 11.5(e) Summary of Verbal Rating 'NVI' with All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	3	4.1	4.1	4.1
1.00	1	1.4	1.4	5.5
2.00	17	23.3	23.3	28.8
3.00	21	28.8	28.8	57.6
4.00	21	28.8	28.8	86.4
5.00	6	8.2	8.2	94.6
6.00	2	2.7	2.7	97.3
7.00	1	1.4	1.4	98.6
9.00	1	1.4	1.4	100.0
TOTAL	73	100.0	100.0	

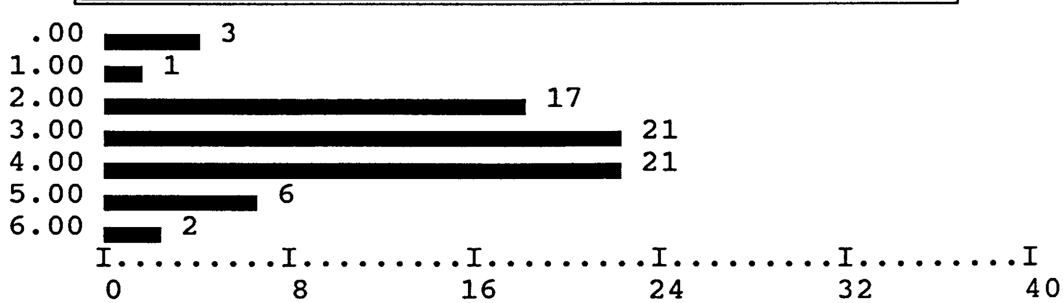


Figure 11.5(f) Summary for Verbal Rating 'NI' With All Factors Combined.

Value	Frequency	Percent	Valid Percent	Cum Percent
1.00	5	.9	.9	.9
2.00	3	.6	.6	1.5
3.00	1	.2	.2	1.7
5.00	1	.2	.2	1.9
6.00	13	2.4	2.4	4.3
7.00	43	8.0	8.0	12.2
8.00	128	23.7	23.7	68.5
9.00	175	32.5	32.5	44.7
10.00	170	31.5	31.5	100.0
TOTAL	539	100.0	100.0	

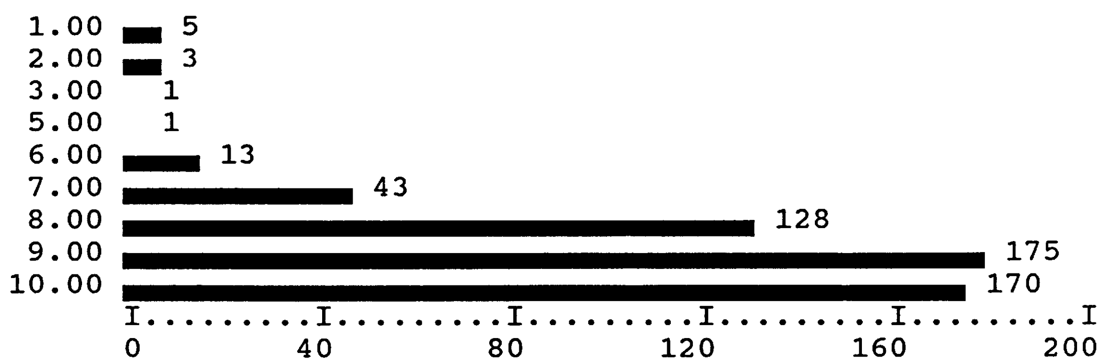


Figure 11.6(a) Summary for Verbal Rating 'VI' in 3-Level Classification.

Value	Frequency	Percent	Valid Percent	Cum Percent
2.00	4	.6	.6	.6
3.00	11	1.7	1.7	2.3
4.00	44	6.7	6.7	9.0
5.00	165	25.3	25.3	38.5
6.00	192	29.4	29.4	63.8
7.00	161	24.7	24.7	88.5
8.00	66	10.1	10.1	98.6
9.00	8	1.2	1.2	99.8
10.00	1	.2	.2	100.0
TOTAL	652	100.0	100.0	

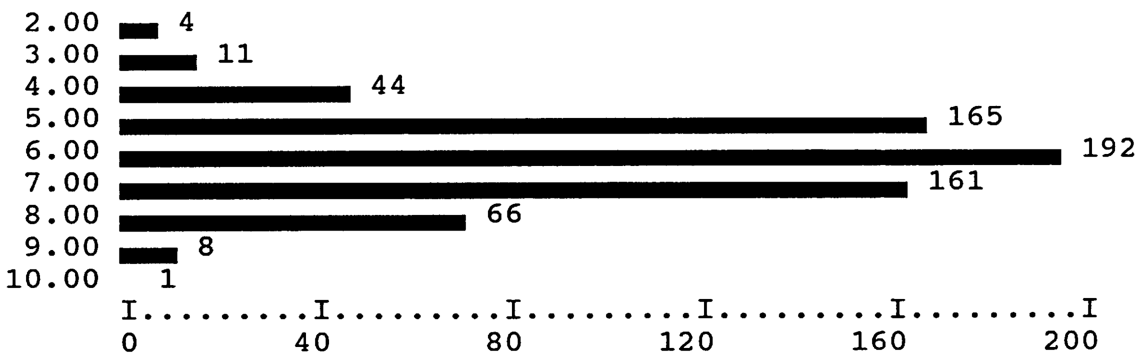


Figure 11.6(b) Summary of Verbal Rating ' I ' in 3-Level Classification

Value	Frequency	Percent	Valid Percent	Cum Percent
0.00	3	2.7	2.7	2.7
1.00	4	3.6	3.6	6.3
2.00	31	27.9	27.9	34.2
3.00	28	25.2	25.2	59.4
4.00	26	23.4	23.4	82.8
5.00	13	11.7	11.7	94.5
6.00	3	2.7	2.7	97.2
7.00	2	1.8	1.8	99.0
8.00	0	0.0	0.0	99.0
9.00	1	.9	.9	100.0
TOTAL	111	100.0	100.0	

Figure 11.6(c) Summary of Verbal Rating ' LI ' in 3-Level Classification

11.2 ANALYSIS AND SUMMARY OF PART-3 SURVEY RESULTS (Rating of Design Return Period Versus Intangible Factors)

For Part-3 of the survey, the main concern was to rate the desirability of eight (8) design return periods when three intangible factors are considered under various site conditions. The eight design return periods for highway drainage structures considered were 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year. Among the seven factors considered in Part-2, three intangible factors, i.e., (1) maintenance frequency, (2) litigation potential, and (3) public service, were selected. The site condition was classified based on location, drainage structure type, average daily traffic, detour length, fill height, and floodplain land use. A total of seventy two (72) categories were developed. Highway engineers, hydraulic engineers, and bridge structural engineers were requested to complete this part of the questionnaire. Each respondent was given six randomly chosen site conditions; three in an urban setting and three in a rural setting.

The objective of this analysis is to develop functional relationships between rating, design frequency, the intangible factors, and the various site conditions. On each survey sheet for Part-3 (see Appendix A.1), there are 48 entries with 24 for verbal ratings and 24 for numerical ratings.

11.2.1 Analysis of Correspondence Between Verbal and Numerical Ratings - The objectives were to (1) examine how respondents assign numerical value for different verbal ratings and (2) to check if the assignments of two ratings are consistent. This was observed by constructing the histograms of numerical rating for each different verbal ratings as shown by Figures 11.7(a)-(g). Although there exists a few unexpected ratings, the great majority of the answers from the respondents are consistent. As can be observed from Figures 11.7(a)-(g), the numerical ratings for the two extremes of verbal rating, i.e., "MOST DESIRABLE (MD)" and "NOT-AT-ALL DESIRABLE (NA)", are predominantly on the scales of 10 and 0, respectively. The numerical scales for those intermediate verbal ratings become more dispersed toward the center of the verbal rating. In fact, the consistency of numeric ratings (or degree of unanimity) among respondents for each verbal rating is indicated by the magnitude of standard deviation of the numerical scale. The verbal rating of "MOST DESIRABLE" has the smallest standard deviation followed by "NOT-AT-ALL-DESIRABLE". The rating "DESIRABLE" is perhaps the most intuitively ambiguous and, therefore, has the largest value of standard deviation.

Although seven levels of verbal rating have been rated and their association with the numeric scale can be established, it was felt that a person completing the questionaire might be unable or might not care for the fine and subtle distinction between "NOT-VERY-DESIRABLE" and "NOT DESIRABLE" as well as other classes of verbal ratings. For this reason, the original seven classes were collapsed into three classes, i.e., combining "MOST DESIRABLE" and "VERY DESIRABLE" into "VERY DESIRABLE (VD)", "DESIRABLE" and "SOMEWHAT DESIRABLE" into "DESIRABLE (D)", and the remainder into "LESS DESIRABLE (LD)". The histogram of the three-class verbal ratings are shown in Figures 11.8(a)-(c). Furthermore, for purpose of making the data more representative those unusual numerical ratings that were not intuitively reasonable were truncated. The resulting histograms for the three rating classes are shown in Figures 11.9(a)-(b).

Value	Frequency	Percent	Valid Percent	Cum Percent
5.00	2	.1	.1	.1
6.00	5	.1	.1	.2
7.00	19	.6	.6	.8
8.00	65	1.9	1.9	2.7
9.00	116	3.4	3.4	6.1
10.00	3188	93.9	93.9	100.0
TOTAL	3395	100.0	100.0	

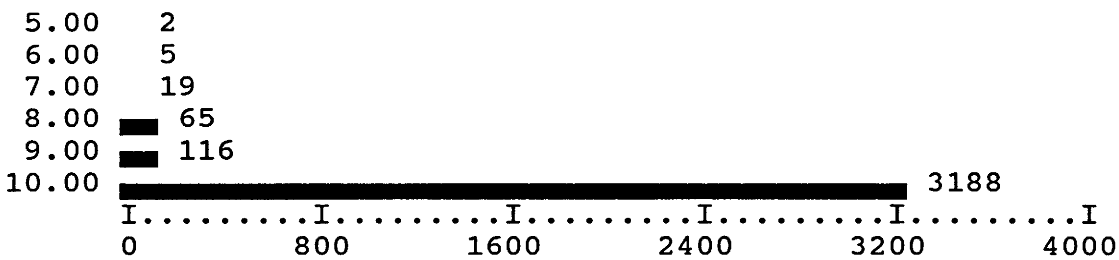


Figure 11.7(a) Summary for Verbal Rating "MD - MOST DESIRABLE "

Value	Frequency	Percent	Valid Percent	Cum Percent
3.00	1	.0	.0	.0
4.00	8	.4	.4	.4
5.00	11	.5	.5	.9
6.00	60	2.8	2.8	3.7
7.00	155	7.2	7.2	10.9
8.00	728	33.7	33.7	44.5
9.00	714	33.0	33.0	77.6
10.00	485	22.4	22.4	100.0
TOTAL	2162	100.0	100.0	

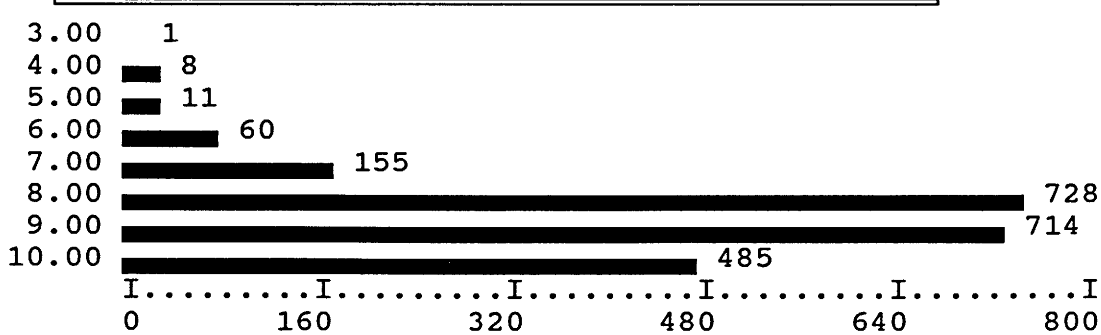


Figure 11.7(b) Summary for Verbal Rating "VD - VERY DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	3	.1	.1	.1
1.00	4	.2	.2	.3
2.00	57	2.5	2.5	2.8
3.00	61	2.7	2.7	5.5
4.00	195	8.6	8.6	14.2
5.00	579	25.6	25.6	39.8
6.00	503	22.3	22.3	62.1
7.00	296	13.1	13.1	75.2
8.00	206	9.1	9.1	84.3
9.00	47	2.1	2.1	86.4
10.00	308	13.6	13.6	100.0
TOTAL	2259	100.0	100.0	

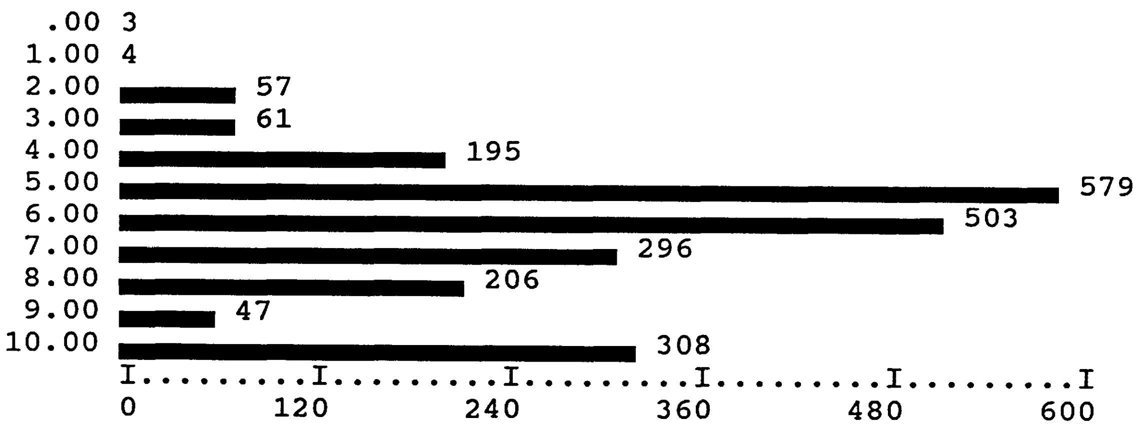


Figure 11.7(c) Summary for Verbal Rating "D - DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	2	.1	.1	.1
2.00	1	.1	.1	.2
3.00	20	1.3	1.3	1.5
4.00	67	4.4	4.4	5.9
5.00	125	8.1	8.1	14.0
6.00	439	28.6	28.6	42.6
7.00	304	19.8	19.8	62.5
8.00	326	21.3	21.3	83.7
9.00	51	3.3	3.3	87.0
10.00	199	13.0	13.0	100.0
TOTAL	1534	100.0	100.0	

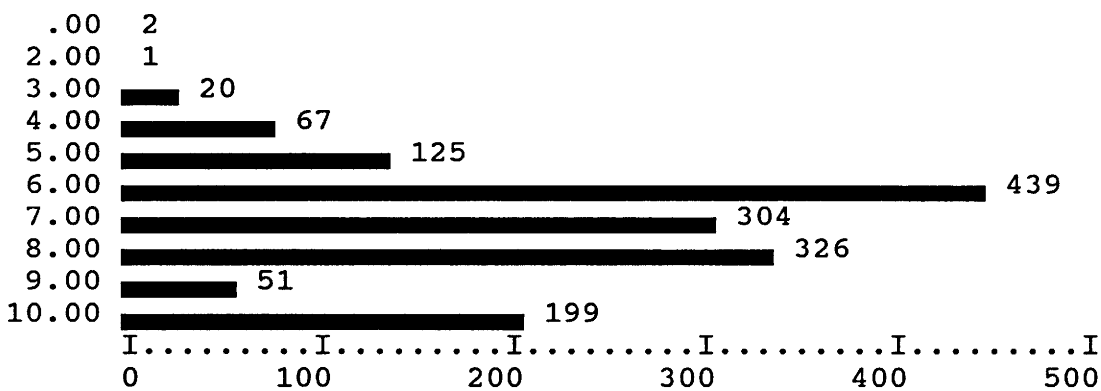


Figure 11.7(d) Summary for Verbal Rating "SD - SOMEWHAT DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	51	4.2	4.2	4.2
1.00	141	11.6	11.6	15.7
2.00	473	38.8	38.8	54.5
3.00	238	19.5	19.5	74.0
4.00	170	13.9	13.9	88.0
5.00	82	6.7	6.7	94.7
6.00	41	3.4	3.4	98.0
7.00	6	.5	.5	98.5
8.00	14	1.1	1.1	99.7
10.00	4	.3	.3	100.0
TOTAL	1220	100.0	100.0	

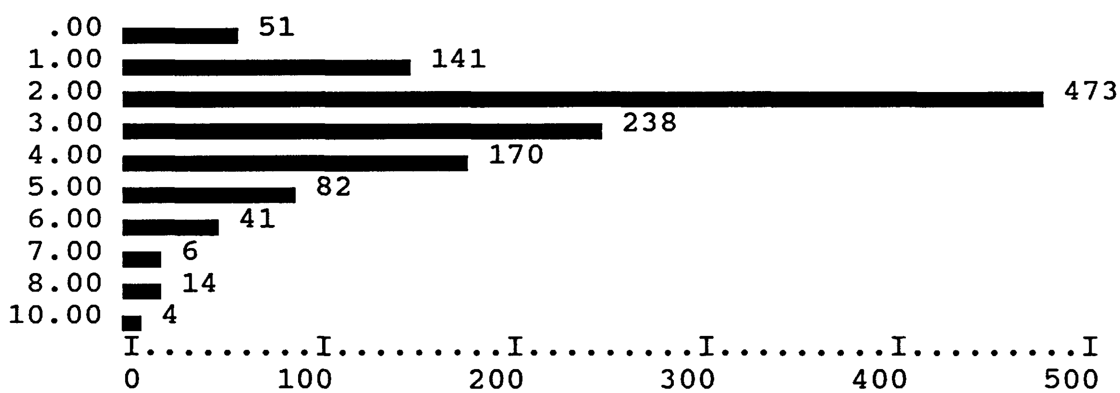


Figure 11.7(e) Summary for Verbal Rating "NV - NOT VERY DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	95	5.1	5.1	5.1
1.00	69	3.7	3.7	8.8
2.00	306	16.4	16.4	25.3
3.00	336	18.1	18.1	43.3
4.00	500	26.9	26.9	70.2
5.00	281	15.1	15.1	85.3
6.00	156	8.4	8.4	93.7
7.00	51	2.7	2.7	96.4
8.00	37	2.0	2.0	98.4
9.00	14	.8	.8	99.1
10.00	16	.9	.9	100.0
TOTAL	1861	100.0	100.0	

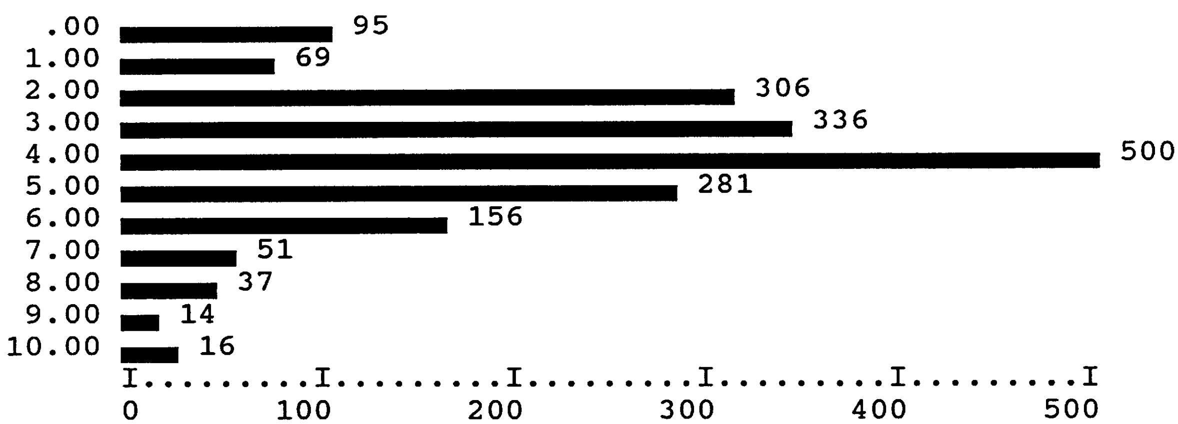


Figure 11.7(f) Summary for Verbal Rating "ND - NOT DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	1443	65.3	65.3	65.3
1.00	391	17.7	17.7	83.0
2.00	221	10.0	10.0	93.0
3.00	63	2.9	2.9	95.9
4.00	53	2.4	2.4	98.3
5.00	27	1.2	1.2	99.5
6.00	7	.3	.3	99.8
7.00	3	.1	.1	100.0
8.00	1	.0	.0	100.0
TOTAL	2209	100.0	100.0	

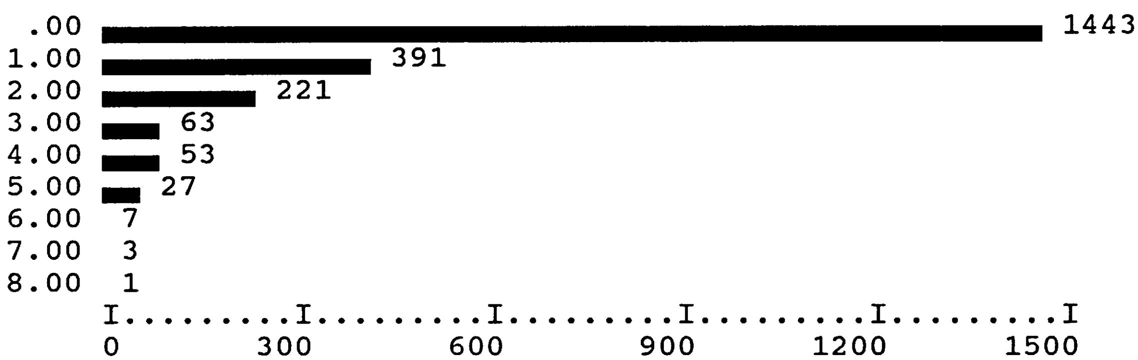


Figure 11.7(g) Summary for Verbal Rating "NA - NOT-AT-ALL DESIRABLE"

Value	Frequency	Percent	Valid Percent	Cum Percent
3.00	1	.0	.0	.0
4.00	8	.1	.1	.2
5.00	13	.2	.2	.4
6.00	65	1.2	1.2	1.6
7.00	174	3.1	3.1	4.7
8.00	793	14.3	14.3	19.0
9.00	830	14.9	14.9	33.9
10.00	3673	66.1	66.1	100.0
TOTAL	5557	100.0	100.0	

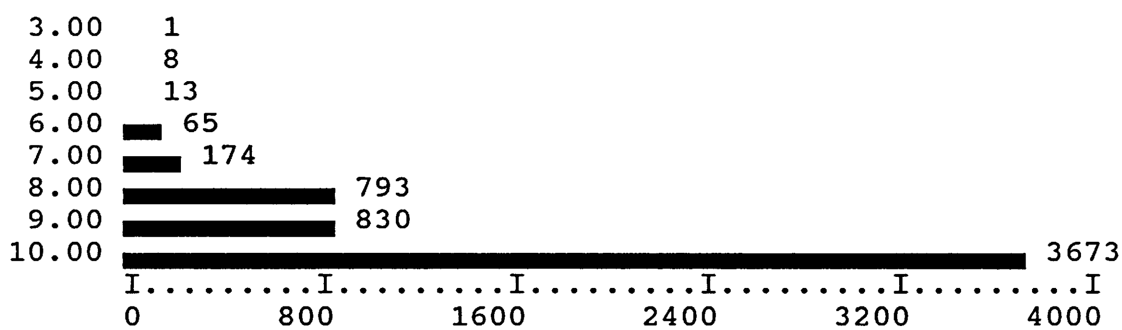


Figure 11.8(a) Summary for Verbal Rating "VD = MD + VD"(All Data are Used)

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	5	.1	.1	.1
1.00	4	.1	.1	.2
2.00	58	1.5	1.5	1.8
3.00	81	2.1	2.1	3.9
4.00	262	6.9	6.9	10.8
5.00	704	18.6	18.6	29.4
6.00	942	24.8	24.8	54.2
7.00	600	15.8	15.8	70.0
8.00	532	14.0	14.0	84.0
9.00	98	2.6	2.6	86.6
10.00	507	13.4	13.4	100.0
TOTAL	3793	100.0	100.0	

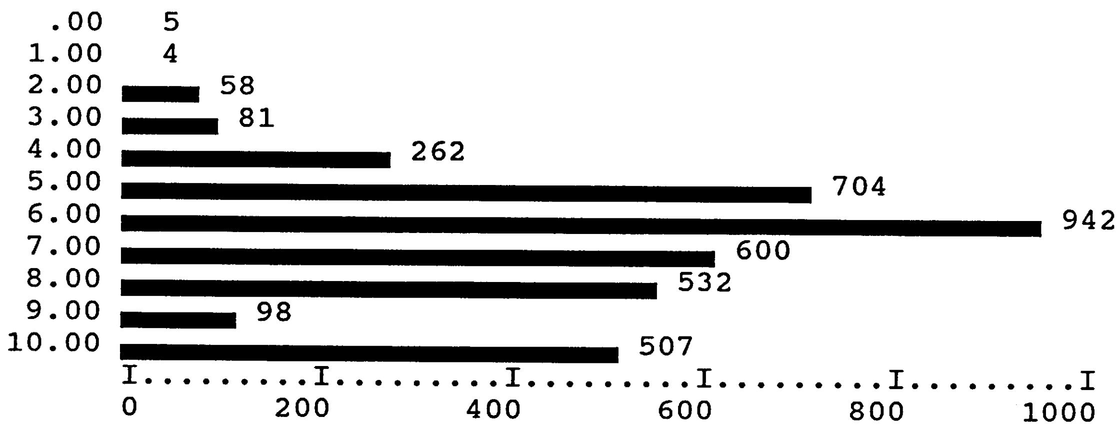


Figure 11.8(b) Summary for Verbal Rating "D = D + SD" (All Data are Used)

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	1589	30.0	30.0	30.0
1.00	601	11.4	11.4	41.4
2.00	1000	18.9	18.9	60.3
3.00	637	12.0	12.0	72.3
4.00	723	13.7	13.7	86.0
5.00	390	7.4	7.4	93.4
6.00	204	3.9	3.9	97.2
7.00	60	1.1	1.1	98.4
8.00	52	1.0	1.0	99.4
9.00	14	.3	.3	99.6
10.00	20	.4	.4	100.0
TOTAL	5290	100.0	100.0	

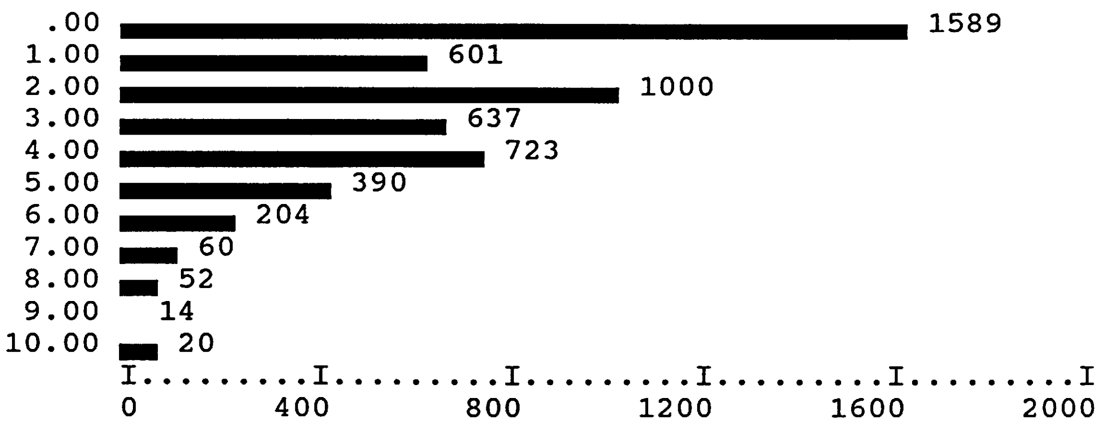


Figure 11.8(c) Summary for Verbal Rating "LD = NV + ND + NA" (All Data are Used)

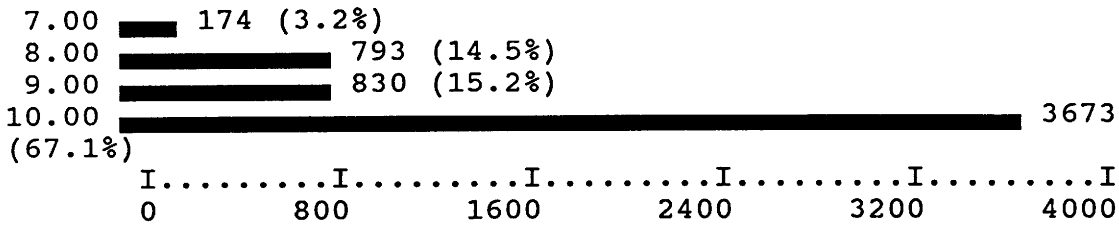


Figure 11.9(a) Summary for Verbal Rating "VD = MD + VD" (Data are Trimmed)

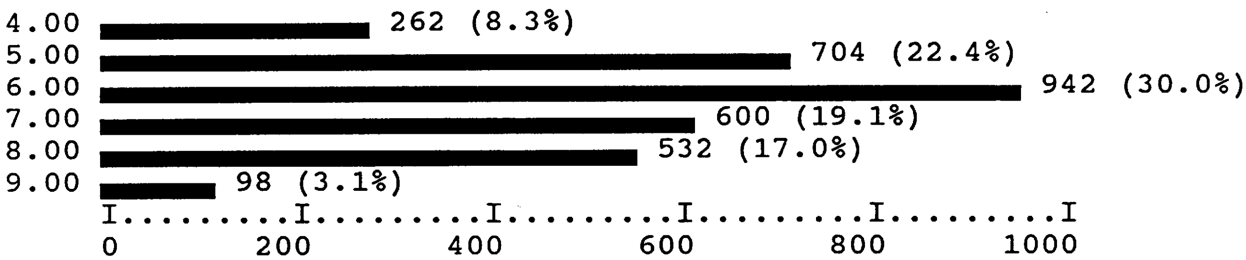


Figure 11.9(b) Summary for Verbal Rating "D = D + SD" (Data are Trimmed)

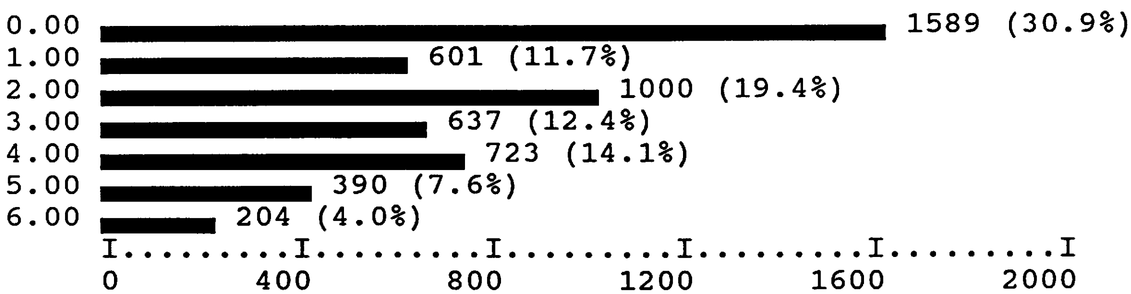


Figure 11.9(c) Summary for Verbal Rating "LD = NV + ND + NA" (Data are Trimmed)

11.2.2 Development of Predictive Model for Assessing Preference Rating - The second task in the analysis of the Part-3 survey results was to develop a predictive model on the basis of the respondents' ratings. The model can be regarded as the consensus of nominal highway engineers on the their rating for different design return periods under various site conditions. The response variable is the verbal rating and the predictive variables are (1) location, (2) structural type, (3) average daily traffic, (4) detour length, (5) fill height, (6) floodplain land use, (7) intangible factor considered, (8) design return period. Because all response and predictive variables are of a categorical nature as shown in the survey form (Appendix A.1), the analysis is done by using discriminant analysis.

The discriminant analysis is a powerful statistical tool for dealing with the classification problems in which an object belonging to a certain class (or category) is a function of several attributes. In the context of our problem, the objective is to assess the verbal rating an engineer makes under given site conditions (the attributes). Through many trial-and-errors, the best discriminant functions (in terms of percentage of correct classification) are

$$\begin{aligned} FUNC1_3 = {} & .2532447\ LOC + .05939721\ ST + .09601001\ ADT \\ & -.08750816\ DETR + .003824205\ FHT - .03709942\ FACTOR \\ & -37.53681\ PROB + 29.48566\ PROB^2 + 8.878023 \end{aligned} \qquad (11.1)$$

$$\begin{aligned} FUNC2_3 = {} & -.2658527\ LOC + .3441108\ ST - .2330221\ ADT \\ & .3913645\ DETR - .1353026\ FHT + .07971823\ FACTOR \\ & 64.21618\ PROB - 40.71331\ PROB^2 -24.15165 \end{aligned} \qquad (11.2)$$

in which LOC = Location: 1-Urban; 2-Rural; ST = Structural type: 1-Bridge; 2-Culvert; ADT = Average daily traffic: 1-(-,750); 2-(750,5000); 3-(5000,-); DETR = Detour length: 1-(-,5mi); 2-(5-20); 3-(20,-); FHT = Fill height: 1-(-,8ft); 2-(8ft-20ft); 3-(20ft,-); LAND = Land use type; FACTOR = Intangible factors: 1-Maintenance frequency; 2-Litigation potential; 3-Public Service; TR = Design return period; PROB = 1.-1./TR with TR being the design return period.

Note that land use type was found to be insignificant statistically in the discriminant analysis and, therefore, was not used in the above following discriminant functions. The above discriminant functions produce a 64.34% correct classification by placing 64.34% of the cases with the correct verbal rating as compared with those rated by the respondents. In other words, the above discriminant functions have 64.34% reliability of modeling the respondents' preference for a given site condition. Table 11.8 shows the classification results. The numbers shown on the diagonal cells are the percentage and cases being correctly classified. Off-diagonal cells are those which are incorrectly classified. As can be seen that classification is the most accurate for "VERY DESIRABLE", followed by "LESS DESIRABLE", and the least accurate is for "DESIRABLE". This result is expected as, referring to Figure 11.8 or 11.9, the uncertainty of numeric rating for "DESIRABLE" is larger than that of for "VERY DESIRABLE" and "NOT DESIRABLE".

Application of the above discriminant functions for simulating what an engineer would rate is as follows: The centroids of the numerical rating for the three verbal ratings (i.e., VD, D, and ND) and the two discriminant functions ($FUNC1_3$ and $FUNC2_3$) were computed on the basis of data and are shown in Table 11.9.

Next, Referring to Figure 11.10, these centroids geometrically represent the locations in $FUNC1_3$-$FUNC2_3$ space around which each verbal rating is clustered. Hence, for a specified site condition, design return period, and intangible factor, a point in $FUNC1_3$-$FUNC2_3$ in space was determined based on the values of $FUNC1_3$ and $FUNC2_3$ computed by the discriminant functions. Then, the distance between this point and the centroids of three verbal rating were computed as

$$DIST_{VD} = \sqrt{(FUNC1_3-.83993)^2+(FUNC2_3+.10056)^2} \qquad (11.3a)$$

$$DIST_{D} = \sqrt{(FUNC1_3-.14171)^2+(FUNC2_3-.28445)^2} \qquad (11.3b)$$

$$DIST_{LD} = \sqrt{(FUNC1_3+.97960)^2 + (FUNC2_3+.06659)^2} \qquad (11.3c)$$

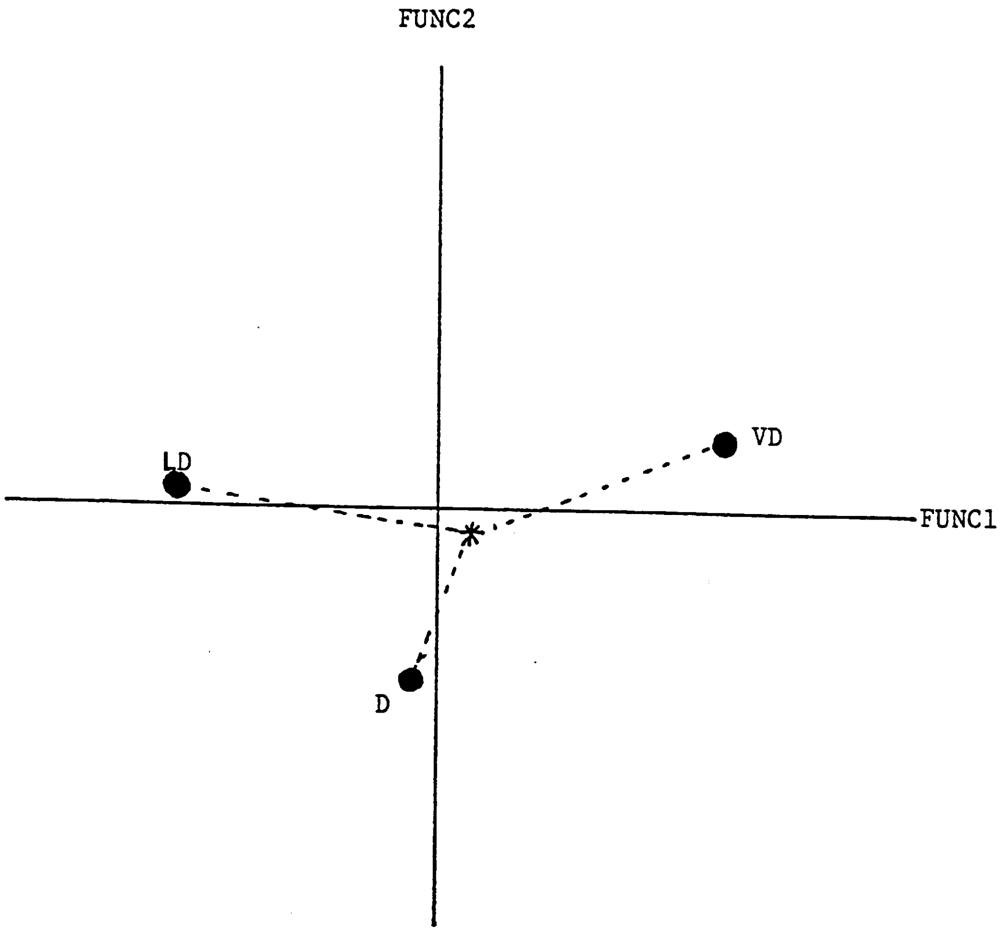


Figure 11.10 Schematic Diagram of Discriminant Analysis.

The verbal rating with the shortest distance from the point associated with the case under consideration was assigned to the case.

Alternatively, the decision as to which verbal rating should be given for a site condition under consideration was made based on the probability that one of the three verbal ratings will be assigned by an engineer. These probabilities were determined as

$$PROB_{VD} = LKLY_{VD}/(LKLY_{VD} + LKLY_{D} + LKLY_{LD}) \tag{11.4a}$$

$$PROB_{D} = LKLY_{D}/(LKLY_{VD} + LKLY_{D} + LKLY_{LD}) \tag{11.4b}$$

$$PROB_{LD} = LKLY_{LD}/(LKLY_{VD} + LKLY_{D} + LKLY_{LD}) \tag{11.4c}$$

in which $PROB_{VD}$, $PROB_{D}$, and $PROB_{LD}$ are the probabilities that verbal ratings "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE" will be assigned by an engineer, respectively. Terms on the right-hand side of Eq.(11.4a-c) were computed on the basis of distance measures defined in Eq.(11.3a-c) as

$$LKLY_{VD} = EXP\left(-\frac{DIST_{VD}^2}{2}\right) \tag{11.5a}$$

$$LKLY_{D} = EXP\left(-\frac{DIST_{D}^2}{2}\right) \tag{11.5b}$$

$$LKLY_{LD} = EXP\left(-\frac{DIST_{LD}^2}{2}\right) \tag{11.5c}$$

The verbal rating having the highest probability was chosen for the preference of the potential decision maker for the condition under consideration.

Similar analysis was perform for the original seven verbal ratings. The discriminant analysis produces six discriminant functions and the highest percentage of correct classification based on the survey data set was found to be only 36.92%. For the reasons described above, the seven-level verbal rating is not recommended for use.

Table 11.8 Classification Results Using Three-Level Verbal Rating.

Actual Rating	No. of Cases	Predicted Rating Membership VD	D	LD
Group 1 VERY DESIRABLE	5470	4612 84.3%	659 12.0%	199 3.6%
Group 2 DESIRABLE	3138	1494 47.6%	1061 33.8%	583 18.6%
Group 3 LESS DESIRABLE	5144	1140 22.2%	829 16.1%	3175 61.7%

Percent of "grouped" cases correctly classified: 64.34%

Table 11.9 Centroids of Numerical Rating for VD, D, and LD and $FUNC1_3$ and $FUNC2_3$ for Intangible Factors.

Rating	$FUNC1_3$	$FUNC2_3$
VD	.83993	-.10056
D	.14171	.28445
LD	-.97960	-.06659

11.3 ANALYSIS AND SUMMARY OF PART-4 SURVEY RESULTS: (Rating of Economic Desirability of Selecting a Non-optimal Design Return Period).

The main concern was to evaluate the relative desirability of non-optimal design return periods against the LTEC design return period under different percentages of cost increment. Both verbal and numerical ratings were available from the survey respondents. As noted earlier, only hydraulic engineers and bridge engineers were requested to complete this part of the questionnaire. Each respondent was requested to use both numerical and verbal ratings for the desirability of various non-optimal return periods associated with different cost levels expressed as a percentage of the optimum cost. Each respondent was given three cases out of a total of six optimal return periods of 2-, 5-, 10-, 25-, 50-, and 100-year.

Similar to the Part-3 analysis, the objective of the analysis was to develop functional relationships between rating the least cost design return period, non-optimal design return periods, and the percentage of cost increment.

11.3.1 Analysis of Correspondence Between Verbal and Numerical Ratings - Although there were six levels of verbal rating on the original survey sheets, they were collapsed into three levels as was done in the Part-3 survey for the same argument given previously in Sections 11.1.4 and 11.2.1 of this report. The relationship between numeric rating and verbal rating are shown as histogram forms in Figures 11.11(a)-(c). It should be noted that the numerical scales associated with the three verbal ratings were trimmed by discarding intuitively unreasonable values.

Value	Frequency	Percent	Valid Percent	Cum Percent
7.00	32	9.7	9.7	9.7
8.00	102	30.9	30.9	40.6
9.00	134	40.6	40.6	81.2
10.00	62	18.8	18.8	100.0
TOTAL	330	100.0	100.0	

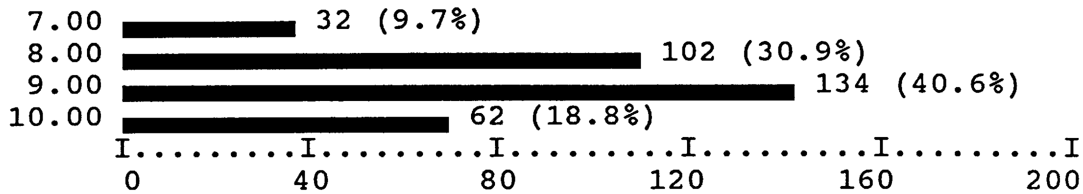


Figure 11.11(a) Summary for Verbal Rating "VD" for Economic Factor (Data are Trimmed)

Value	Frequency	Percent	Valid Percent	Cum Percent
3.00	33	6.5	6.5	6.5
4.00	74	14.5	14.5	21.0
5.00	115	22.5	22.5	43.5
6.00	127	24.9	24.9	68.4
7.00	106	20.8	20.8	89.2
8.00	55	10.8	10.8	100.0
TOTAL	510	100.0	100.0	

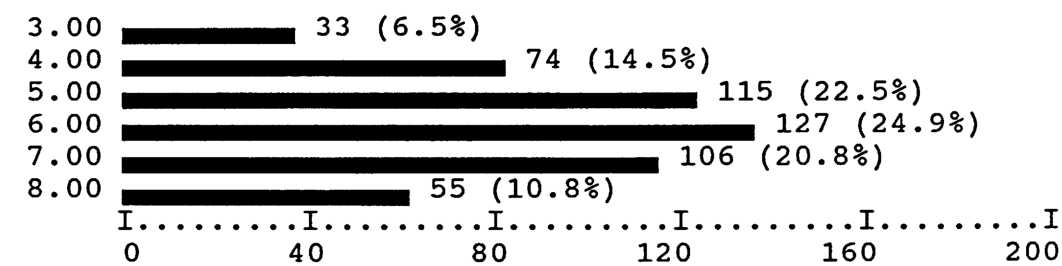


Figure 11.11(b) Summary for Verbal Rating "D" for Economic Factor (Data are Trimmed)

Value	Frequency	Percent	Valid Percent	Cum Percent
.00	350	43.4	43.4	43.4
1.00	127	15.7	15.7	59.1
2.00	149	18.5	18.5	77.6
3.00	88	10.9	10.9	88.5
4.00	46	5.7	5.7	94.2
5.00	30	3.7	3.7	97.9
6.00	17	2.1	2.1	100.0
TOTAL	807	100.0	100.0	

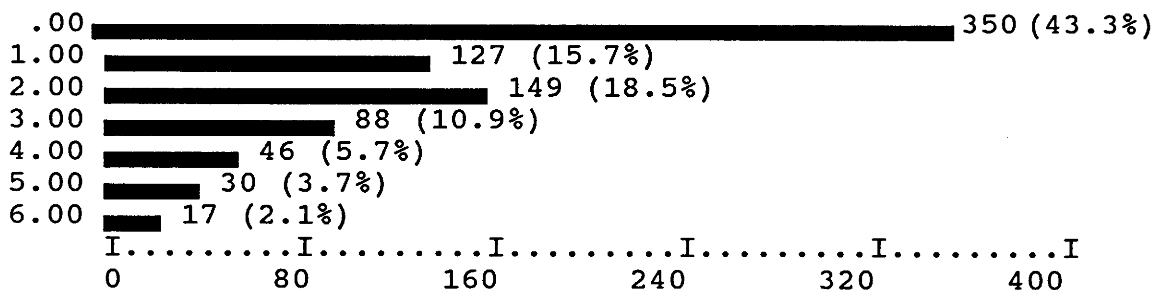


Figure 11.11(c) Summary for Verbal Rating "LD" for Economic Factor (Data are Trimmed)

11.3.2 Predictive Model for Assessing Verbal Rating - Again, discriminant analysis procedure was employed to develop a model that allows a prediction of the degree of desirability for a non-optimal design return period conditioned on a specified LTEC return period and percentage of cost increment. A three-level verbal rating was used as the dependent variable while the LTEC return period, non-optimal design return period, and percentage of incremental cost were selected as predictive variables. The resulting discriminant functions are

$$FUNC1_4 = -2.637129 - 0.1133372\ln(PCT) + 0.1483055\ln(PCT)^2 - 5.732338\ln(TRINV/OPTRIN) + 7.249127\ln(TRINV/OPTRINV)^2 \quad (11.6a)$$

$$FUNC2_4 = -24.01042 + 10.64839\ln(PCT) - 1.142319\ln(PCT)^2 + 0.28711\ln(TRINV/OPTRINV) - 0.14871\ln(TRINV/OPTRINV)^2 \quad (11.6b)$$

in which PCT is the percentage (in %) of cost increment of non-optimal design return period (TR) over the LTEC return period (OPTR); ln( ) is the natural logarithmic transform; TRINV = 1.-1./TR; and OPTRINV = 1.-1./OPTR. The above discriminant functions resulted in a 60.78% correct classification (see Table 11.10).

Table 11.10 Classification Results for Economic Factor

Actual Rating	No. of Cases	Predicted Group Membership VD	D	LD
Group 1 VERY DESIRABLE	330	179 54.2%	119 36.1%	32 9.7%
Group 2 DESIRABLE	510	115 22.5%	263 51.6%	132 25.9%
Group 3 LESS DESIRABLE	807	40 5.0%	208 25.8%	559 69.3%

Average Percent of "grouped" cases correctly classified: 60.78%

The centroids of the three verbal ratings in $FUNC1_4$-$FUNC2_4$ space based on the data set are given in Table 11.11. Therefore, the selection of an appropriate verbal rating for a specified condition of economic cost, non-optimal design return period, and least-cost return period was based on the same shortest distance criterion or the largest probability criterion as described previously in Section 11.2.2 of this report. The distance measure was computed as the following:

$$DIST_{VD} = \sqrt{(FUNC1_4 + 1.11392)^2 + (FUNC2_4 + .30305)^2} \quad (11.7a)$$

$$DIST_{D} = \sqrt{(FUNC1_4 + .34485)^2 + (FUNC2_4 - .34419)^2} \quad (11.7b)$$

$$DIST_{LD} = \sqrt{(FUNC1_4 - .67344)^2 + (FUNC2_4 + .09359)^2} \quad (11.7c)$$

The probability that each verbal rating is likely to be chosen under a given condition can be computed by Eqs. (11.4a-c).

Table 11.11 Centroids of Numerical Rating for VD, D, and LD and $FUNC1_4$ and $FUNC2_4$ for Economic Consideration.

Rating	$FUNC1_4$	$FUNC2_4$
VD	-1.11392	-.30305
D	-.34485	.34419
LD	.67344	-.09359

12.
MULTI-ATTRIBUTE DECISION-MAKING (MADM) FOR DETERMINING THE EXTENDED-LTEC DESIGN FREQUENCY

As noted in the INTRODUCTION chapter, this research attempts to quantitatively, on the basis of the LTEC design frequency, incorporate the effects of some intangible factors to determine an appropriate design frequency, called the extended-LTEC design frequency, for highway drainage structures. The purpose behind this effort was to devise guidance for the design engineer to use in assessing the importance of these factors through the use of the experts' opinion as obtained from the questionnaire of Chapter 11. This system was devised to reflect the intelligence of 'experts' around the country as well as 'experts' in Wyoming.

12.1 MADM FOR DETERMINING THE EXTENDED-LTEC DESIGN FREQUENCY UNDER UNCERTAINTY

The conventional LTEC analysis for a highway drainage structure considers only the economic cost consisting of structural costs and flood related damages. In fact, decision-making to select an appropriate design frequency for a highway drainage structure involves considering other factors in addition to the tangible economic costs. The analyses of survey data in Chapter 11 provides the needed information for modeling the preference rating of an engineer for different design return periods under various site conditions. The multi-attribute decision-making problem in the context of selecting an appropriate design return period for highway drainage structures can be cast into an information matrix as shown in Table 12.1. Table 12.1 is a special case of the more general situation shown in Figure 9.1 in Chapter 9 for the problem context under consideration. The decision alternatives are the different design frequencies listed in the first column. The information matrix contains the preference rating $R_{i,j}$ indicating the desirability of the i^{th} design frequency when the j^{th} factor is considered. The bottom row is for the weight W_j representing the importance of the j-th factor in the selection of a design flood-frequency for a highway drainage structure.

Table 12.1 Information Matrix for Determining Optimal Design Flood Frequency by the SAW Method.

(ALTERNATIVES)	FACTORS (ATTRIBUTES)			
Design Frequency	Total Cost	Maint. Freq.	Litig. Poten.	Public Service
2-yr	R_{11}	R_{12}	R_{13}	R_{14}
5-yr	R_{21}	R_{22}	R_{23}	R_{24}
10-yr	R_{31}	R_{32}	R_{33}	R_{34}
25-yr	R_{41}	R_{42}	R_{43}	R_{44}
50-yr	R_{51}	R_{52}	R_{53}	R_{54}
100-yr	R_{61}	R_{62}	R_{63}	R_{64}
200-yr	R_{71}	R_{72}	R_{73}	R_{74}
REL. IMPORTANCE	W_1	W_2	W_3	W_4

The method adopted herein for determining a preferable design frequency while simultaneously considering the four factors indicated in Table 12.1 is the Simple Additive Weighing (SAW) method. Once the levels of desirability $R_{i,j}$ and of importance W_j are specified, the overall rating for each decision alternative F_i is then evaluated by

$$F_i = \frac{\sum_{j=1}^{4} R_{ij} W_j}{\sum_{j=1}^{4} W_j}, \ for\ i = 1,2,\ldots,7 \tag{12.1}$$

where F_i, in the context of Table 12.1, are $\{F_1, F_2, \ldots, F_7\}$ = {2-yr, 5-yr, ..., 200-yr}.

The use of the SAW method is simple and straightforward if the numerical values for ratings and weights can be assigned uniquely without uncertainty. The optimal extended-LTEC design frequency will be the one associated with the highest value of overall rating. However, the rating and the relative importance, more often than not, are subject to certain degrees of uncertainty. This is evidenced from the survey results presented in Chapter 11 in that the degree of desirability of an individual or a group of individuals for a given combination of alternatives and attributes vary. Referring to Table 11.2 as an example, although the average ratings of "IMPORTANCE" between Wyoming and non-Wyoming respondents were not significantly different statistically for the majority of the factors considered, however, the view on "PUBLIC SERVICE" between the two groups is quite different.

Furthermore, for a given verbal expression of the relative desirability of a design frequency or the relative importance of a factor, it does not have a unique numerical value corresponding to it. Referring to Figure 11.8(a) as an example, among a total of 5,470 cases of evaluating "VERY DESIRABLE" in the questionnaires analyzed, there are 174 cases giving it a numerical rating of 7, 793 cases assigning 8, 830 cases assigning 9, and 3,673 cases assigning 10. The parentheses in the figure indicates the percentage of total cases giving a certain numeric rating for a specified verbal rating. Figure 11.8(a) thus indicates that there are some degrees of vagueness and inexactness in evaluating individual preferences.

Instead of using a single value such as the averaged numerical rating for each verbal rating, the uncertainty of the numerical scale associated with the verbal rating by different individual can be considered. In this study the ratings to be used for each cell R_{ij} in the information matrix are "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE". The last row, W_j, indicates the relative importance of each factor considered in the problem which is expressed as "VERY IMPORTANT", "IMPORTANT", and "LESS IMPORTANT". From Figures 11.7 and 11.10, it is realized that there exists certain degree of vagueness in each of the verbal rating in that the numerical rating associated with a verbal rating is not unique. Consequently, the verbal ratings such as "IMPORTANT" and "LESS DESIRABLE" can be considered as fuzzy variables. The new concept of fuzzy set theory was used in this study to incorporate the possible variations in ratings of desirability and importance in MADM for selecting an extended-LTEC design flood frequency.

In the conventional fashion, using the SAW method for MADM requires decision-makers to specify a unique numerical value indicating their degree of desirability and importance for a design frequency and factor under consideration. Decision-makers may feel uneasy about the exact nature of this rating assignment as required by the conventional SAW method. This is because no flexibility is allowed for decision-makers to use different numerical values reflecting their inexactness toward the rating. Therefore, fuzzy set theory allows one to handle situations where terms with ambiguity, inexactness, and vagueness such as "DESIRABLE", "VERY DESIRABLE", and "LESS IMPORTANT" are used to rate the desirability and relative importance. The fuzzy set theory is applied to problems where the sources of uncertainty are non-statistical in nature. In many situations it may be more appropriate to consider the possibility of an event occurring rather than calculating its probability. This approach also results in consistent findings between different engineers as it integrates differences in their personal preference under the given site conditions.

12.2 FUZZY SET THEORY AND ITS APPLICATIONS TO MADM

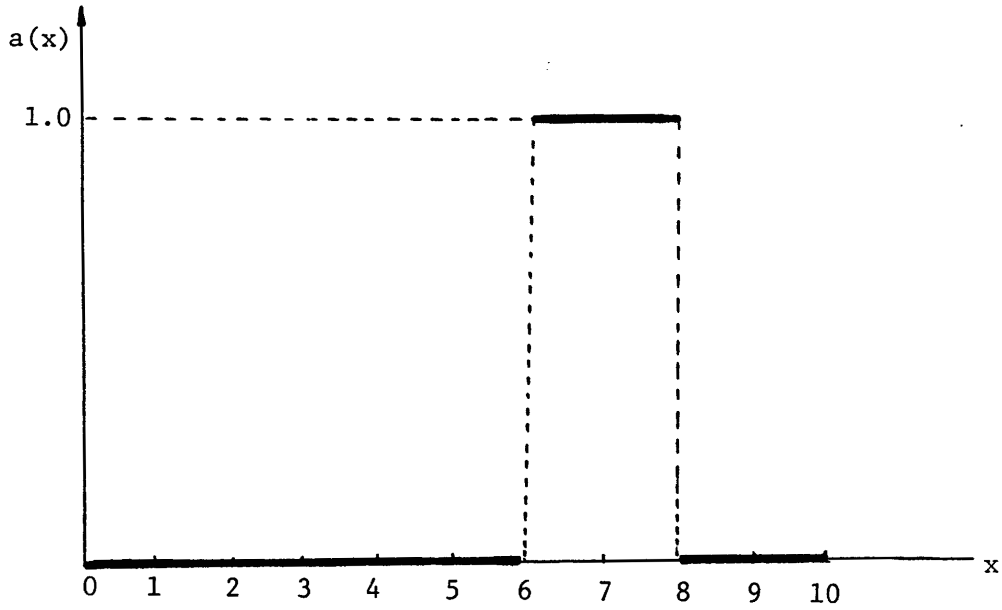
Fuzzy set theory is a generalization of the conventional set theory which considers that an object can only be classified into one of two categories. Consider the problem at hand where numerical values from [0,10] are to be assigned to the verbal rating "IMPORTANT". In the conventional set theory, one might conceive:

> Important, if the numerical value x $\in$ [6,8] and
> Otherwise, if the numerical value x $\notin$ [6,8].

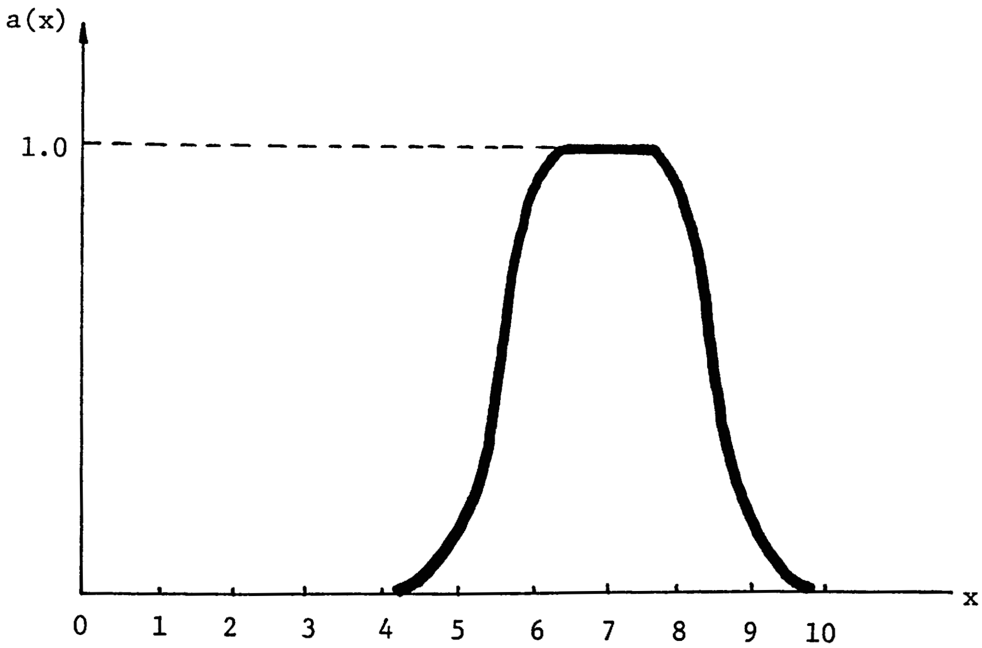
This crisp and exact fashion of categorizing the terms "IMPORTANT" by the conventional set theory can best be shown in Figure 12.1(a). The vertical axis represents the membership function of different numerical values being classified as "IMPORTANT" in which $a(x)=1$ indicates that the corresponding x is "IMPORTANT" whereas $a(x)=0$ indicates otherwise.

On the other hand, fuzzy set theory allows the membership function value a(x) to lie between 0 and 1 for indicating the degree of one's belief that the corresponding numerical value x is to be considered as "IMPORTANT". As a result, the membership function may not have sharp corners (Figure 12.1(b)) when compared with that for the conventional set theory.

Based on the survey results presented in Chapter 11, the membership functions for linguistic ratings "VERY IMPORTANT", "IMPORTANT", and "LESS IMPORTANT" are given in columns (2)-(4) of Table 12.2 and are shown in Figure 12.2(a). Note that the membership functions plotted in Figure 12.2(a) for relative importance were derived from Figure 11.6 after the peak values are normalized to unity. With only three rating classes for relative importance and with "VERY IMPORTANT" being the upper extreme rating, the shape of the membership function for "VERY IMPORTANT" should behave a monotonic non-decreasing function. That is, the ordinate of membership function for "VERY IMPORTANT" at $x=10$, in theory, should be at least as high as that at $x=9$. Therefore, $a_{VI}(x=10)$ was adjusted to unity. Furthermore, those cases observed to have very low numerical ratings for "VERY IMPORTANT" were considered unreasonable. Instead of dropping them from the data set, they were lumped into the numerical rating at $x=6$. For the verbal rating "IMPORTANT", the cases observed at the two extremes at $x=2$ and $x=9$, 10 were lumped into $x=3$ and $x=8$, respectively. Similarly, cases observed for "LESS IMPORTANT" at $x=0$ and $x=1$ were lumped into $x=2$ resulting of membership of unity at $x=2$, i.e., $a_{LI}(x=2)=1$. Due to the fact that "LESS IMPORTANT" is the lower extreme of the three-class rating, the membership function of "LESS IMPORTANT" should be a monotonically non-increasing function. Therefore, the membership function values for "LESS IMPORTANT" at $x=0$ and $x=1$ were set at unity. Similarly,



(a) Membership function for the conventional set



(b) Membership function for the fuzzy set

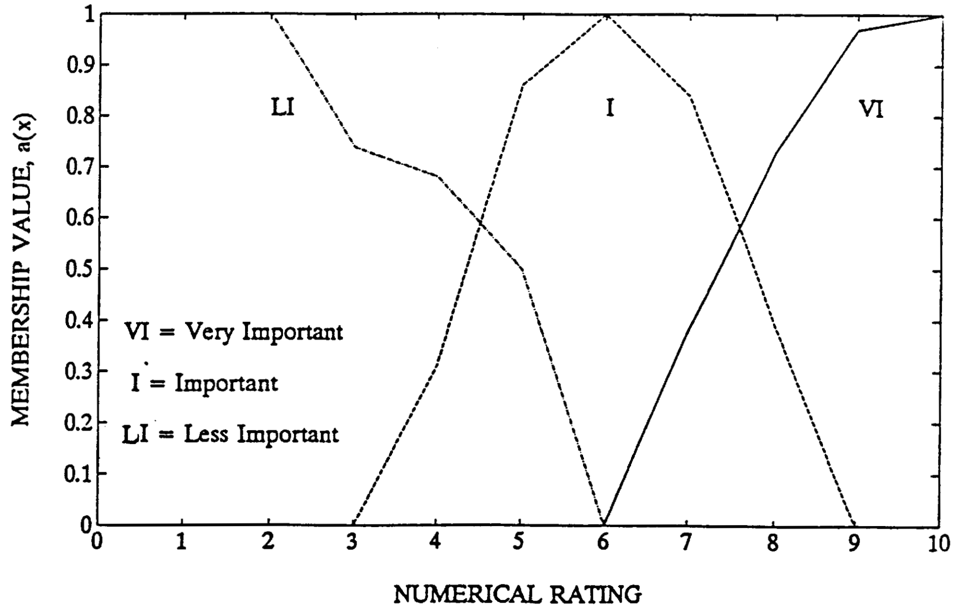
Figure 12.1 Comparison of Membership Functions Between the Conventional Set and Fuzzy Set.

Table 12.2 Membership Functions for Verbal Ratings

x	Relative Importance			Relative Desirability		
	VI	I	LI	VD	D	LD
0.0	0.00	0.00	1.00	0.00	0.00	1.00
1.0	0.00	0.00	1.00	0.00	0.00	0.85
2.0	0.00	0.00	1.00	0.00	0.00	0.66
3.0	0.00	0.00	0.74	0.00	0.00	0.50
4.0	0.00	0.31	0.68	0.00	0.28	0.34
5.0	0.00	0.86	0.50	0.00	0.75	0.21
6.0	0.00	1.00	0.00	0.00	1.00	0.00
7.0	0.38	0.84	0.00	0.07	0.83	0.00
8.0	0.73	0.39	0.00	0.22	0.36	0.00
9.0	1.00	0.00	0.00	0.49	0.00	0.00
10.0	1.00	0.00	0.00	1.00	0.00	0.00

Note: VI = Very Important; VD = Very Desirable
I = Important ; D = Desirable
LI = Less Important; LD = Less Desirable

(a) For Relative Importance



(b) For Relative Desirability

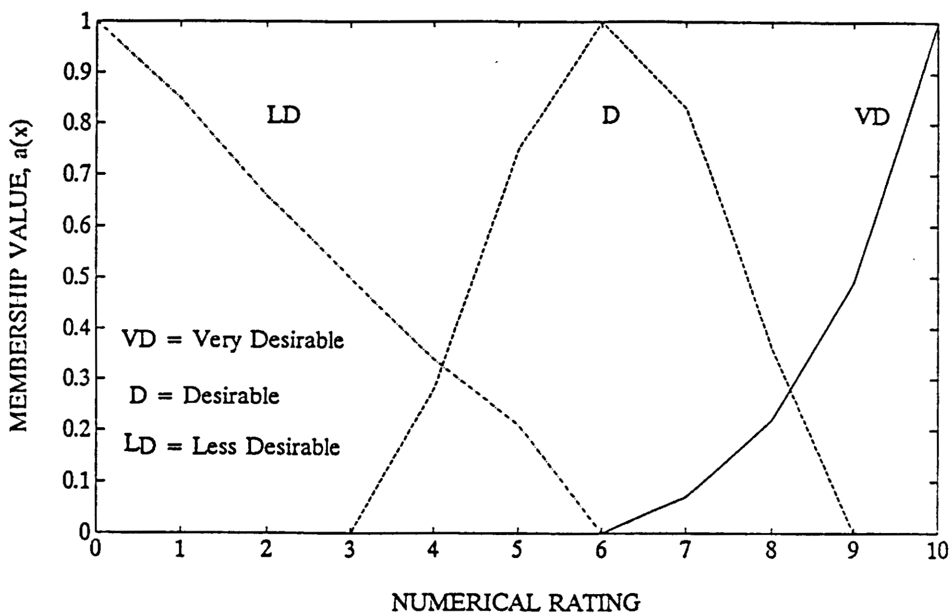


Figure 12.2 Membership Functions for Verbal Ratings.

based on Figure 11.10, the membership function curves for verbal rating on relative desirability as shown in Figure 12.2(b) were obtained in the same fashion. The results are tabulated in columns (5)-(7) of Table 12.2 and shown in Figure 12.2(b).

12.3 FUZZY ALGEBRA

The verbal ratings used for desirability of different design frequencies in this study are treated as fuzzy variables. Like ordinary variables in algebra, they can be used for arithmetic operations such as addition, subtraction, multiplication, and division. However, due the inexact nature of the fuzzy variables, these basic algebraic operations have to be modified. Using the SAW method for MADM, the algebraic operations include addition, multiplication, and division.

Fuzzy addition, fuzzy multiplication, and fuzzy division are all based on the max-min principle (Zimmermann, 1991; Klir and Folger, 1988). For example, consider two fuzzy variables A and B whose membership functions are integer-valued defined over the interval [0,10], that is, [0, 1, 2, 3,...., 8, 9, 10], $A=\{ a(x) \mid 0 \leq x \leq 10 \}$, $B=\{ b(y) \mid 0 \leq y \leq 10\}$

$$A(+)B\ (z) = \text{Max}[\ \text{Min}(a(x),b(x)) \mid z=[x+y],\ 0 \leq x,y \leq 10\ ] \qquad (12.2)$$

$$A(*)B\ (z) = \text{Max}[\ \text{Min}(a(x),b(x)) \mid z=[x*y],\ 0 \leq x,y \leq 10\ ] \qquad (12.3)$$

$$A(:)B\ (z) = \text{Max}[\ \text{Min}(a(x),b(x)) \mid z=[x/y],\ 0 \leq x,y \leq 10\ ] \qquad (12.4)$$

in which $[x \circ y]$ represents the integer-valued result from the operator ' $\circ$ ' applied to x and y. Taking fuzzy addition as an example, referring to Eq.(12.2), the degree of membership of z in A(+)B is determined by considering all possible pairs (x,y) whose sum is equal to z and by comparing the degree of membership of each pair. For example, if z=3, the degree of membership of A(+)B(z=3) would be the result of the following operations.

$$\text{Max}\ \{\ \min[a(0),b(3)],\ \min[a(1),b(2)],\ \min[a(2),b(1)],\ \min[a(3),b(0)]\ \}$$

The minimum of the membership value for each pair is first selected and, then, the largest value of the four minima are taken to be the degree of membership for A(+)B(z=3). The same principle applies to fuzzy multiplication and division.

Note that when fuzzy variables A and B are defined over {0,1,2, ..., 9,10}, A(+)B is also a fuzzy variable defined over the set of integers from 0 to 20, A(*)B is defined over the integer set from 0 to 100, and A(:)B is defined over the integer set from 0 to 10 by deleting any element not over an integer base.

The membership functions associated with the different verbal ratings of desirability to be used in the SAW method can be determined in two ways. The first way is to adopt the membership function as shown in Table 12.2 for whichever of the three desirability ratings has the highest likelihood of being chosen according to the discriminant function. For example, if the likelihood values for verbal ratings "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE" are 0.5, 0.3, and 0.2, respectively, the membership function adopted will be the one for "VERY DESIRABLE". The second way is to use a omposite membership function in which the three membership functions are weighted by their respective likelihood value. Referring to the above example, the composite membership function f(x) is

$$f(x) = 0.5\ VD(x) + 0.3\ D(x) + 0.2\ LD(x),\ for\ 0 \le x \le 10 \qquad \textbf{(12.5)}$$

in which VD(x), D(x), and LD(x) are membership functions for "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE", respectively.

12.4 DETERMINATION OF MEMBERSHIP FUNCTION FOR VERBAL RATINGS

A computer program FUZZY.FOR was developed to determine the extended-LTEC design frequency by performing the fuzzy MADM. Again, like the program LTEC.FOR, the program FUZZY.FOR is a working tool for computing the at-site extended-LTEC design frequency. It was applied to various site conditions in the synthesized data base. The inputs to the program are site characteristics given in Table 12.3. The specified site conditions are used in the discriminant functions, i.e., Eqs.(11.1) and (11.2), for determining the likelihood

Table 12.3 Input Site Conditions for Program FUZZY.FOR

VARIABLE NAME	DESCRIPTIONS
nLOC	Location of the drainage structural site. 1 for urban area; 2 for rural area
nST	Structure type at the site. 1 for Bridge 2 for Culvert
nADT	Average daily traffic at the site. 1 if < 750; or 2 if 750 - 5000; or 3 if > 5000
nDETR	Length of the detour at the site. 1 if < 5 miles; or 2 if 5-20 miles; or 3 if > 20 miles
nFHT	Fill height where overtopped at the site. 1 if < 8 ft; or 2 if 8 - 20 ft; or 3 if > 20 ft
nLAND	Land use type at the site. - Rural Areas: 1 for desert or prairie; 2 for irrigated meadow; 3 for farm or ranch; - Urban Areas: 1 for Rec area w/out buildings; 2 for 1-3 residential buildings; 3 for more than 3 residential buildings

(see Eqs.(11.3) and (11.4)) of each combination of design frequency and the three intangible factors considered as being "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE". As for the factor "TOTAL COST", the at-site LTEC design frequency and the percentage of incremental cost associated with the non-LTEC design frequencies are identified and computed from the program LTEC.FOR. With respect to the factor "TOTAL COST", the relative desirability of different design frequencies as affected by thepercentage of incremental cost and site conditions are determined by the discriminant function shown in Eq.(11.6) derived based on the survey results.

12.5 SELECTION OF EXTENDED-LTEC DESIGN FREQUENCY

Because of the inexact nature of the ratings for relative desirability and importance, the selection of the optimal design frequency considering all four factors is not a trivial task. Once the membership function of the final rating for each design frequency is obtained, the selection of the optimal extended-LTEC design frequency can be made based on some 'distance' criteria between the final membership function of a design frequency and that of "VERY DESIRABLE". In this study, the least Euclidean distance or least metropolitan distance criteria were used.

Using the Euclidean distance criterion, one calculates the Euclidean distances between the final membership function associated with each design frequency and the membership functions for "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE" (Klir and Folger, 1988). That is,

$$D_E(i) = \sqrt{\sum_{x=0}^{10} \left[f_i(x) - h(x)\right]^2}, \; for \; i=1,2,...,7 \qquad (12.6)$$

in which $D_E(i)$ is the Euclidean distance between the final membership function for the i^{th} design frequency $f_i(x)$ and that for the particular desirability ratings h(x) under consideration.

The second criterion, metropolitan distance (or called Hamming distance) $D_M(i)$, can be determined as

$$D_M(i) = \sum_{x=0}^{10} | f_i(x) - h(x) |, \; for \; i = 1,2,...,7 \tag{12.7}$$

Figure 12.3 illustrates the idea of Euclidean distance and Metropolitan distance in a three-dimensional space between the two points A and B. Based on the numerical values of $D_E(i)$ and $D_M(i)$ for the i^{th} design frequency, the linguistic rating associated with the shortest distance will be used as the rating for the extended-LTEC design return period.

12.6 AN EXAMPLE

Consider the case that a box culvert in a urban area is to be designed. Through the LTEC analysis, the LTEC design frequency is 10 years. The site conditions for the culvert location are given in the first block of Table 12.4. The relative importance of all four factors (i.e., total cost, maintenance frequency, litigation potential, and public service), as the designer's personal opinion, are all regarded as "VERY IMPORTANT". The percentages of incremental cost associated with the non-LETC frequencies over that of the LETC frequency, obtained from the LTEC analysis, are also given in the last block of Table 12.4.

Based on the information given, the linguistic ratings and their corresponding likelihoods for the seven different design frequencies under the four factors are shown in Table 12.5(a). Table 12.5(a) contains the results from using the composite membership function with likelihoods as the weights. The top part of Table 12.5(a) shows the likelihood of each (design frequency, factor) pair being rated "VERY DESIRABLE", "DESIRABLE", and "LESS DESIRABLE" under the specified site condition according to the results of analyzing survey data. For example, consider the pair (25-yr, litigation potential), the use of composite membership leads to a likelihood of 43% being rated as "VERY DESIRABLE", 40% for "DESIRABLE", and 17% for "LESS DESIRABLE".

The lower half of Table 12.5(a) show the Euclidean and metropolitan distances of each design frequency being away from the three desirability ratings. Consider the design frequency of 5-yr, this design frequency has a Euclidean distance of 1.3510 away from the verbal rating "VERY DESIRABLE", 1.6078 from "DESIRABLE", and 2.0380 from "LESS DESIRABLE". From this information, one can say that 5-yr design frequency is not desirable because it has the shortest distance to the rating "LESS DESIRABLE" among all three ratings. The symbol # is used to indicate the appropriate rating for each design frequency.

To determine which design frequency is the most preferable as a whole, one can look the column under the verbal rating "VERY DESIRABLE". As can be seen, among all the design frequencies considered, 50-yr is the optimum because it has the shortest distance to the rating "VERY DESIRABLE". Therefore, the extended-LTEC design frequency for the box culvert under consideration is 50-yr. Similarly, the use of metropolitan distance as the criterion yields the same indication. A three-dimensional schematic diagram illustrating the Euclidean distance between a design frequency from three verbal ratings is shown in Figure 12.4.

Table 12.5(b) shows the results of adopting the linguistic ratings based on the maximum likelihood criterion. In other words, the linguistic rating having the highest likelihood value was chosen for the degree of desirability of the item under consideration. As can be seen, the optimal extended-LTEC design flood frequency from the fuzzy MADM is 25 years because this extended-LTEC design frequency has the shortest Euclidean (0.6208) and Metropolitan (0.9000) distance for the "VERY DESIRABLE (VD)" rating. The second best design frequency is 50 years. Conversely, the 2 to 5 year extended-LTEC frequency is unacceptable as it has the shortest distances for the "LEAST DESIRABLE" rating.

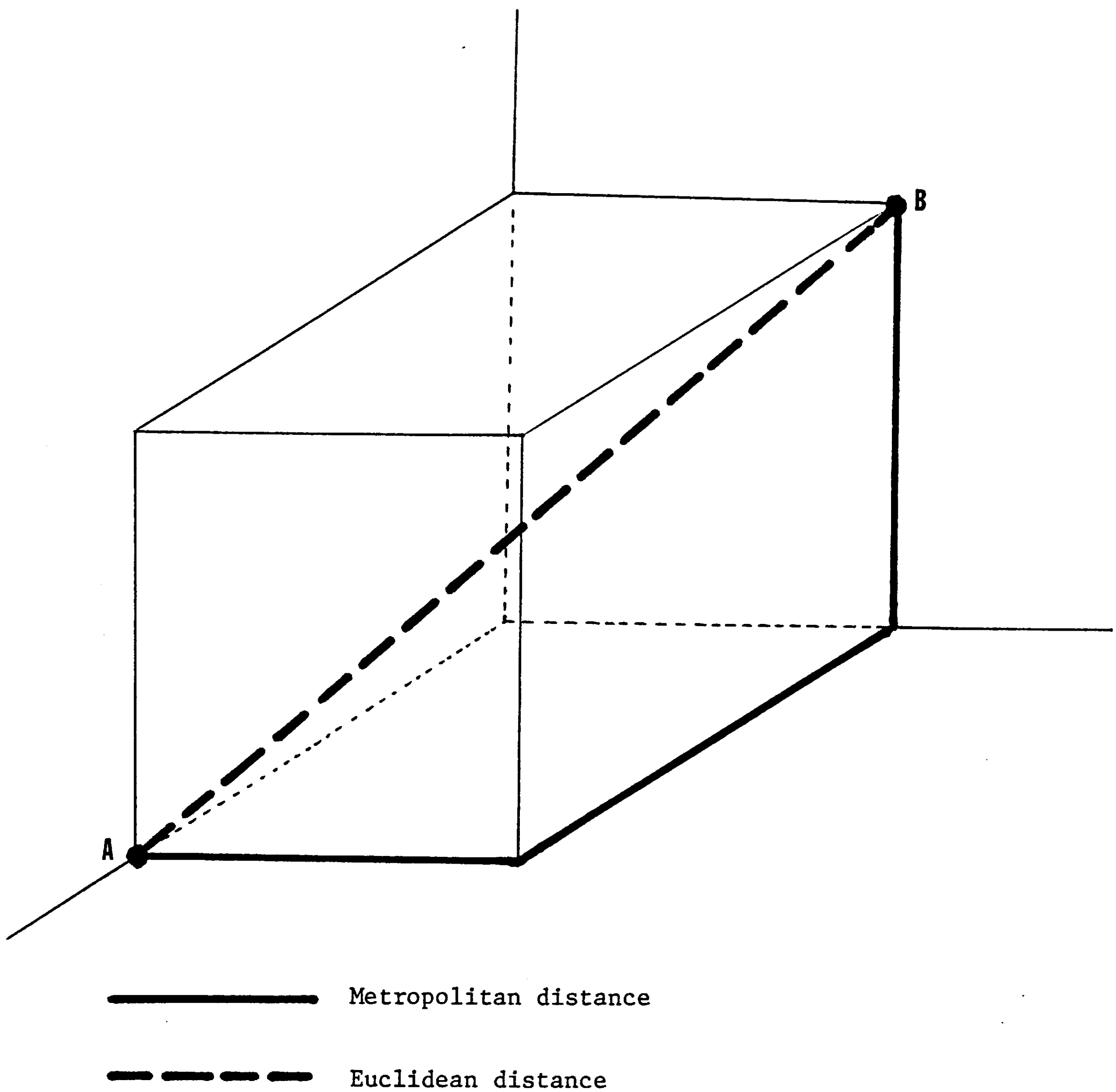
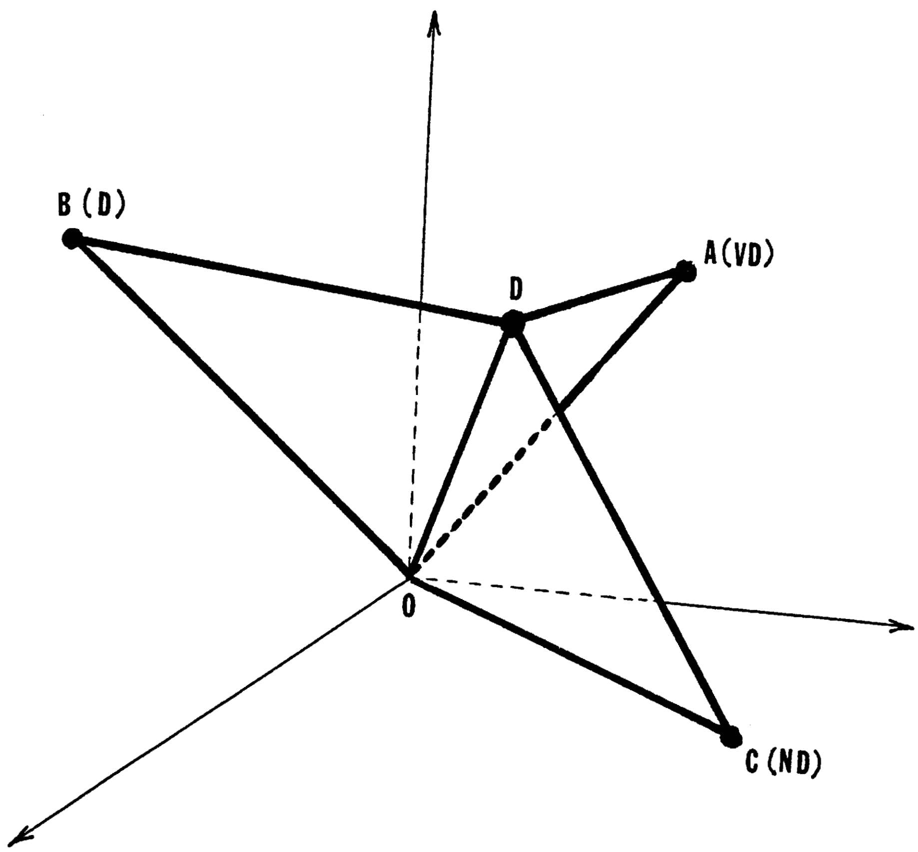


Figure 12.3 Illustration of Euclidean Distance and Metropolitan Distance.



$\overrightarrow{OA}$ = Vector for verbal rating "VD"
$\overrightarrow{OB}$ = Vector for verbal rating "D"
$\overrightarrow{OC}$ = Vector for verbal rating "ND"
$\overrightarrow{OD}$ = Vector of rating for 10-yr design frequency

$|\overrightarrow{DA}|$ = Euclidean distance between points A and D
$|\overrightarrow{DB}|$ = Euclidean distance between points B and D
$|\overrightarrow{DC}|$ = Euclidean distance between points C and D

Figure 12.4 Schematic Diagram Illustrating Euclidean Distance Between A Design Frequency and Different Verbal Ratings.

Table 12.4 Example Inputs to Program FUZZY.FOR

```
SITE CONDITIONS:

   LOCATION                  =    Urban
   STRUCTURE TYPE            =    Box Culvert
   AVERAGED DAILY TRAFFIC    =    1500
   DETOUR LENGTH             =    10 miles
   FILL HEIGHT               =    16 feet
   LAND USE                  =    1 residential building

RELATIVE IMPORTANCE FOR THE FOUR FACTORS ARE:

   (1) DRAINAGE STRUCTURE COST:    Very Important
   (2) MAINTENANCE FREQUENCY  :    Very Important
   (3) LITIGATION POTENTIAL   :    Very Important
   (4) PUBLIC SERVICE         :    Very Important

LTEC DESIGN FREQUENCY = 10.0 YEARS

PERCENTAGE OF INCREMENTAL COST:

   2-YR    5-YR    10-YR   25-YR   50-YR  100-YR  200-YR
      0       0        0      50     100     200     300
```

Table 12.5(a). Example Results From FUZZY.FOR Using Weighted Membership Function

Design Freq.	Economic Factor			Maintenance Frequency			Litigation Potential			Public Service		
	VD	D	LD	VD	D	LD	VD	D	LD	VD	D	LD
2 yr	(0.00	0.00	1.00)	(0.03	0.06	0.91)	(0.03	0.06	0.91)	(0.03	0.06	0.91)
5 yr	(0.00	0.00	1.00)	(0.03	0.21	0.76)	(0.03	0.21	0.76)	(0.03	0.21	0.76)
10 yr	(1.00	0.00	0.00)	(0.16	0.41	0.43)	(0.16	0.41	0.43)	(0.16	0.41	0.43)
25 yr	(0.50	0.40	0.10)	(0.43	0.40	0.17)	(0.43	0.40	0.17)	(0.43	0.40	0.17)
50 yr	(0.26	0.53	0.21)	(0.55	0.35	0.10)	(0.55	0.35	0.10)	(0.55	0.35	0.10)
100 yr	(0.13	0.40	0.47)	(0.61	0.32	0.08)	(0.61	0.32	0.08)	(0.61	0.32	0.08)
200 yr	(0.08	0.23	0.70)	(0.64	0.30	0.07)	(0.64	0.30	0.07)	(0.64	0.30	0.07)

EUCLIDEAN DISTANCE				METROPOLITAN DISTANCE			
ALT.	RATINGS LD	D	VD	ALT.	RATINGS LD	D	VD
2 yr	1.1483#	1.8471	2.1246	2 yr	2.4464#	4.7318	5.9844
5 yr	1.3510#	1.6078	2.0380	5 yr	3.6897#	4.1314	5.9554
10 yr	2.7415	1.6610#	2.3118	10 yr	8.7168	4.2068#	6.2030
25 yr	2.4678	1.5125#	1.5851	25 yr	7.3178	3.6094#	4.3386
50 yr	2.5619	1.6064	1.4915#*	50 yr	7.6557	3.8110#	3.8262*
100 yr	2.5456	1.3482#	1.6178	100 yr	7.6659	3.0843#	4.2162
200 yr	2.4547	1.1600#	1.6441	200 yr	7.3332	2.7819#	4.4281

Note: # suggests the best verbal rating for the design frequency under consideration.
* suggests the best extended-LTEC design frequency.

Table 12.5(b) Example Results From FUZZY.FOR Using Membership Function with the Maximum Likelihood.

Design Freq.	Economic Factor			Maintenance Frequency			Litigation Potential			Public Service		
	VD	D	LD	VD	D	LD	VD	D	LD	VD	D	LD
2 yr	(0.00	0.00	1.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)
5 yr	(0.00	0.00	1.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)
10 yr	(1.00	0.00	0.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)	(0.00	0.00	1.00)
25 yr	(1.00	0.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)
50 yr	(0.00	1.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)
100 yr	(0.00	0.00	1.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)
200 yr	(0.00	0.00	1.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)	(1.00	0.00	0.00)

EUCLIDEAN DISTANCE				METROPOLITAN DISTANCE			
Design Freq.	RATINGS			Design Freq.	RATINGS		
	LD	D	VD		LD	D	VD
2 yr	1.1176#	1.9464	2.1973	2 yr	2.0147#	4.8753	6.1147
5 yr	1.1176#	1.9464	2.1973	5 yr	2.0147#	4.8753	6.1147
10 yr	1.8549	1.4962#	2.4765	10 yr	4.9772	3.5778#	6.9972
25 yr	2.3336	1.9174	0.6208#*	25 yr	6.9400	4.7700	0.9000#*
50 yr	2.5120	1.7711	0.9570#	50 yr	7.7900	4.3400	1.7500#
100 yr	2.4782	1.2329#	1.4181	100 yr	7.6726	3.0826#	3.3474
200 yr	2.4782	1.2329#	1.4181	200 yr	7.6726	3.0826#	3.3474

Note: # suggests the best verbal rating for the design frequency under consideration.
* suggests the best extended-LTEC design frequency.

13.
CONSTRUCTION OF DATA BASE FOR LTEC/EXTENDED-LTEC DESIGN FREQUENCIES AND SITE CONDITIONS

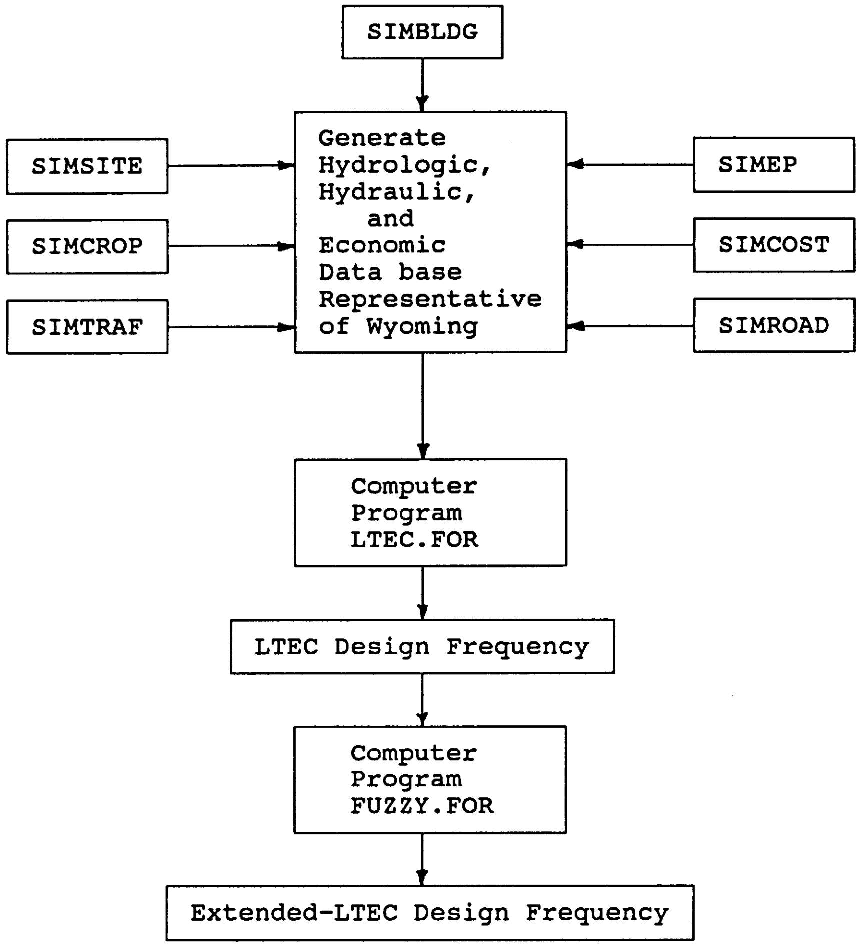
One of the major goals of this study is to develop a guideline to complement existing WDT Policy 18-6 for determining the appropriate design frequency for Wyoming highway drainage structures. This guideline should provide a mechanism to determine the LTEC and extended-LTEC design frequencies based on the hydrologic and hydraulic conditions, and various tangible and intangible factors of the site under consideration. From the descriptions given in previous chapters, the program LTEC.FOR is for determining the at-site LTEC design frequency whereas the program FUZZY.FOR further determines the corresponding extended-LTEC design frequency for the site by incorporating three intangible factors including maintenance frequency, litigation potential, and public service. One can run the two programs in tandem to obtain the LTEC and extended-LTEC design frequencies for a given site under consideration. The task could be computational intensive if a design engineer has to evaluate or review several drainage structural designs. Furthermore, in the preliminary design stage, hydraulics engineers are perhaps uncertain about the many of the inputs and parameters to be used in highway drainage structural design. Then, investigation of the effects of uncertainties in various design inputs and parameters on the appropriate design frequency could be important task. In this case, the use of program LTEC.FOR and FUZZY.FOR for such uncertainty and sensitivity analyses is not practical.

Consequently, as an alternative approach, empirical formulas that relate the LTEC and extended-LTEC design frequencies to various site conditions can be developed. The idea is similar to those of developing empirical hydraulic response equations for highway drainage structures as described in Chapter 7. The use of such empirical equations would greatly reduce the computational burden and allows quick evaluation of the appropriate design frequency and enhance the design efficiency. To achieve this objective, data bases to which the programs LTEC.FOR and FUZZY.FOR will be applied to obtain the LTEC and the corresponding extended-LTEC design frequencies must be established. It is important that the site conditions to be generated in the data bases must be of representative of Wyoming. Otherwise, the resulting empirical equations would be little value for drainage structure design in Wyoming. Therefore, the data bases to be synthesized for developing these empirical working equations must be constructed to contain hydrologic, hydraulic, and economic conditions representative to the State of Wyoming. For this purpose, a working computer program, called SIMPRO.FOR, was developed to generate synthetic site conditions and prepare input files for programs LTEC.FOR and FUZZY.FOR. A list of the subroutines in the program SIMPRO.FOR and brief statements of their function is given in Table 13.1. Figure 13.1 is a flowchart illustrating the overall algorithm of the approach. The following sections describe the elements in SIMPRO.FOR and their background.

Referring to the basic theory of the LTEC analysis presented in Chapter 2, it is understood that the LTEC design frequency for a given site depends on the various tangible economic factors, hydraulics, and hydrology at the site. Specifically, the hydrological flood frequency relation at the drainage structure site is an important factor affecting the LTEC design frequency. For the State of Wyoming, two sets of regional flood frequency relationship were developed (Druse et al., 1988). Limited investigations indicated that the regional frequency curve from the basin-characteristics method may be quite different from the one using channel-geometry method. Additionally, flood data are sometimes available at the structure site from which flood frequency relationship can be derived. In this situation, the hydraulics engineer may wish to select a unique site specific flood frequency relationship for use in the LTEC analysis. This site specific relationship could be different from those provided by the regional relationships. Consequently, for a given drainage structure site in Wyoming, there could be two or three different LTEC design frequencies from which to choose depending on the frequency relationship selected for use in the LTEC analysis. Because of the potential problem related to the channel-geometry flood frequency relationship as indicated in Table 8.5 for mountainous regions coupled with the fact that for this project it is computationally impractical to develop data bases for different flood frequency relationships, the basin-characteristics method is adopted in the program LTEC.FOR as the base-line flood frequency relationship. This base-line flood frequency relationship is modified to conform to a preferred flood frequency relationship from which the LTEC design frequency is sought. In Section 5 of Chapter 14, a simple mechanism developed for this purpose is described that estimates the LTEC design flood frequency corresponding to flood frequency curve other than that defined by the basin-characteristics method.

Table 13.1 List and Brief Descriptions of Subroutines in SIMPRO.FOR

No.	Name	Functions
1	SIMSITE	To generate data base for synthetic drainage basin representative of the State of Wyoming
2	SIMCROP	To generate data base for no. of crops, crop type, and irrigation condition.
3	SIMEP	To generate the data base for embankment soil type, vegetal cover, overflow type.
4	SIMTRAF	To generate traffic related data base including ADTE, detour distance, repair rate, accident rate, etc.
5	SIMBLDG	To generate the data base for buildings in floodplain such as their type, value, and location.
6	SIMCOST	To generate the data base for unit cost of concrete, steel, pavement, embankment, bridge, interest rate, expected project life, etc.
7	SIMROAD	To generate data base for road information such as structure type and size, no. of lanes, lane width, shoulder width, pavement thickness, etc.
8	SIMIMP	To generate the data base for relative importance of four factors affecting extended-LTEC frequency.



<u>Explanations:</u>

SIMBLDG - Generate data of buildings on flood plain.
SIMSITE - Generate hydraulic and hydrologic conditions at structural site.
SIMCROP - Generate crop data
SIMTRAF - Generate traffic data.
SIMEP - Generate data for embankment.
SIMCOST - Generate unit cost data.
SIMROAD - Generate data for roadway geometry.

Figure 13.1 Diagram Illustrating the Algorithm of Generating Synthetic Site Data Base.

13.1 GENERATION OF SYNTHETIC DRAINAGE SITES

Based on the basin/channel characteristics collected in Chapter 5, the selection of appropriate synthetic drainage sites representative of Wyoming drainage basins is possible. However, the characterization of such synthetic drainage sites on which the LTEC analysis is to be performed should not be postulated arbitrarily. The reason is that, in reality, basin/channel characteristics are not entirely independent. As a result, Monte Carlo simulation in amultivariate setting was applied to generate such synthetic drainage sites. In doing so, correlation structures between relevant basin/channel characteristics such as basin area, channel slope, channel top width, and top width-depth ratio can be preserved. Consequently, unrealistic synthetic drainage sites will not be generated.

The first step in the multivariate simulation to generate synthetic drainage sites is to examine the statistical properties of the relevant basin/channel characteristics including their correlation structures. Based on all the available data collected in Chapter 5, the statistical properties of the relevant basin/channel characteristics and their correlations are shown in Tables 13.2 and 13.3. It should be pointed out that the summary of the statistics and correlation matrix shown in Tables 13.2 and 13.3, respectively, are for the log-transformed variables. The reason for using the log-transformed variables was that the transformed data are much closer to the normal distribution than are the original data (Figures 13.2a-f). Log-transformation of the basin/channel variables leads to a much more symmetric distribution. This observation further facilitates the use of readily available multivariate normal random variate generation.

A simple hypothesis test was performed to assess whether the true correlation coefficient ρ between each pair of basin/channel characteristics (on the log scale) is zero. That is, the hypothesis test problem considered is

$$H_o\text{: } \rho = 0 \quad \text{versus} \quad H_a\text{: } \rho \neq 0$$

Under the normality assumption (which was verified for the log-transformed variables), the test statistic is

Table 13.2 Summary Statistics of Basin/Channel Characteristics at Log-Transformed Scale.

	N	Mean	STDEV
ln(W)	413	3.672	0.982
ln(W/D)	410	2.327	0.766
ln(Sr)	311	-3.218	1.357
ln(Sl)	308	-3.211	1.268
ln(DA)	479	3.421	2.141
ln(Sc)	356	4.182	1.330

Note: W = channel top width (ft.)
W/D = channel top width-depth ratio (ft./ft.)
Sr = floodplain slope on the right (ft./ft.)
DA = drainage area (sq. miles)
Sc = channel slope (ft./mile)

Table 13.3 Correlation Matrix of Log-Transformed Basin/Channel Characteristics.

	ln(W)	ln(W/D)	ln(Sr)	ln(Sl)	ln(DA)	ln(Sc)
ln(W)	1.000	0.693*,**	-0.359*,**	-0.214*,**	0.499*,**	-0.498*,**
ln(W/D)		1.000	-0.177*,**	-0.052	0.235*,**	-0.275*,**
ln(Sr)			1.000	0.721*,**	-0.239*,**	0.521*,**
ln(Sl)				1.000	-0.202*,**	0.490*,**
ln(DA)					1.000	-0.533*,**
ln(Sc)						1.000

Note: * = significant at 5%
** = significant at 1%

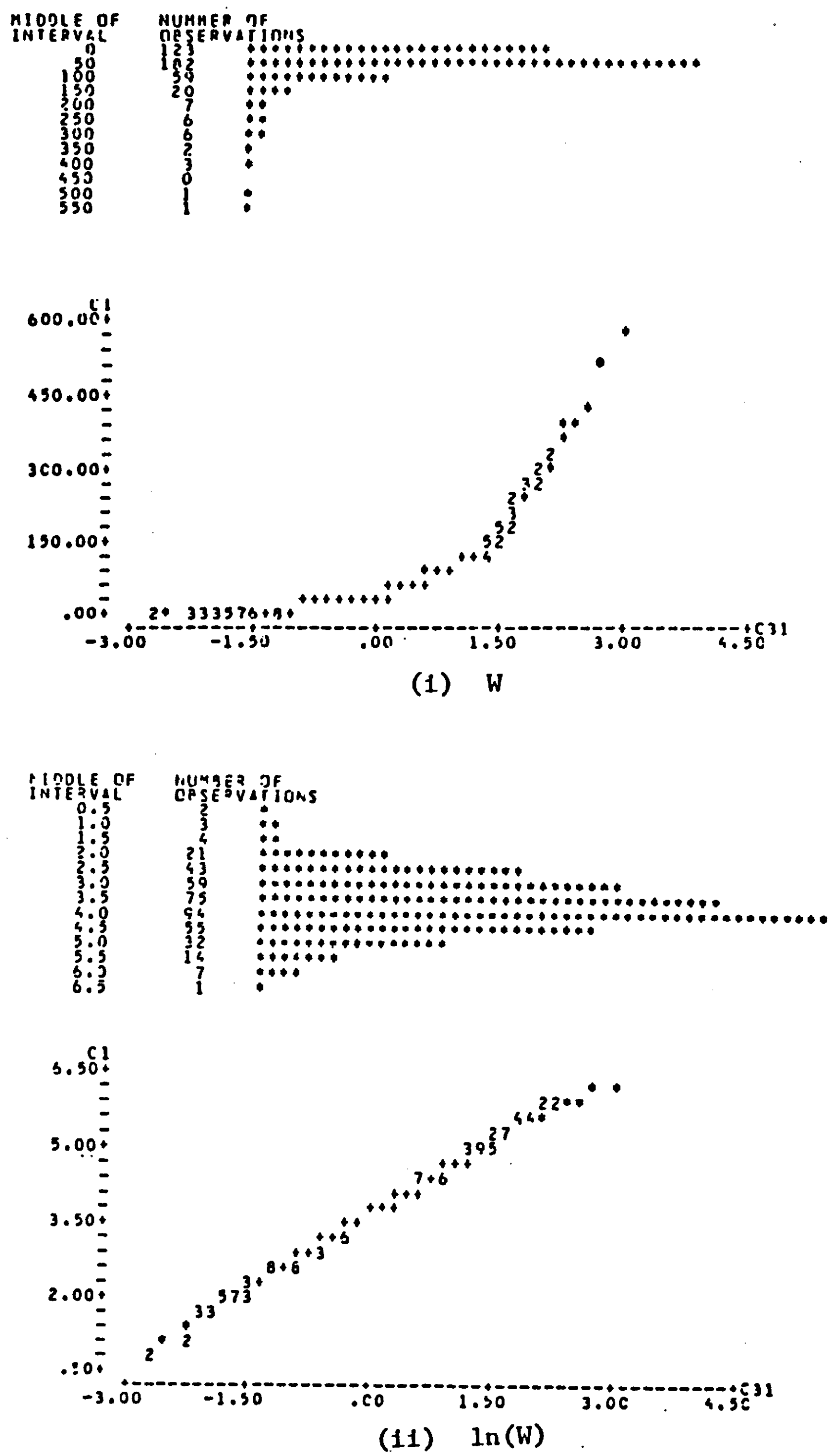
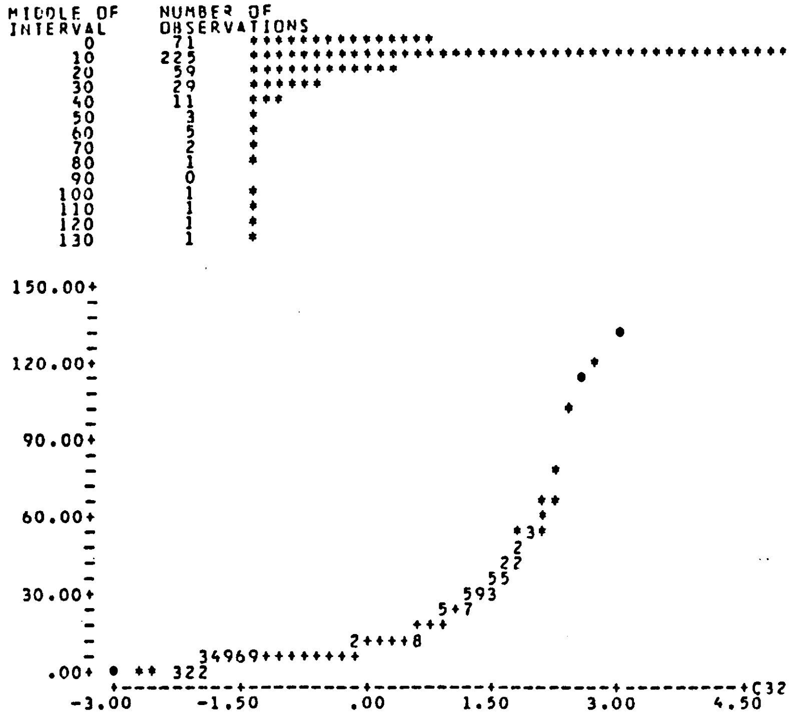
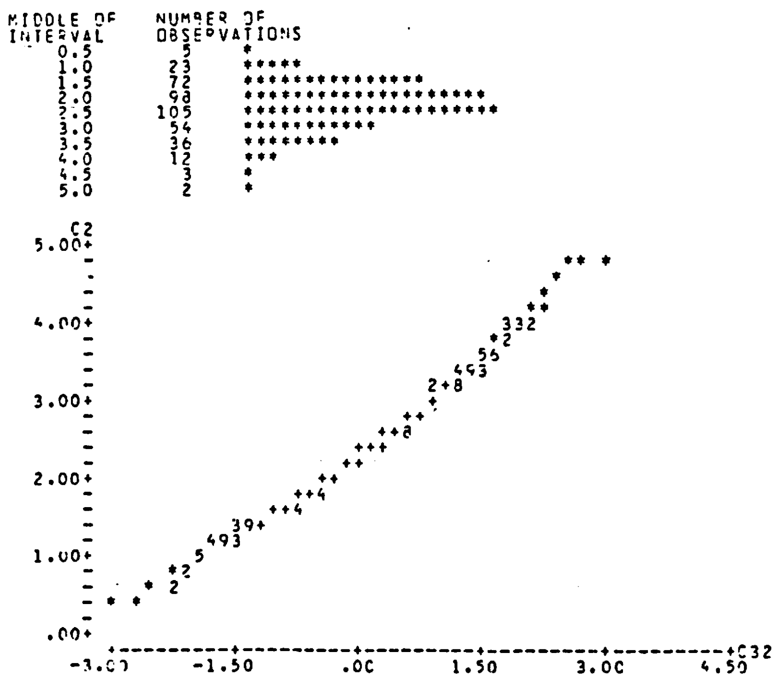


Figure 13.2(a) Histograms and Normal Score Plots for (i) W and (ii) ln(W).



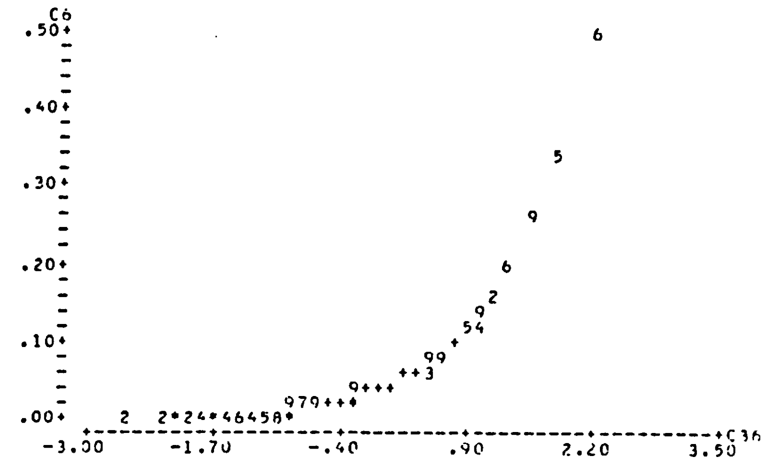
(i) W/D



(ii) ln(W/D)

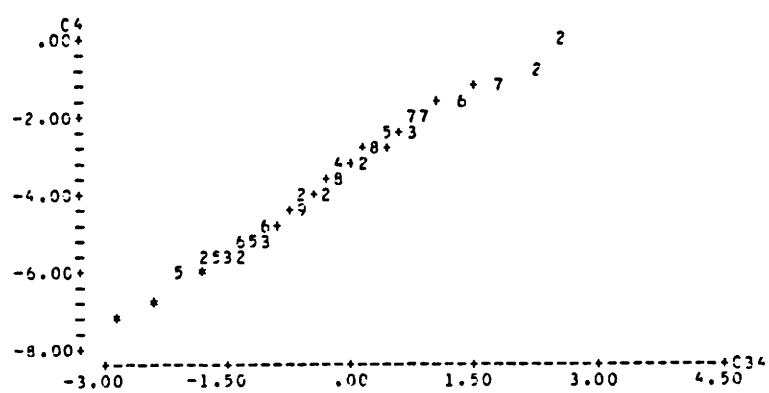
Figure 13.2(b) Histograms and Normal Score Plots for (i) W/D and (ii) ln(W/D).

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
0.00	81
0.05	90
0.10	26
0.15	15
0.20	6
0.25	9
0.30	0
0.35	5
0.40	0
0.45	0
0.50	6



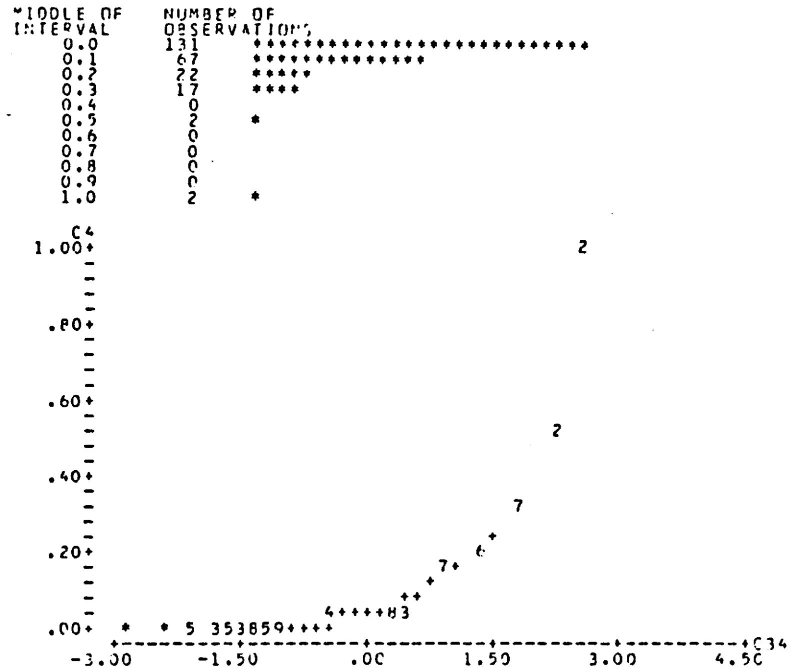
(i) Sr

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
-7.0	1
-6.5	1
-6.0	7
-5.5	17
-5.0	15
-4.5	21
-4.0	26
-3.5	24
-3.0	50
-2.5	22
-2.0	30
-1.5	15
-1.0	7
-0.5	2
0.0	2

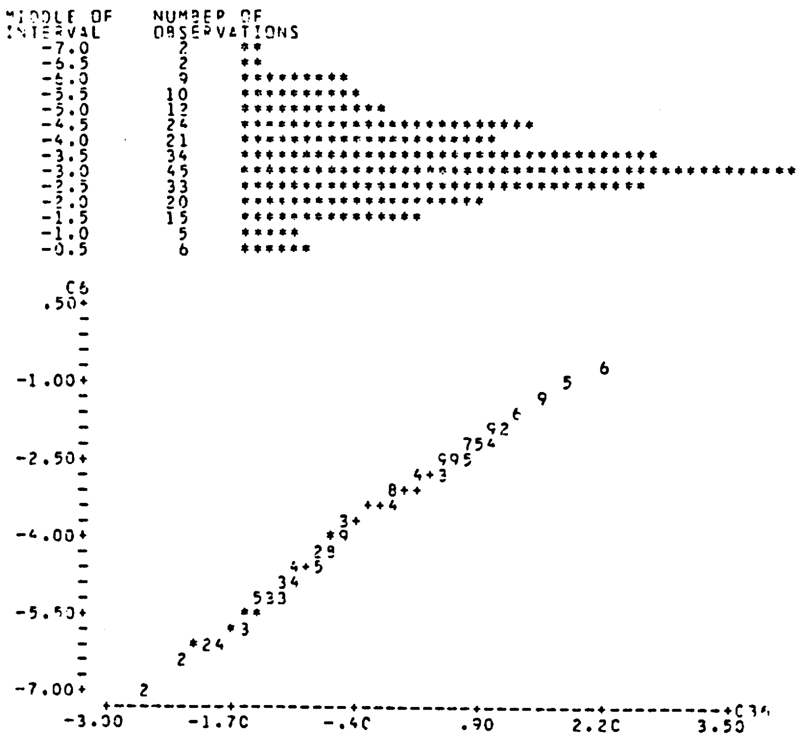


(ii) ln(Sr)

Figure 13.2(c) Histograms and Normal Score Plots for (i) Sr and (ii) ln(Sr).

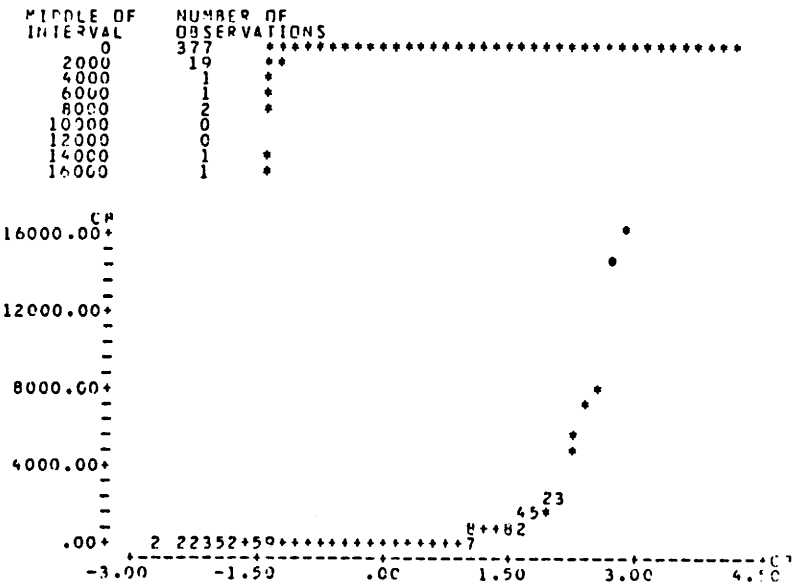


(i) S_1

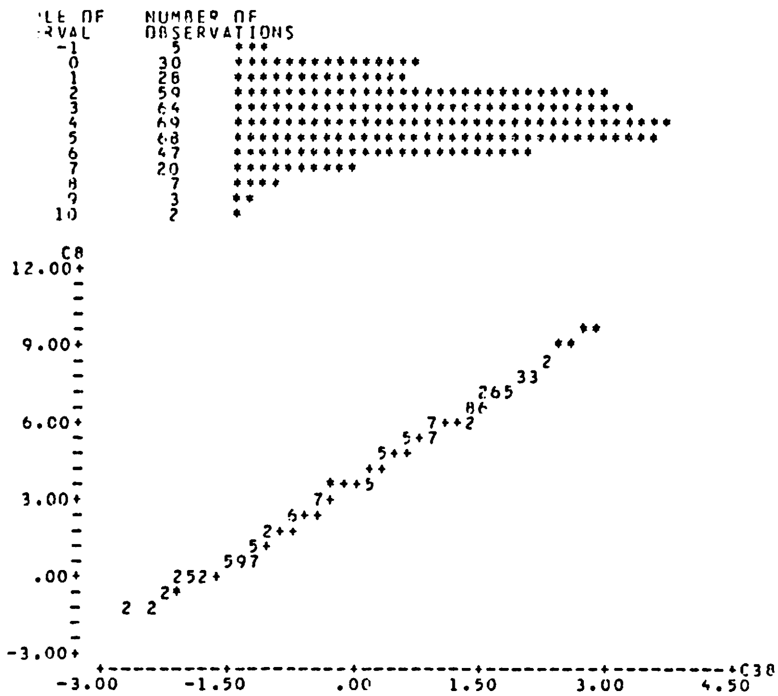


(ii) $\ln(S_1)$

Figure 13.2(d) Histograms and Normal Score Plots for (i) Sl and (ii) ln(Sl).

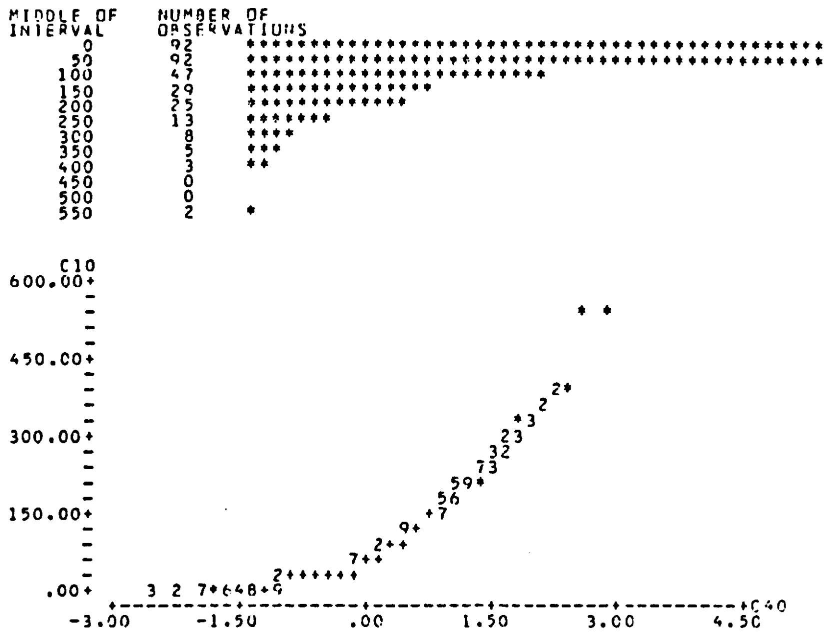


(i) A

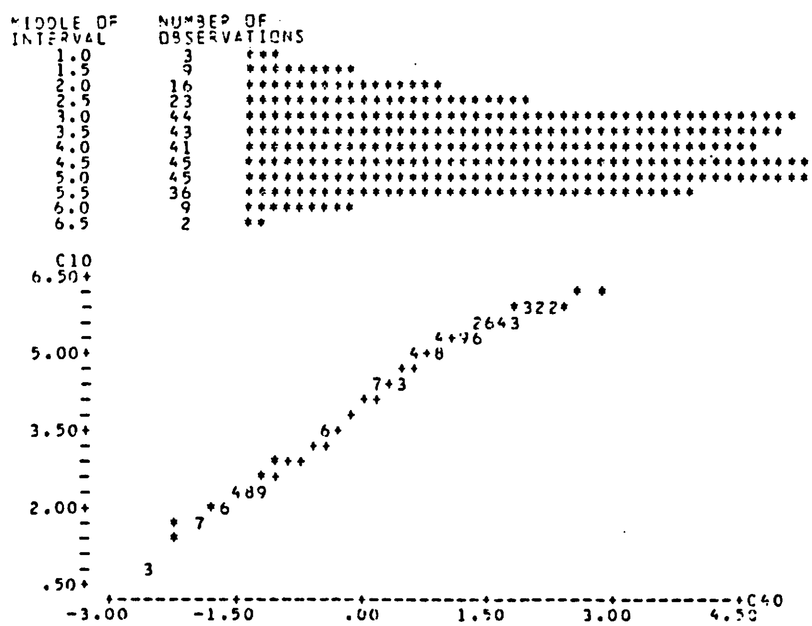


(ii) ln(A)

Figure 13.2(e) Histograms and Normal Score Plots for (i) DA and (ii) ln(DA).



(i) Sc



(ii) ln(Sc)

Figure 13.2(f) Histograms and Normal Score Plots for (i) Sc and (ii) ln(Sc).

$$T = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \tag{13.1}$$

in which the test statistic T has a t-distribution with n-2 degrees of freedom with n being the sample size and r is the sample correlation coefficient between two random variables under consideration. From Table 13.2, it is shown that all pairs except (ln(W/D), ln(Sl)) have statistically significant non-zero correlation coefficients at both the 1% and 5% levels. Based on the correlation matrix shown in Table 13.3, it is possible to generate basin/channel characteristics for the synthetic drainage sites.

To improve the representativeness of the generated results, the site conditions to be generated can follow the classification of hydrologic regions for the State of Wyoming according to a USGS regional flood study (Druse et al., 1988). That is,

(1) Mountainous Region:
Features: - small peak flow large annual runoff
- contributed by snowmelt

(2) Plains Region (Northern and Eastern Plains)
Features: - high peak flow varies from year-to-year
- contributed by rain storm

(3) High Desert Region (South-central and Southwestern Deserts
Features: - peak flow is smaller than region
- contributed by wide spread rain storms and snow.

In the recent regional study by Druse et al. (1988), two methods are used in developing the regional flood-frequency relations: (a) Basin-Characteristic method and (b) Channel-Geometry method. Forms of regression equations that relate flood magnitude to basin or channel characteristics are listed in Table 6.1. The regional hydrological variables considered were: (1) A: drainage area, (2) W: main channel top width, (3) WD: width-depth ratio, (4) SR: floodplain slope on the right-hand side, (5) SL: floodplain slope on the left-hand side, (6) SB: basin slope, and (7) GF: geographic factor.

For the synthetic site data base, variables in the Mountainous Region, A and W were generated by a log-transformed scale while WD, SR, SL, and SB were generated by multiple regression based on A and W. Similarly, for the Plains Region, A, W, GF and SB were generated by a multivariate normal random variate generator while SR, SL, and WD were generated by multiple regression equations. For the High Desert Region, A, W, and GF were generated by a multivariate normal random variates generator while the remaining characteristics were calculated by the regression equations. The data base for assessing statistical properties multivariate normal random variate generator on the additional information from Druse et al. (1988). Statistics of site characteristics and the regression equations develop for the three hydrologic regions were given in Tables 13.4 through 13.6.

The subroutine SIMSITE was developed to generate basin/channel characteristics of synthetic drainage sites representative of Wyoming based on the statistical properties of the above site characteristics. Sample printouts from SIMSITE are shown in Tables 13.7 through 13.9.

13.2 GENERATING AGRICULTURAL DATA BASE

The LTEC analysis considers potential flood damage to crops upstream of roadway crossing. The flood-caused crop damage depends on such things as inundation depth and duration, and crop types and values. Referring to Section 6.1 of this report, there are eight important economic crops in Wyoming, namely, (1) other hay, (2) oats, (3) wheat, (4) alfalfa hay, (5) barley, (6) dry beans, (7) corn-grain, and (8) sugar beets. In addition to these economic crops, range land and desert lands, the more common "crops" found at Wyoming drainage sites, were also considered as two other crop types. The flood damage to economic crops is calculated according to Eq.(6.1) whereas the flood damage to range land and desert lands is simply a fixed amount of dollars multiplied by the area of inundation.

In generating the synthetic data base on crops, subroutine SIMCROP first determines whether the upstream floodplain is a range land, desertland, or crop land. If it is a range land or desert land, no crop will be generated. Otherwise, SIMCROP determines whether the crop land is irrigated or non-irrigated because the crop yields per unit acre are different (Tables 6.1 and 6.2).

Table 13.4 Sample Statistics and Correlation Matrix of Basin Characteristics for Mountainous Regions in Wyoming

(a) Sample Statistics -

Basin Charac.	Mean	Stdev	Basin Charac.	Mean	Stdev
DA	152.21	347.26	ln(DA)	3.9769	1.5224
SB	1086.7	405.46	ln(SB)	6.9088	0.44923
ELEV	8865.6	6000.4	ln(ELEV)	9.0404	0.23958
PR	21.855	6.7708	ln(PR)	3.0403	0.29574
W	41.901	29.672	ln(W)	3.4739	0.79432

(b) Correlation:

	DA	SB	ELEV	PR
SB	0.221			
ELEV	-0.029	-0.024		
PR	0.108	0.383	0.012	
W	0.786	0.547	0.082	0.280

	ln(DA)	ln(SB)	ln(ELEV)	ln(PR)
ln(SB)	0.234			
ln(ELEV)	-0.043	-0.056		
ln(PR)	0.123	0.279	0.204	
ln(W)	0.834	0.422	0.160	0.349

(c) Regression Equations:

Site Variables	Regression Equations	r	Se
WD	= exp(0.352 + 0.567 ln(W) - 0.373 ln(A))	0.762	0.4812
SR	= exp(-1.6 - 0.338 ln(W) - 0.166 ln(A))	0.455	1.188
SL	= exp(-2.17 - 0.238 ln(W) - 0.113 ln(A))	0.30	1.333
SB	= exp(7.61 - 0.46 ln(W) - 0.142 ln(A))	0.615	0.8674

Note: DA - Drainage area (sq. mi.);
SB - Slope of basin (ft/mi);
ELEV - Mean basin elevation (ft);
PR - Average annual precipitation (inches).
W - Width of channel (ft.)

Table 13.5 Sample Statistics and Correlation Matrix of Basin Characteristics for Plains Region in Wyoming

(a) Sample Statistics -

Basin Charac.	Mean	Stdev	Basin Charac.	Mean	Stdev
DA	247.53	647.62	ln(DA)	2.7719	2.6368
SB	711.23	357.93	ln(SB)	6.4236	0.56899
ELEV	4821.1	915.89	ln(ELEV)	8.4625	0.19344
PR	13.119	3.2243	ln(PR)	2.5420	0.25996
W	29.730	29.108	ln(W)	3.0239	0.84866
Gf	1.1169	0.24331			

(b) Correlation Matrix:

	DA	SB	ELEV	PR	W
SB	-0.130				
ELEV	-0.017	0.274			
PR	0.038	0.150	-0.234		
W	0.662	-0.167	0.180	0.107	
Gf	0.033	0.207	-0.017	-0.090	0.015

	ln(DA)	ln(SB)	ln(ELEV)	ln(PR)	ln(W)
ln(SB)	0.084				
ln(ELEV)	0.142	0.285			
ln(PR)	0.105	0.052	-0.266		
ln(W)	0.785	-0.065	0.155	0.177	
Gf	-0.127	0.227	0.015	-0.045	-0.037

(c) Regression Equations:

Regression Equations	r	Se
WD = exp(.111+0.584 ln(W)-.0318 ln(A)+.0387 ln(SB))	0.763	0.4819
SR = exp(-5.86-0.022 ln(W)-0.0691 ln(A)+.687 ln(SB))	0.637	1.032
SL = exp(-7.50-0.157 ln(W)-.0085 ln(A)+.859 ln(SB))	0.612	1.109

Note: DA - Drainage area (sq. mi.);
SB - Slope of basin (ft/mi);
ELEV - Mean basin elevation (ft);
PR - Average annual precipitation (inches);
W - Width of channel (ft);
Gf - Geographical factor.

Table 13.6 Correlation Matrix Among Basin Characteristics for High Desert Region in Wyoming

(a) Sample Statistics -

Basin Charac.	Mean	Stdev	Basin Charac.	Mean	Stdev
DA	156.82	297.07	ln(DA)	3.1490	2.0003
SB	700.79	277.75	ln(SB)	6.4505	0.50384
ELEV	6889.2	445.40	ln(ELEV)	8.8356	0.066629
PR	10.571	2.2913	ln(PR)	2.3360	0.21152
W	18.030	13.502	ln(W)	2.6570	0.70205
Gf	0.92400	0.26997			

(b) Correlation Matrix:

	DA	SB	ELEV	PR	W
SB	0.022				
ELEV	0.344	0.073			
PR	-0.013	0.404	-0.135		
W	0.517	0.230	0.162	0.153	
Gf	-0.156	0.134	-0.181	0.397	0.110

	ln(DA)	ln(SB)	ln(ELEV)	ln(PR)	ln(W)
ln(SB)	-0.042				
ln(ELEV)	0.435	0.072			
ln(PR)	-0.066	0.479	-0.128		
ln(W)	0.777	0.104	0.118	0.187	
Gf	-0.232	0.178	-0.177	0.411	0.187

(c) Regression Equations:

Regression Equations	r	Se
WD = exp(0.352 + 0.567 ln(W) - 0.0373 ln(A))	0.762	0.4812
SR = exp(-1.6 - 0.338 ln(W) - 0.166 ln(A))	0.455	1.188
SL = exp(-2.17 - 0.238 ln(W) - 0.113 ln(A))	0.30	1.133
SB = exp(7.61 - 0.46 ln(W) - 0.142 ln(A))	0.615	0.8674

Note: DA - Drainage area (sq. mi.);
SB - Slope of basin (ft/mi);
ELEV - Mean basin elevation (ft);
PR - Average annual precipitation (inches);
W - Width of channel (ft);
Gf - Geographical factor.

Table 13.7 Twenty Samples of Synthetic Drainage Basins Generated by Subroutine SIMSITE for Mountainous Regions in the State of Wyoming

DA	W	WD	Sr	Sl	SB
46.68	27.75	9.92	.0479	.0587	393.03
4.35	27.70	15.28	.0037	.4807	757.73
2082.44	187.38	37.25	.0175	.0031	305.05
2047.39	237.55	22.67	.0071	.0227	385.73
19.34	41.52	7.70	.0312	.0059	409.74
145.85	23.00	10.26	.0968	.0421	136.26
14.24	33.64	10.64	.0722	.0027	117.05
49.90	23.55	5.52	.1462	.0401	231.97
486.56	56.46	7.26	.0392	.0568	265.27
107.86	37.25	4.13	.1269	.0358	450.07
17.11	19.97	9.70	.1224	.0029	117.39
9.59	35.24	22.62	.0282	.1792	353.79
34.32	22.11	8.37	.0135	.0641	250.84
313.55	56.24	16.56	.0093	.0973	116.66
1.85	11.85	5.00	.1717	.3140	390.25
26.65	35.68	10.23	.0912	.0025	416.74
390.95	59.88	16.73	.0021	.0031	364.43
5.97	28.48	11.99	.0785	.0553	641.18
7.82	7.44	2.69	.1107	.0534	720.99
210.17	66.26	15.36	.2057	.1025	207.00

Definitions of Variables:

DA = drainage basin area (sq. miles)
W = channel top width (f*t)
WD = ratio of channel width to depth (ft/ft)
Sr = floodplain slope right hand side (ft/ft)
Sl = floodplain slope left hand side (ft/ft)
SB = drainage basin slope (ft/mile)

Table 13.8 Fifteen Samples of Synthetic Drainage Basins Generated by Subroutine SIMSITE for the Plains Region in the State of Wyoming

DA	W	GF	WD	Sr	Sl	SB
3.39	20.72	1.15	9.93	.2825	.3736	666.01
116.52	29.57	1.21	21.40	.4772	.0971	836.57
.42	14.75	1.22	5.23	.2466	.0595	762.69
39.33	9.72	1.16	5.41	.0995	.2940	705.28
.20	8.78	1.23	8.06	.0792	.7332	745.03
.02	10.75	1.23	6.88	.2728	.2133	732.42
24.37	18.26	1.18	10.08	.2121	.0382	738.94
.31	19.73	1.19	11.82	.5902	.0266	663.20
60.05	22.27	1.16	13.51	.2136	.0982	611.46
9676.25	37.99	1.15	7.98	.0758	.5691	644.68
20.20	9.03	1.19	6.22	.2638	.1659	728.50
536.35	29.12	1.16	7.18	.3000	.5642	681.83
.03	8.62	1.22	6.29	.6893	.0850	711.36
122.62	28.67	1.18	18.66	.1070	.1195	812.79
.01	6.47	1.20	6.07	.7697	.0391	705.56

Definitions of Variables:

- DA = drainage basin area (sq. miles)
- W = channel top width (ft)
- GF = geographic factor
- WD = ratio of channel width to depth (ft/ft)
- Sr = floodplain slope right hand side (ft/ft)
- Sl = floodplain slope left hand side (ft/ft)
- SB = drainage basin slope (ft/mile)

Table 13.9 Twenty Samples of Synthetic Drainage Basins Generated by Subroutine SIMSITE for the High Desert Region in the State of Wyoming.

DA	W	GF	WD	Sr	Sl	SB
6.91	12.34	.96	6.73	.0865	.0883	748.45
80.45	13.58	.93	1.83	.3408	.1196	137.52
.02	9.33	.94	3.37	.2398	.2031	227.55
.29	13.85	.96	10.91	.1062	.0332	1542.66
54.22	16.16	.95	5.44	.0358	.0190	145.14
2.79	21.41	.96	11.58	.0058	.0096	277.29
134.38	13.06	.93	8.91	.0506	.0139	863.18
.22	13.07	.96	5.91	.0816	.0411	1533.48
3.06	14.90	.97	8.11	.2906	.1122	616.06
3857.18	12.96	.91	3.54	.0046	.0210	217.73
.03	9.02	.97	4.81	.3786	.2792	247.43
.04	10.71	.95	8.27	.2469	.1216	2020.09
280.84	37.98	.97	10.73	.0221	.0338	654.87
.21	5.35	.93	4.90	.2439	.2624	306.22
83.47	21.78	.92	10.74	.5276	.0193	203.31
4682.50	25.35	.95	2.96	.0826	.1174	249.43
750.07	10.77	.90	4.86	.0032	.3990	215.65
1.22	12.81	.95	7.92	.0391	.1095	290.57
.09	3.44	.97	4.20	.1188	.9381	523.32
.01	3.89	.95	1.97	.4856	.1932	1699.67

Definitions of Variables:

- A = drainage basin area (sq. miles)
- W = channel top width (ft)
- GF = geographic factor
- WD = ratio of channel width to depth (ft/ft)
- SR = floodplain slope right hand side (ft/ft)
- SL = floodplain slope left hand side (ft/ft)
- SB = drainage basin slope (ft/mile)

Once the irrigation practice of the synthetic crop land is determined, the number of crops and their types can be generated in the following manner. Suppose that there are a total of eight types of crops planted in Wyoming. The percentages of planted area of those crops in Wyoming averaged over a ten-year period (1975-1984) are shown in Table 6.2. Based on these percentages, random integer variates, say 3-10, can be generated using a multinomial distribution. The percentage of area of a certain crop planted in a given site can then be determined based on the proportion of the number of the crop type in the randomly generated sample. For example, using a multinomial generator it is possible to obtain, out of a total of eight, one case of wheat, one of barley, one of oats, one of corn, three of alfalfa hay, and one other hay, for a particular synthetic drainage site. It would then be assumed that the percentage of the inundated synthetic floodplain is planted with 1/8 of wheat, 1/8 of barley, 1/8 of oats, 1/8 of corn, 3/8 of alfalfa hay, and 1/8 of other hay. Although it is possible to have several crop types in a floodplain upstream of roadway crossing, however, due to the limited extended of inundated area and the large scale farming practice in the United States, it is practical to assume that there is only one major crop at each site that is susceptible to flood damage.

13.3 GENERATION OF DATA BASE FOR EMBANKMENT

Subroutine SIMEP was developed to generate the properties of typical highway embankments for the synthetic data base. In particular, embankment properties to be generated are base soil type (i.e., non-cohesive, high-cohesive, and low-cohesive), embankment surface condition (i.e., paved or non-paved), vegetal cover type (i.e., no vegetal cover, Bermuda grass, weeping lovegrass, or crabgrass). With many possible combinations that could describe the embankment properties, information on embankment erosion for different types of vegetal cover is not complete from Chen and Anderson (1987). In other words, some combinations of vcgetal cover, soil type, and embankment surface condition are not available from Chen and Anderson (1987). Using random number generators could result in a data base that would cause execution failure of the program LTEC.FOR. Therefore, to be conservative and practical, the synthesized road surface is paved and embankment slope has no vegetal cover. This leaves only one variable to be generated for the data base, i.e., soil type, which can easily be done by discrete uniform random number generator.

13.4 GENERATION OF TRAFFIC RELATED DATA BASE

Required traffic related data in this LTEC analysis for a range of typical highway drainage structures are Average Daily Traffic Equivalent (ADTE), increased travel distance due to a detour, vehicle composition, occupancy rate, unit cost of occupant, averaged vehicle speed on detour, accident ratio, and cost of damage claimed per accident.

Data for ADTE on Wyoming highways of various types were available from the WDT (1984) and are shown in Table 13.10. A uniform random generator was used for developing a representative data base to produce the ADTE. The bounds that define the range of ADTE in Wyoming for a given highway system should consider expected future growth.

Before generating the increased detour travel distance, the program first decides whether the detour is at the road site or away from the site. For most situations in Wyoming, the detour is located at the drainage structure site while flood damage is repaired. In such cases, the increased travel distance on a detour would be less than a half mile, and is nearly identical to the original travel distance. The speed of travel could vary from, say, 25 - 45 mph. On the other hand, if the road is closed for repair and traffic is diverted to other routes, then the increased travel distance would be longer. In a urban area where roadway density is high, the increased detour could be several miles whereas in a rural area it could be much longer. A uniform random number generator was used to produce synthetic data to represent the increased travel distance and vehicle speed on a detour.

The investigators have not found a useful publication that provides vehicle composition on Wyoming highways. An estimate can possibly be made based on WDT traffic accident reports (Woming Highway Department, 1984). Estimating vehicle composition based on these comprehensive accident reports is valid if the assumption that the percentage of accidents of a specific vehicle type is directly proportional to the number of vehicles of that type on the road and that each vehicle of a given type is equally likely to have an accident. Based on this assumption, the vehicle composition on Wyoming highways was estimated and is shown in Table 13.11.

Table 13.10 Equivalent Average Daily Traffic in the State of Wyoming.

Road Type	ADTE Rural Area	ADTE Urban Area
Interstate	4,360	7,796
Primary	1,294	8,944
Secondary	486	4,210
State highway only	356	2,345
Service road	242	1,591
Urban system	---	5,428

Table 13.11 Percentage of Vehicle Type on Wyoming Highways.

	Vehicle Composition										
	Rural					Urban					
Vehicle Type	Road Types A	B	C	D	E	Road Types A	B	C	D	E	F
+1	31.4	17.9	14.2	16.6	30.0	19.4	5.5	4.8	3.4	8.2	4.5
2	20.0	24.0	25.1	24.4	20.4	23.5	27.6	27.8	28.3	26.8	27.9
3	46.4	55.5	58.0	56.4	47.3	54.5	63.9	64.4	65.3	62.1	64.6
4	2.2	2.6	2.7	2.6	2.3	2.6	3.0	3.0	3.0	2.9	3.0

* A = interstate
B = primary
C = secondary
D = state highway only
E = service road
F = urban system

\+ 1 = large
2 = intermediate
3 = compact/subcompact
4 = van

Using the foregoing assumption for estimating the synthesized vehicle composition, the vehicle occupant composition can be estimated in a similar manner. According to the WDT's occupation classification (WHD, 1984a), the weighted average unit cost of occupancy (in $/hr/person) can be estimated as in Table 13.12. The column containing occupant's hourly wage was our best guess which, of course, is subject to future revision and may be better based on trucking values as indicated earlier.

There are many other variables affecting traffic related damages for which it is difficult to devise a synthesized data base due to lack of reliable data. These variables are embankment repair rate, accident rate, and unit cost claimed per damage. The nominal values used in this study are 60 cu.yd./day, 360 accident/100 million vehicle-miles, and $5,500/claim, respectively. In generating the data base, these quantities were also treated as random variables which are set to vary between the multipliers of 0.6 and 1.6. For example, the repair rate varies between the lower bound of 0.6(60)=36 and upper bound of 1.6(60)=96. It is believed that, in doing so, the generated values for the variables capture the potential variation that could exist in the 'real world'.

13.5 GENERATION OF DATA BASE ON BUILDINGS

In assembling a synthetic data base for use in a regression analysis that is representative of Wyoming drainage sites, it is necessary to recognize that some sites will have some level of floodplain development. To address the possibility of buildings being located in the synthetic floodplain presented the most challenging task because the problem is four-dimensional involving types of buildings, their numbers, values, and elevations. The number of synthetic buildings (regardless of their types) in an inundated synthetic floodplain was generated by the Poisson distribution which requires the specification of building density and susceptible flooding area. The susceptible flooding area, for simplicity, was delineated by Figure 13.3. It was assumed that the susceptible flooding area upstream of the drainage structure site covers an area of 30W in length and 10W in width with W being the top-width of the main channel. For clarity, a flowchart showing the logic in SIMBLDG is given in Figure 13.4.

Table 13.12 Estimation of Weighted Average Unit Cost of Vehicle Occupants on Wyoming Highways.

Occupations	Hourly Wage ($/hr) (1)	Percentage in Accident			
		Fatal (2)	Injury (3)	Property (4)	Avg. (5)
Unknown +	12.0	40.0	26.5	24.4	30.3
Military	12.0	1.0	1.2	1.2	1.1
Unemployed	2.0	4.0	5.3	4.7	4.7
Miscellanies	20.0	0.5	0.8	0.9	0.7
Retired	3.0	6.5	3.4	3.3	4.7
Student	2.0	8.0	11.0	10.9	10.1
Laborer	10.0	6.0	6.8	5.4	6.1
Craftsman	18.0	3.5	5.8	6.5	5.3
Domestic	2.0	2.0	4.6	4.9	3.8
Transportation	15.0	12.5	10.5	7.6	10.2
Agri, ranch, forest	15.0	2.0	2.0	1.6	1.9
Service work	12.0	3.0	3.1	3.8	3.3
Clerical-sales	15.0	1.0	5.0	7.1	4.4
Professional management	25.0	8.5	10.9	14.3	11.2
Energy	15.0	1.5	2.9	2.3	2.2
		100.0	100.0	100.0	100.0

Weighted unit occupancy cost = $\Sigma(1)*(5)/100$ = $13.95/hr

+ Hourly wage of unknown is assumed to be the average hourly wage of all other occupations.

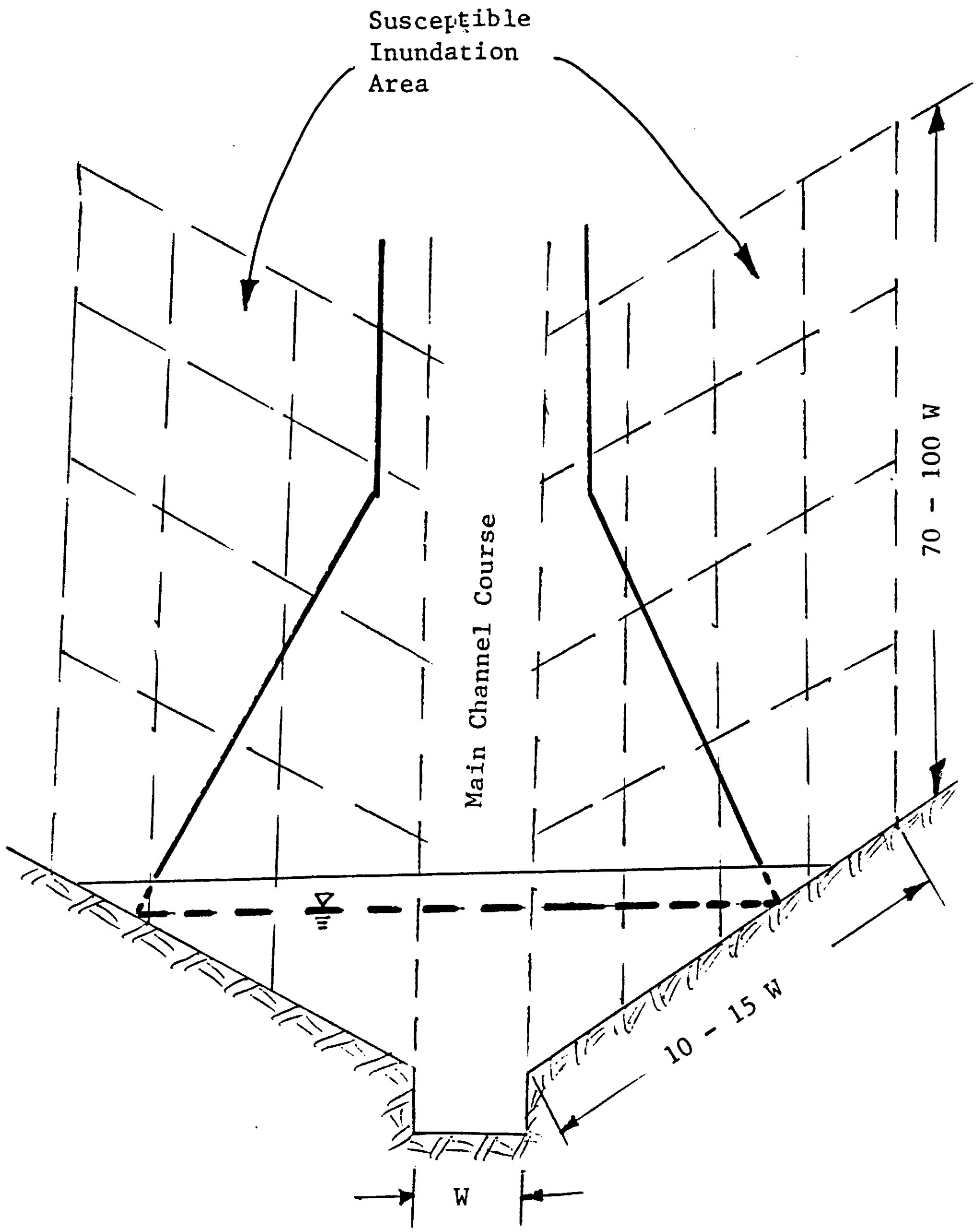


Figure 13.3 Schematic Sketch of Delineation of Susceptible Inundation Area.

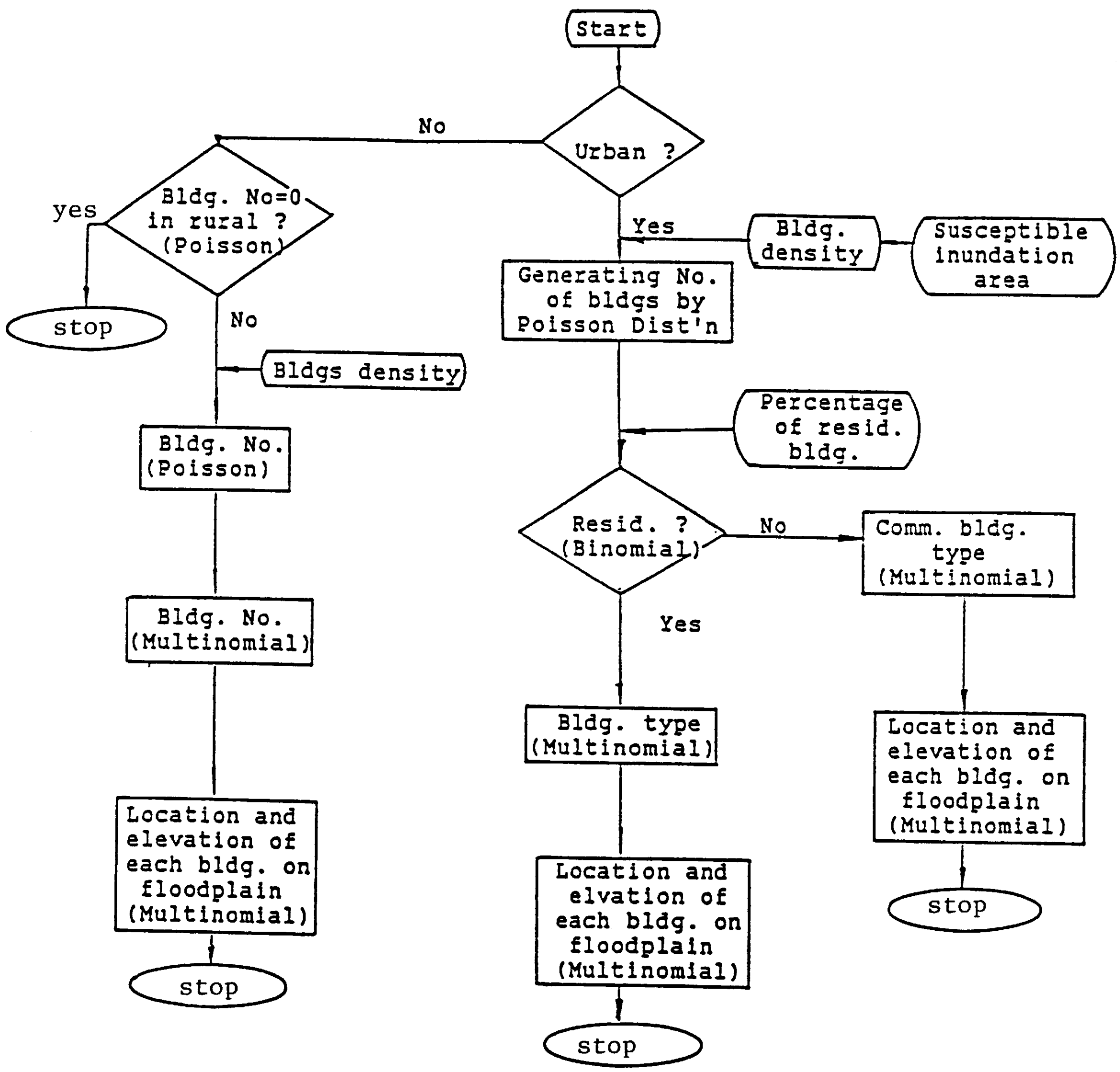


Figure 13.4 Flow Chart of Subroutine SIMBLDG

In generating synthetic data base for the number of buildings in a susceptible inundated area by Poisson distribution, urban and rural areas were treated differently. For urban areas, the building density was expressed in terms of the average number of buildings per acre, if the upstream floodplain is not a park or other open space. For rural areas, the building density was defined as the number of buildings per site. One hundred forty five 7.5-minute topographical maps in Wyoming were randomly selected to estimate the building density. A total of 1,323 rural drainage sites and 22 urban drainage sites were encountered. Building density is summarized in Table 13.13. It can be seen from Table 13.13 that the average building density is about the same as the variance, therefore, the Poisson distribution is justified to generate the number of buildings. From Table 13.13, it was found that the averaged building density in a rural area is 2.333 bldgs/site. In a rural area, a decision is first made as to whether the site has buildings or not. According to the finding shown in Table 13.13, 6.8% of the roadway crossing sites in rural areas had a building in the upstream floodplain. A binomial random generator was used to determine whether a synthetic site had building. If it had a building, a Poisson random generator then is used to determine the number of buildings using the building density of 2.33 bldgs/site. After the building number is generated, the process goes on to determine, among those buildings, how many are farm residential buildings and how many are shacks.

In urban areas of Wyoming, the building density is 2.01 buildings per acre. Because the building density is site specific and could vary from site to site, six building densities, i.e., 2.0, 1.0, 0.5, 0.25, 0.125, and 0.05 bldgs/acre were considered for urban areas when the number of buildings are to be generated. Two categories of building are considered in an urban area, namely, residential buildings and commercial buildings. The Poisson random number generator for a specified building density and susceptible inundation area produces only the total number of buildings regardless their categories. In this study, six types of residential buildings (Table 6.4) and seventy three types of commercial buildings (Table 6.6), according to Corps of Engineers (1980), were considered.

To determine the number of buildings of each category in a synthesized site, one needs the information about the percentage of residential and commercial buildings in the State of Wyoming, once the total number of buildings are known. For this purpose, twenty-one cities in Wyoming as shown in Table 13.14 were selected from Mountain Bell phone directories. For each city in the phone book, about 20 to 30 percent of its pages were randomly selected as the sample set to estimate the average number of residential buildings and commercial buildings per page. The total number of residential and commercial buildings of the city were then estimated by multiplying the average number per page by the number of total pages for that city. The percentages of residential and/or commercial buildings of the city were then calculated. The weighted average percentages, accordingly, for Wyoming were calculated by using the sum of residential and/or commercial buildings from the 21 cities (Table 13.14). As shown in Table 13.14, on the average 81% of the buildings in urban areas of Wyoming are residential whereas 19% are commercial buildings.

Once the number of buildings (regardless of their types) for a given synthetic site is generated, the number of residential and commercial buildings is determined according to the ratio given in Table 13.14 using a binomial random generator. The location of each building of a specified category and type was determined in two steps. First, the susceptible inundation area was divided into a number of strips parallel to the channel. The width of each strip is 200 feet including the length of a house with yard and road. A multinomial distribution was used to generate the number of synthetic buildings in each strip with each building equally having an equal probability of being located on either side of the channel. The probabilities used in multinomial distribution for generating building numbers in each strip was unequal with lowest probability for the strip next the channel and increasing linearly for strips farther away from the channel. This was under the premise that people are aware of the flooding potential when they locate their homes or businesses.

Second, once the number of buildings in each strip is determined, lines perpendicular to the channel were drawn which divide the entire susceptible inundation area into a number of blocks (Figure 13.3) with each block being considered as a potential land parcel in which one unit of a synthetic building is to be accommodated. To determine exactly the location of synthesized buildings in each strip, it was assumed that each building is equally likely to be located in each parcel in the designated strip. A discrete uniform random number generator was used for each parcel along a strip.

Table 13.13 Building density in the State of Wyoming*.

	Rural	Urban
Percentage of bldg. occupants on site	6.80%	100%
Average bldg. density	2.233 bldgs/site	2.01 bldgs/acre
Standard deviation	1.423	1.21

* The topographic maps investigated are compiled at different times. The average year of the maps publication is 1961 with a standard deviation of about six years.

Table 13.14 Estimation of Ratio of Residential Buildings to Commercial Buildings in the State of Wyoming.

No.	City	Est. no. of Resid. Bldgs.	Est. no. of Commer. Bldgs.	% of Resid. Bldgs.	% of Commer. Bldgs.
1	Buffalo	2,006	566	78.0	22.0
2	Casper	23,125	6,726	77.5	22.5
3	Cheyenne	23,631	6,031	79.7	20.3
4	Cody	5,110	1,156	81.6	18.4
5	Douglas	2,598	947	73.3	26.7
6	Evanston	4,557	984	82.2	17.8
7	Gillette	9,434	1,839	83.7	16.3
8	Green River	4,221	537	88.7	11.3
9	Kemmerer	1,594	473	77.1	22.9
10	Lander	3,823	986	79.5	20.5
11	Laramie	11,645	1,717	87.2	12.8
12	Newcastle	1,953	539	78.4	21.6
13	Powell	3,168	686	82.2	17.8
14	Rawlins	3,392	702	82.9	17.1
15	Riverton	5,096	1,323	79.4	20.6
16	Rock River	180	35	83.7	16.3
17	Rock Springs	8,222	1,798	82.1	17.9
18	Saratoga	770	187	80.5	19.5
19	Sheridan	8,700	1,842	82.5	17.5
20	Thermopolis	2,184	411	84.2	15.8
21	Worland	2,802	694	80.1	19.9
Weighted Average for Wyoming		128,211	30,179	80.9	19.1

After determining the synthetic building locations, their types were specified. To do so, a discrete uniform random number generator was again applied which assumes that each residential building type in Table 6.4 and commercial building type in Table 13.14 was equally probable. With regard to the values of buildings of various types, they were also treated as random variables that vary within ±20% of the assumed nominal values. A sample output from the subroutine SIMBLDG is given in Table 13.15.

13.6 GENERATION OF UNIT COST FOR VARIOUS ITEMS

This part of the study was mainly concerned with the fact that many of the unit cost items in computing the first cost and second cost in the LTEC design are subject to uncertainty. In addition, the expected project service life and interest rate are also uncertain. Therefore, they should be treated as random variables. Specifically, the unit cost items that are considered random are unit embankment cost, unit concrete cost, unit steel cost, unit pavement cost, mobilization cost, variation of unit bridge cost, and cost adjustment factor due to inflation. For simplicity, each random variable was assumed to have a continuous uniform distribution with lower and upper bounds specified. According to Wyoming Construction (1986), the bounds of most unit costs were specified to consider the possible cost variation in the future with their current values being as follows:

Item	Lower Bound	Upper Bound	
Unit embankment cost ($/cu.yd.)	2.50	6.00	
Unit pavement cost ($/cu.yd.)	25.00	60.00	
Unit concrete cost ($/cu.yd.)	300.00	500.00	
Unit steel cost ($/lb)	0.45	0.80	
Mobilization cost ($)	200.00	600.00	
Cost adjustment factor	1.30	1.70	
Expected service life (years)	40.00	100.00	for bridges
	20.00	100.00	for culverts
Interest rate	0.04	0.10	

Table 13.15 Sample Output of Subroutine SIMBLDG for Generating Number of Buildings on Floodplain.

Area (Sq Mi)	Width (ft)	Width to Depth Ratio	Floodplain Slope		Basin Slope (ft/mi)
			Left (ft/ft)	Right (ft/ft)	
13.52	19.61	10.19	.2307	. 1016	459. 03

Bankfull Elevation (ft)	Number of Buildings	
	Residential	Commercial
1000. 00	16	3

Residential Bldg Type	Elevation (ft)	Commercial Bldg Type	Elevation (ft)
3	1023.07	38	1080.92
2	1000.00	28	1083.90
1	1020.32	7	1072.22
4	1054.83		
2	1040.46		
1	1040.46		
5	1036.24		
6	1034.78		
6	1055.10		
1	1043.47		
1	1063.79		
1	1063.79		
1	1060.86		
4	1083.93		
5	1115.69		
6	1079.71		

The variation in the unit bridge cost was generated from normal random number generators with a mean of zero and standard deviation of \$5.855/sq. ft.. This generated variation of unit bridge cost was then added to the nominal unit bridge cost computed by Eq.(4.5).

13.7 GENERATION OF DATA BASE FOR ROADWAY CROSSING STRUCTURE

Although the computer program LTEC.FOR determines the geometry of highway drainage structure with the least annual total expected cost, there are still some parameters or variables for the drainage structure that must be specified. These parameters/variables include number of traffic lanes, width of each lane, pipe culvert type, required minimum cover for culverts, pier width for bridge, pavement thickness, and width of shoulder. These design parameters/variables could vary from site to site. For simplicity, all design variables, but the number of traffic lane and pipe culvert type, are treated as uniform random variables. The number of traffic lane was considered as a discrete uniform random variable that can take on a value of either 2 or 4. The pipe culvert type was selected randomly by assuming that each type shown in Table 3.1 is equal likely to be chosen. The lower and upper bounds of other design variables adopted are as the following:

Item	Lower Bound	Upper Bound
Minimum cover depth	2'	4'
Width per lane	10'	13'
Bridge pier width	4'	6'
Width of shoulder	6'	12'
Pavement thickness	4	8

14.
ANALYSIS OF DATA BASE FOR LTEC/EXTENDED-LTEC DESIGN FREQUENCIES AND SITE CHARACTERISTICS

In this chapter, a vast data base was assembled representing a wide range of drainage sites typical to a State such as Wyoming. The procedures and findings are presented on the empirical equations obtained by analyzing this data base for typical, synthetic drainage sites using the LTEC and extended-LTEC practices presented earlier. It should be noted that the resulting working relationship presented in the following section for the LTEC design frequency, strictly speaking, is applicable when the flood frequency curve at the drainage site is describable by the basin-characteristics method. In case that the LTEC design return period for the flood frequency relationship other than that from the basin-characteristics mthod is desired, a simple method is described in Section 14.5.

The analyses of this data base for typical, synthetic drainage sites obtained in Chapter 13 were conducted in two steps. The first step is, on the basis of information generated, to establish working relationships between the LTEC design frequency, which considers economic cost of highway drainage structures, for highway crossing structures and the site characteristics. Once the LTEC design frequency is determined, the second step is to establish relationships for the extended-LTEC design frequency by incorporating preference evaluations of the design engineer about the total economic cost along with three intangible factors including maintenance frequency, litigation potential, and public service. These relations enable design engineers to quickly estimate a reasonable LTEC and extended-LTEC design frequencies, given knowledge about the site characteristics, without having to go through an extensive site specific hydraulic simulations and the LTEC analysis.

14.1 DEVELOPMENT OF RELATIONSHIPS BETWEEN LTEC DESIGN FREQUENCY AND SITE CHARACTERISTICS

Multiple regression analysis was performed in that the dependent variable is the LTEC design return period while site characteristics on geometry and hydraulic properties of channel, road configuration, upstream land use, traffic condition, and various cost elements were employed as predictors. To achieve higher accuracy relationships, function relationships were established separately for different locations (urban and rural), hydrologic regions (mountainous, high plains, and deserts), and structural types (bridges, box culverts, and pipe culverts). Various forms of dependent variable have been examined for their performances. It was found that using ln(T-1) as the dependent variable, with T being the LTEC design return period in years, yielded the most desirable results. A theoretical advantage of the form ln(T-1) is that it is equivalent to

$$\ln(T-1) = \ln\left(\frac{1-\frac{1}{T}}{\frac{1}{T}}\right) \tag{14.1}$$

which is the logarithmic transform of the ratio of non-exceedance probability to exceedance probability. The resulting range for the dependent variable ln(T-1) would, theoretically, extend from $-\infty$ to ∞; a condition better suited for the conventional regression analysis.

In the generated synthetic data base for a wide range of typical site variables, the LTEC design return period takes two forms. One form of the LTEC return period is that its value is obtained at discretized levels of 2-, 5-, 10-, 25-, 50-, and 100-yr. For a given site condition in the synthetic data base, the corresponding discretized LTEC return period having the least total expected costs is obtained by the program LTEC.FOR. The LTEC design frequency so obtained is called herein as the *discrete LTEC design frequency*. Because the value of the LTEC design frequency is continuous by nature, it is possible that the discrete LTEC design frequency, as shown in Figure 14.1, may not be where the actual LTEC design frequency lies. Therefore, interpolation among the discretized return periods for the LTEC return period is conducted. Specifically, quadratic interpolation (Edgar and Himmelblau, 1988) was applied in this study. The resulting LTEC design frequency through the interpolation procedure is called herein as the *continuous LTEC design frequency*. Note that, from Figure 14.1, there could be some differences between the two types of LTEC design frequencies for a given site condition. Tables 14.1 and 14.2 are the resulting predictive equations, along with the standard error, multiple correlation coefficient, and sample size, for the LTEC design return period in urban and rural areas, respectively, using discrete LTEC return period as the dependent variable. Tables 14.3 and 14.4 are the predictive equations using the continuous LTEC return period as the

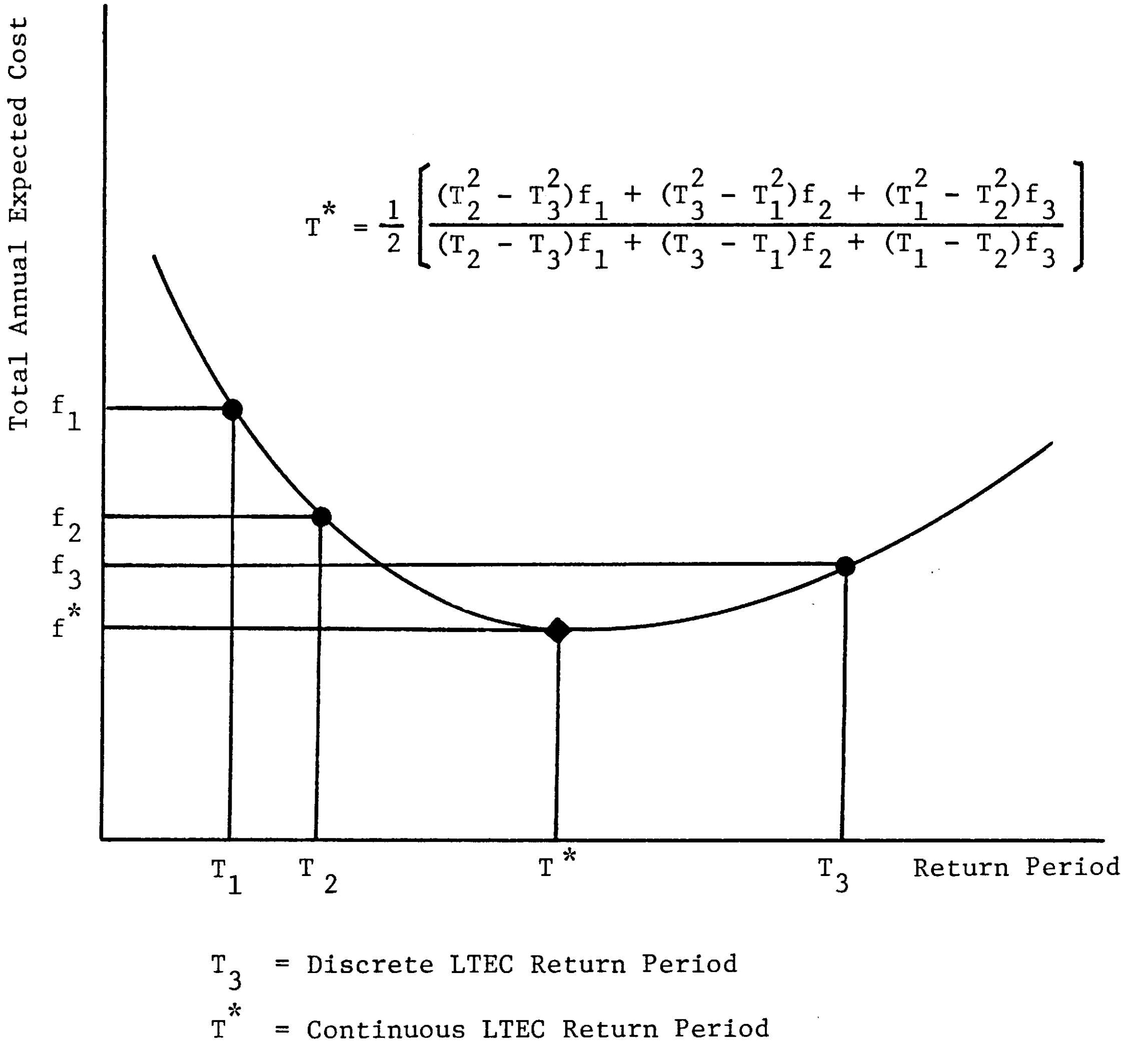


Figure 14.1 Quadratic Interpolation for Continuous LTEC Design Return Period

Table 14.1(a) Predictive Equations for the LTEC Design Return Period for *Bridges* in *Urban Areas* Based on *Discretized* Design Return Period.

Urban / Mountainous Region / Bridges:

ln(T-1) = -11.14-1.1095 ln(W)+0.23 ln(Sl)+0.1498 ln(Sr)-1.3068 ln(Sc)-0.5385 ln(Np)
-0.12 ln(Nc)+0.6478 ln(DA)+0.5948 ln(PR)+0.05 ln(Nl)+0.23 ln(WP)
-3.6332 ln(THICKPV)-0.06 ln(RATE)+1.514 ln(LIFE)+0.062 NBLDG
+0.01165 BLDGVAL-0.0039953 BLDGELE+0.1828 ln(DELL)
-1.25 ln(RREP)+0.35 ln(TM)-0.36 ln(AVSD)+1.21 ln(AR)+0.17 ln(ADTE)
+0.453 IndxS-2.582 ln(CC)-0.23 ln(Uemb)-0.568 ln(Ubdg)-0.532 ln(Up)
+0.3798 ln(CM)+0.8405 ln(Uoc)+0.62 ln(Udmg)

s.e. = 0.738; r =0.884; n=51.

Urban / High Plain Region / Bridges:

ln(T-1) = -7.600+0.9973 ln(W)-0.08 ln(Sl)+0.45 ln(Sr)+0.47 ln(Sc)+0.26 ln(Np)
+0.11 ln(Nc)-0.1364 ln(DA)-1.511 ln(GF)+0.04 ln(Nl)+0.228 ln(Wp)
+1.0451 ln(THICKPV)-0.1256 ln(RATE)+0.6163 ln(LIFE)
+0.042332 NBLDG+0.001 BLDGVAL-0.003564 BLDGELE
+0.34 ln(DELL)-0.87 ln(RREP)+0.9552 ln(TM)-0.30 ln(AVSD)
+0.52 ln(AR)+0.3216 ln(ADTE)-0.25 IndxS-3.00 ln(CC)
-0.5896 ln(Uemb)-0.2402 ln(Ubdg)-0.7285 ln(Up)+0.24 ln(CM)
+0.51 ln(Uoc)+0.6177 ln(Udmg)

s.e. = 0.5554; r =0.871; n=54.

Urban / Deserts / Bridges:

ln(T-1) = -7.01+0.8211 ln(Sl)+0.2933 ln(Sr)-0.04 ln(Sc)-0.4661 ln(Np)
-0.25 ln(Nc)+0.3045 ln(DA)+1.692 ln(GF)-2.00 ln(Nl)+0.02 ln(WP)
+4.146ln(BRIWID)+0.3761ln(THICKPV)-0.9519ln(RATE)+1.0196ln(LIFE)
+0.03414 NBLDG+0.002671 BLDGVAL-0.011325 BLDGELE
+0.2084 ln(DELL)-1.32 ln(RREP)+0.1194 ln(TM)-0.595 ln(AVSD)
+0.23 ln(AR)+0.1941 ln(ADTE)-0.2194 IndxS-4.668 ln(CC)-1.7381 ln(Uemb)
-1.30 ln(Ubdg)-0.561 ln(Up)+0.1789 ln(CM)+0.2737 ln(Uoc)+0.21 ln(Udmg)

s.e. = 0.7328; r =0.904; n=43.

Table 14.1(b) Predictive Equations for the LTEC Design Return Period for *Box Culverts* in *Urban Areas* Based on *Discretized* Design Return Period.

Urban / Mountainous Region / Box Culverts:

ln(T-1)= -33.52-0.22 ln(W)+1.3726 ln(D)+0.7904 ln(Sl)+0.7418 ln(Sr)
-0.82 ln(Np)+0.3652 ln(Nc)+0.2972 ln(DA)+3.2904 ln(PR)
-0.8394 COVERDEP-0.13 ln(RDWID)+1.5136 ln(THICKPV)
-1.2346 ln(RATE)+2.1128 ln(LIFE)+0.106 NBLDG
+0.00338 BLDGVAL-0.0043 BLDGELE+0.586 ln(DELL)-0.15 ln(RREP)
+1.17 ln(TM)-0.43 ln(AVSD)+0.6055 ln(AR)+0.3473 ln(ADTE)
-0.22 ln(CC)-0.2156 ln(Uemb)-0.32 ln(Us)-0.25 ln(Uc)-0.4347 ln(Up)
+0.5412 ln(CM)+0.81 ln(Uoc)+0.54 ln(Udmg)

s.e. = 0.8567; r =0.914; n=59.

Urban / High Plain Region / Box Culverts:

ln(T-1) = 4.235+1.6444 ln(D)+0.06 ln(Sl)-0.15 ln(Sr)-0.4484 ln(Sc)-0.99 ln(Np)
-0.20 ln(Nc)-0.1984 ln(DA)-1.344 ln(GF)-0.5679 ln(COVERDEP)
-0.7112 ln(RDWID)+0.7379 ln(THICKPV)-0.7005 ln(RATE)
+0.5018 ln(LIFE)+0.04 NBLDG+0.002316 BLDGVAL
-0.00337 BLDGELE+0.4549 ln(DELL)-0.49 ln(RREP)+0.3 ln(TM)
-0.65037 ln(AVSD)+1.022 ln(AR)+0.35 ln(ADTE)-2.04 ln(CC)
-0.14 ln(Uemb)-2.33 ln(Us)-4.47 ln(Uc)-0.17 ln(Up)+0.5042 ln(CM)
+0.84 ln(Uoc)+0.6639 ln(Udmg)

s.e. = 0.7151; r =0.934; n=59.

Urban / Deserts / Box Culverts:

ln(T-1) = - 5.947+0.5241 ln(W)-0.4424 ln(D)-0.18354 ln(Sr)-0.49 ln(Sc)
+0.7155 ln(Np)+1.4651 ln(Nc)+0.25 ln(DA)+1.5618 ln(PR)-2.525 ln(Nl)
+1.4027 ln(COVERDEP)+2.4 ln(RDWID)-1.424 ln(THICKPV)
-0.3322 ln(RATE)+0.34 ln(LIFE)+0.04399 NBLDG+0.001635 BLDGVAL
-0.003642 BLDGELE+0.17883 ln(DELL)-0.27 ln(RREP)+0.42 ln(TM)
-0.31 ln(AVSD)+0.38 ln(AR)+0.2238 ln(ADTE)+0.0972 IndxS
-1.335 ln(CC)-1.1265 ln(Uemb)-0.38 ln(Us)-0.98 ln(Uc)-0.29 ln(Up)
+0.43 ln(CM)+0.7521 ln(Uoc)+0.00032 Udmg

s.e. = 0.6747; r =0.894; n=56.

Table 14.1(c) Predictive Equations for the LTEC Design Return Period for *Pipe Culverts* in *Urban Areas* Based on *Discretized* Design Return Period.

Urban / Mountainous Region / Pipe Culverts:

ln(T-1) = 13.983+0.1861 ln(W)-0.3569 ln(Sc)-0.3794 ln(Np)-0.929 ln(Nc)
-0.23 ln(DA)+3.76 ln(Nl)-0.01485 IndxP-6.08 ln(RDWID)
-0.2 ln(THICKPV)-0.9739 ln(RATE)+0.26 ln(LIFE)+0.011 NBLDG
+0.0012 BLDGVAL-0.003 BLDGELE+0.251 ln(DELL)
-1.3565 ln(RREP)+1.042 ln(TM)-0.557 ln(AVSD)+1.0639 ln(AR)
+0.16 ln(ADTE)-2.228 ln(CC)-1.4652 ln(Uemb)-0.7203 ln(Up)
+0.2177 ln(CM)+0.16 ln(Uoc)+0.06 ln(Udmg)

s.e.= 0.7849; r= 0.808; n= 64

Urban / High Plain Region / Pipe Culverts:

ln(T-1) = 3.59-1.6764 ln(W)+2.4822 ln(D)-0.2352 ln(Sl)-0.71 ln(Sr)-0.55 ln(Sc)
+0.05 ln(Np)+0.4139 ln(Nc)+0.0627 ln(DA)-2.2104 ln(GF)-0.8174 ln(Nl)
+0.01901 IndxP-0.33 ln(RDWID)-0.22 ln(RATE)+0.4382 ln(LIFE)
+0.04154 NBLDG+0.0023 BLDGVAL-0.006 BLDGELE
+0.2775 ln(DELL)-1.4295 ln(RREP)+0.3962 ln(ADTE)+0.34 ln(TM)
-1.39 ln(AVSD)+0.39 ln(AR)-0.2162 IndxS-3.523 ln(CC)-0.5822 ln(Uemb)
-0.9208 ln(Up)+0.5316 ln(CM)+0.363 ln(Uoc)+0.435 ln(Udmg)

s.e.= 0.9469; r= 0.867; n= 83

Urban / Deserts / Pipe Culverts:

ln(T-1) = 1.58-0.5815 ln(W)+0.7942 ln(D)+0.25332 ln(Sl)+0.7605 ln(Sr)
+0.533 ln(Sc)-0.2627 ln(Np)+0.05 ln(Nc)+0.2593 ln(DA)+1.0778 ln(PR)
-1.59 ln(GF)-0.62 ln(Nl)-0.10 ln(COVERDEP)-0.02828 IndxP
-0.9623 ln(RDWID)-1.0701 ln(RATE)+0.3371 ln(LIFE)
+0.03324 NBLDG+0.001966 BLDGVAL-0.014371 BLDGELE
+0.20679 ln(DELL)-1.13 ln(RREP)+1.033 ln(TM)-0.62 ln(AVSD)
+0.369 ln(AR)+0.2818 ln(ADTE)-2.793 ln(CC)-0.45 ln(Uemb)
-0.52 ln(Up)+0.7241 ln(CM)+0.12 ln(Uoc)+0.08 ln(Udmg)

s.e.= 0.6826; r= 0.911; n= 72

Table 14.2(a) Predictive Equations for the LTEC Design Return Period for *Bridges* in *Rural Areas* Based on *Discretized* Design Return Period.

Rural / Mountainous Region / Bridges:

ln(T-1) = -11.840-0.4705 ln(D)-0.11 ln(Sl)-0.441 ln(Sc)-0.6916 ln(Np) +1.4122 ln(Nc)+0.35723 ln(DA)+1.52 ln(PR)-1.90 ln(Nl)+3.757 ln(Wp) +1.593 ln(BRIWID)-3.5949 ln(THICKPV)-0.07 ln(RATE) +0.4974 ln(LIFE)+0.047 NRES+0.0005 BLDGVAL-0.002 BLDGELE +0.3018 IndxI+0.01403 (IndxC-1)+0.006 KFARM+0.1281 ln(DELL) -1.31 ln(RREP)+0.66 ln(TM)-0.58 ln(AVSD)+0.673 ln(AR)+0.2119 ln(ADTE) -1.21 ln(CC)+0.64 ln(CM)-0.962 ln(Uemb)-0.32 ln(Ubdg)-0.7965 ln(Up) +0.63 ln(Uoc)+0.9841 ln(Udmg)

s.e. = 0.5776; r= 0.898; n= 51

Rural / High Plain Region / Bridges:

ln(T-1) = -3.546+0.3055 ln(W)+0.4016 ln(D)+0.4293 ln(Sl)+0.1165 ln(Sr) +0.6949 ln(Sc)+0.5911 ln(Np)+0.88 ln(Nc)-0.59 ln(DA)-2.3573 ln(GF) +0.47 ln(Wp)-0.11 ln(BRIWID)+0.837 ln(THICKPV)-0.2002 ln(RATE) +1.6739 ln(LIFE)+0.035 NRES+0.003 BLDGVAL-0.002 BLDGELE +0.390 IndxI+0.011 (IndxC-1)+0.005 KFARM+0.17 ln(DELL) -0.33 ln(RREP)+0.26 ln(TM)-0.17 ln(AVSD)+1.096 ln(AR)+0.2 ln(ADTE) -1.76 ln(CC)-0.45 ln(Uemb)-0.56 ln(Ubdg)-0.4365 ln(Up)+0.4535 ln(CM) +0.47 ln(Uoc)+0.23 ln(Udmg)

s.e. = 0.5590; r= 0.914; n= 54

Rural / Deserts / Bridges:

ln(T-1) = 4.54+0.9464 ln(D)-0.07 ln(Sl)-0.1144 ln(Sr)-0.05 ln(Sc)+1.3034 ln(Np) +0.10 ln(Nc)-0.3264 ln(DA)+1.2114 ln(PR)-1.093 ln(GF) +5.236 ln(Nl)+0.842 ln(Wp)-8.3 ln(BRIWID)-2.5331 ln(RATE) +1.0996 ln(LIFE)+0.26 NRES+0.002 BLDGVAL-0.005 BLDGELE +0.04 KFARM+0.577 IndxI+0.04903 (IndxC-1)+0.1731 ln(DELL) -0.362 ln(RREP)+0.6411 ln(TM)-0.6124 ln(AVSD)+0.87 ln(AR) +0.235 ln(ADTE)-0.99 IndxS-3.616 ln(CC)+0.6677 ln(CM)-2.17 ln(Uemb) -0.774 ln(Ubdg)-1.978 ln(Up)+0.542 ln(Uoc)+2.2351 ln(Udmg)

s.e. = 0.7530; r= 0.903; n= 43

Table 14.2(b) Predictive Equations for the LTEC Design Return Period for *Box Culverts* in *Rural Areas* Based on *Discretized* Design Return Period.

Rural / Mountainous Region / Box Culverts:

ln(T-1) = 14.843+1.9866 ln(W)-0.49 ln(D)+0.20179 ln(Sl)+0.59679 ln(Sr)
+0.3 ln(Sc)-0.9405 ln(Nc)-0.3949 ln(DA)-0.8603 ln(PR)+4.6438 ln(Nl)
-3.1059 ln(COVERDEP)-3.004 ln(RDWID)-0.16 ln(RATE)+0.37 ln(LIFE)
+0.17 NRES+0.015 BLDGVAL-0.0083 BLDGELE+0.02 KFARM
+0.113 IndxI+0.0187 (IndxC-1)+0.24 ln(DELL)-0.76 ln(RREP)
+0.17414 ln(TM)-0.63 ln(AVSD)+0.237 ln(AR)+0.21 ln(ADTE)
-0.32 IndxS-1.23 ln(CC)-0.47 ln(Uemb)-2.3108 ln(Us)-2.3583 ln(Uc)
-0.3227 ln(Up)+1.34 ln(CM)+0.9622 ln(Uoc)+0.15 ln(Udmg)

s.e.= 0.5994; r= 0.956; n= 58

Rural / High Plain Region / Box Culverts:

ln(T-1) = -4.278+0.5 ln(W)+2.0437 ln(D)-0.4314 ln(Sl)-0.4082 ln(Sr)
+0.9592 ln(Sc)-0.7031 ln(Np)-0.1431 ln(DA)-3.7078 ln(Nl)
+0.948 ln(COVERDEP)+3.07 ln(RDWID)-1.186 ln(THICKPV)-0.13 ln(RATE)
+0.6893 ln(LIFE)+0.15 NRES+0.01 BLDGVAL-0.0103 BLDGELE
+0.206 IndxI+0.01205 (IndxC-1)+0.002 KFARM+0.23 ln(DELL)
-0.7822 ln(RREP)+0.25 ln(TM)-0.52 ln(AVSD)+0.142 ln(AR)
+0.4448 ln(ADTE)-0.6333 IndxS-1.51 ln(CC)+1.1039 ln(CM)-0.2426 ln(Uemb)
-0.31 ln(Us)-2.2586 ln(Uc)-1.6228 ln(Up)+0.8629 ln(Uoc)+0.5067 ln(Udmg)

s.e.= 0.7063; r= 0.943; n= 53

Rural / Deserts / Box Culverts:

ln(T-1) = -33.67+1.0187 ln(W)+1.0612 ln(D)+0.2144 ln(Sl)+0.3575 ln(Sc)
-2.2619 ln(Np)-0.9457 ln(Nc)-0.37 ln(DA)-4.0887 ln(PR)+2.2465 ln(GF)
-6.387 ln(Nl)+1.0777 ln(COVERDEP)+6.68 ln(RDWID)
-1.0879 ln(RATE)+0.3563 ln(LIFE)+0.2602 NRES+0.003 BLDGVAL
-0.024 BLDGELE+0.04 KFARM+1.0079 IndxI+0.0103 (IndxC-1)
+0.2687 ln(DELL)-0.945 ln(RREP)+0.415 ln(TM)+0.655 ln(AR)
-0.27 ln(AVSD)+0.02 ln(ADTE)-0.5698 IndxS-0.15 ln(CC)+1.15 ln(CM)
-0.19 ln(Uemb)-0.33 ln(Up)-3.82 ln(Us)-0.4617 ln(Uc)+0.9521 ln(Uoc)
+0.083 ln(Udmg)

s.e.= 0.8023; r= 0.926; n= 54

Table 14.2(c) Predictive Equations for the LTEC Design Return Period for *Pipe Culverts* in *Rural Areas* Based on *Discretized* Design Return Period.

Rural / Mountainous Region / Pipe Culverts:

ln(T-1) = 5.000+0.11 ln(W)-0.4347 ln(D)+0.3627 ln(Sl)-0.08 ln(Sr)-0.2517 ln(Sc)
-0.711 ln(Np)-0.7024 ln(Nc)-0.2091 ln(DA)-1.5117 ln(PR)+0.05918 IndxP
-1.0983 ln(RDWID)-0.7153 ln(THICKPV)-0.2717 ln(RATE)
+0.9035 ln(LIFE)+0.009 NRES+0.0011 BLDGVAL-0.004 BLDGELE
+0.002 KFARM+0.476 IndxI+0.016 (IndxC-1)+0.3159 ln(DELL)
-1.28 ln(RREP)+1.40 ln(TM)-0.8047 ln(AVSD)+0.6928 ln(AR)
+0.07 ln(ADTE)-2.14 ln(CC)+0.4574 ln(CM)-1.6988 ln(Uemb)
-1.8269 ln(Up)+1.1234 ln(Uoc)+0.3755 ln(Udmg)

s.e.= 0.8268; r= 0.855; n= 69

Rural / High Plain Region / Pipe Culverts:

ln(T-1) = -3.213-0.9216 ln(W)+1.5891 ln(D)-0.376 ln(Sl)-0.4037 ln(Sr)
+0.3534 ln(Sc)+0.257 ln(Np)+0.2 ln(Nc)-0.1155 ln(DA)-3.9248 ln(GF)
-0.16 ln(Nl)+0.007 IndxP-0.21 ln(RDWID)-0.4164 ln(RATE)
+0.73 ln(LIFE)+0.012*NRES+0.0008*BLDGVAL-0.002 BLDGELE
+0.13 IndxI+0.017 (IndxC-1)+0.0004 KFARM+0.2262 ln(DELL)
-0.11 ln(RREP)+0.14 ln(TM)-0.66 ln(AVSD)+0.49 ln(AR)+0.15 ln(ADTE)
-0.2156 IndxS-1.32 ln(CC)-0.21 ln(Uemb)-0.5901 ln(Up)+0.24 ln(CM)
+0.41 ln(Uoc)+0.3537 ln(Udmg)

s.e.= 0.7648; r= 0.945; n= 66

Rural / Deserts / Pipe Culverts:

ln(T-1) = -14.200+0.15 ln(W)+0.9652 ln(D)+0.15 ln(Sl)-0.06 ln(Sr)+0.1639 ln(Sc)
-0.46 ln(Np)+0.7275 ln(Nc)-0.391 ln(DA)-2.7395 ln(GF)
-3.5297 ln(Nl)-0.04098 IndxP+3.904 ln(RDWID)-0.3627 ln(THICKPV)
-0.22 ln(RATE)+0.9367 ln(LIFE)+0.021*NRES+0.001328 BLDGVAL
-0.02 BLDGELE+0.04147 IndxI+0.02361 (IndxC-1)+0.003 KFARM
+0.13293 ln(DELL)-0.7085 ln(RREP)+0.893 ln(TM)-0.671 ln(AVSD)
+0.2677 ln(AR)+0.2308 ln(ADTE)-0.2931 IndxS-1.164 ln(CC)+0.5193 ln(CM)
-0.8 ln(Uemb)-0.43 ln(Up)+0.53 ln(Uoc)+0.2543 ln(Udmg)

s.e. = 0.7335; r= 0.934; n= 74

Table 14.3(a) Predictive Equations for the LTEC Design Return Period for *Bridges* in *Urban Areas* Based on *Continuous* Design Return Period.

Urban / Mountainous Region / Bridges:

$$\begin{aligned}\ln(T-1) = {} & -11.81-1.1312\ln(W)+0.18\ln(Sl)+0.1495\ln(Sr)-1.542\ln(Sc)-0.5847\ln(Np) \\ & +0.07\ln(Nc)+0.6876\ln(DA)+0.5593\ln(PR)+0.19\ln(Wp)+0.14\ln(Nl) \\ & -3.5482\ln(THICKPV)-0.07\ln(RATE)+1.5387\ln(LIFE) \\ & +0.058\,NBLDG+0.01416\,BLDGVAL-0.0037\,BLDGELE \\ & +0.1967\ln(DELL)-1.226\ln(RREP)+0.36\ln(TM)-0.3943\ln(AVSD) \\ & +1.1551\ln(AR)+0.51\,IndxS+0.22\ln(ADTE)-2.6\ln(CC)-0.25\ln(Uemb) \\ & -0.63\ln(Ubdg)-0.4763\ln(Up)+0.4183\ln(CM)+0.753\ln(Uoc)+0.5327\ln(Udmg)\end{aligned}$$

s.e.= 0.699; r= 0.909; n= 51

Urban / High Plain Region / Bridges:

$$\begin{aligned}\ln(T-1) = {} & -7.824+1.0315\ln(W)-0.07\ln(Sl)+0.4617\ln(Sr)+0.4483\ln(Sc) \\ & +0.2688\ln(Np)+0.10\ln(Nc)-0.1335\ln(DA)-1.5567\ln(GF)+0.21\ln(Wp) \\ & -0.17\ln(Nl)+1.0591\ln(THICKPV)-0.11\ln(RATE)+0.63\ln(LIFE) \\ & +0.036287\,NBLDG+0.001\,BLDGVAL-0.003904\,BLDGELE \\ & +0.42\ln(DELL)-0.8815\ln(RREP)+1.17\ln(TM)-0.254\ln(AVSD) \\ & +0.4855\ln(AR)+0.3305\ln(ADTE)-3.14\ln(CC)-0.52\ln(Uemb)-0.23\,IndxS \\ & -0.22\ln(Ubdg)-0.7884\ln(Up)+0.20\ln(CM)+0.5256\ln(Uoc)+0.5913\ln(Udmg)\end{aligned}$$

s.e.= 0.5127; r= 0.891; n= 54

Urban / Deserts / Bridges:

$$\begin{aligned}\ln(T-1) = {} & -7.448+0.6347\ln(Sl)+0.2755\ln(Sr)-0.06\ln(Sc)-0.6644\ln(Np) \\ & -0.21\ln(Nc)+0.216\ln(DA)-1.1\ln(PR)+2.232\ln(GF)-1.3823\ln(Nl) \\ & +0.3238\ln(Wp)+4.35\ln(BRIWID)-0.9378\ln(RATE)+0.9906\ln(LIFE) \\ & +0.0464\,NBLDG+0.0023\,BLDGVAL-0.0104\,BLDGELE+0.18\ln(DELL) \\ & -1.02\ln(RREP)+0.11\ln(TM)-0.583\ln(AVSD)+0.21\ln(AR)+0.1565\ln(ADTE) \\ & -0.1987\,IndxS-4.12\ln(CC)-2.2692\ln(Uemb)-1.0\ln(Ubdg)-0.4685\ln(Up) \\ & +0.2552\ln(CM)+0.186\ln(Uoc)+0.15\ln(Udmg)\end{aligned}$$

s.e.= 0.7835; r= 0.899; n= 43

Table 14.3(b) Predictive Equations for the LTEC Design Return Period for *Box Culverts* in *Urban Areas* Based on *Continuous* Design Return Period.

Urban / Mountainous Region / Box Culverts:

ln(T-1) = -34.80-0.23 ln(W)+1.2879 ln(D)+0.791 ln(Sl)+0.7225 ln(Sr)
+0.1707 ln(Sc)-0.8096 ln(Np)+0.4361 ln(Nc)+0.3795 ln(DA)+3.5097 ln(PR)
-0.8497 COVERDEP+1.7083 ln(THICKPV)-1.2175 ln(RATE)
+2.1622 ln(LIFE)+0.09809 NBLDG+0.003063 BLDGVAL-0.0047 BLDGELE
+0.6018 ln(DELL)-0.14 ln(RREP)+1.2422 ln(TM)-0.42 ln(AVSD)
+0.63 ln(AR)+0.3413 ln(ADTE)-0.27 ln(CC)-0.2068 ln(Uemb)-0.3746 ln(Us)
-0.22 ln(Uc)-0.4495 ln(Up)+0.5366 ln(CM)+0.83 ln(Uoc)+0.529 ln(Udmg)

s.e.= 0.8362; r= 0.928; n= 59

Urban / High Plain Region / Box Culverts:

ln(T-1) = 4.156+1.4724 ln(D)+0.1649 ln(Sr)-0.04 ln(Sl)-0.5777 ln(Sc)+0.05 ln(Np)
-0.9346 ln(Nc)-0.1333 ln(DA)-1.383 ln(GF)-0.6068 ln(COVERDEP)
-0.7314 ln(RDWID)+0.7882 ln(THICKPV)-0.6335 ln(RATE)
+0.4649 ln(LIFE)+0.0251 NBLDG+0.00261 BLDGVAL-0.002371 BLDGELE
+0.4002 ln(DELL)-0.523 ln(RREP)+0.25 ln(TM)-0.7063 ln(AVSD)
+1.0339 ln(AR)+0.3931 ln(ADTE)-2.227 ln(CC)-0.24 ln(Uemb)-2.41 ln(Us)
-4.2096 ln(Uc)-0.15 ln(Up)+0.4974 ln(CM)+0.9542 ln(Uoc)+0.6548 ln(Udmg)

s.e.= 0.7112; r= 0.934; n= 59

Urban / Deserts / Box Culverts:

ln(T-1) = - 5.168+0.5186 ln(W)-0.4994 ln(D)-0.06 ln(Sl)+0.24656 ln(Sr)
+0.4976 ln(Sc)+0.6216 ln(Np)+1.6304 ln(Nc)+0.27 ln(DA)
+1.52 ln(PR)-0.8115 ln(GF)-2.689 ln(Nl)+1.4092 ln(COVERDEP)
+2.559 ln(RDWID)-1.3487 ln(THICKPV)-0.3221 ln(RATE)+0.35 ln(LIFE)
+0.0412 NBLDG+0.00278 BLDGVAL-0.003558 BLDGELE
+0.20985 ln(DELL)-0.25 ln(RREP)+0.47 ln(TM)-0.24 ln(AVSD)
+0.41 ln(AR)+0.228 ln(ADTE)-1.31 ln(CC)
-1.0928 ln(Uemb)-0.37 ln(Us)-0.97 ln(Uc)-0.27 ln(Up)+0.47 ln(CM)
+0.7962 ln(Uoc)+0.00050876 Udmg

s.e.= 0.5719; r= 0.925; n= 56

Table 14.3(c) Predictive Equations for the LTEC Design Return Period for *Pipe Culverts* in *Urban Areas* Based on *Continuous* Design Return Period.

Urban / Mountainous Region / Pipe Culverts:

ln(T-1) = 14.226+0.1742 ln(W)-0.3118 ln(D)-0.07 ln(Sl)-0.2733 ln(Sc)
-0.3175 ln(Np)-0.9616 ln(Nc)-0.1454 ln(DA)+3.9208 ln(Nl)-0.01048 IndxP
-5.912 ln(RDWID)-0.11 ln(THICKPV)-1.0841 ln(RATE)+0.281 ln(LIFE)
+0.008 NBLDG+0.001 BLDGVAL-0.0031 BLDGELE+0.2369 ln(DELL)
-1.391 ln(RREP)+1.1618 ln(TM)-0.5953 ln(AVSD)+0.5852 ln(AR)
+0.14 ln(ADTE)-2.691 ln(CC)-1.6864 ln(Uemb)-0.6513 ln(Up)
+0.3253 ln(CM)+0.2786 ln(Uoc)+0.07 ln(Udmg)

s.e.= 0.6718; r= 0.889; n= 64

Urban / High Plain Region / Pipe Culverts:

ln(T-1) = 3.584-1.7597 ln(W)+2.5725 ln(D)-0.2481 ln(Sl)-0.7207 ln(Sr)-0.54 ln(Sc)
+0.07 ln(Np)+0.3901 ln(Nc)+0.0771 ln(DA)-2.3434 ln(GF)
-0.7628 ln(Nl)-0.7061 ln(COVERDEP)-0.12 ln(THICKPV)+0.01833 IndxP
-0.18 ln(RATE)+0.4706 ln(LIFE)+0.05448 NBLDG
+0.002572 BLDGVAL-0.0047 BLDGELE+0.3098 ln(DELL)
-1.417 ln(RREP)+0.36 ln(TM)-1.35 ln(AVSD)+0.41 ln(AR)+0.2635 ln(ADTE)
-0.2375 IndxS-3.26 ln(CC)-0.5634 ln(Uemb)-1.0233 ln(Up)+0.5959 ln(CM)
+0.3931 ln(Uoc)+0.4434 ln(Udmg)

s.e.= 1.012; r= 0.871; n= 83

Urban / Deserts / Pipe Culverts:

ln(T-1) = 0.551-0.5558 ln(W)+0.6229 ln(D)+0.2298 ln(Sl)+1.0428 ln(Sr)
+0.4584 ln(Sc)-0.2525 ln(Np)+0.03 ln(Nc)+0.2858 ln(DA)
+1.1022 ln(PR)-1.5876 ln(GF)+0.70 ln(COVERDEP)-1.0803 ln(RDWID)
-0.25 ln(THICKPV)-0.93 ln(RATE)+0.37 ln(LIFE)+0.04234 NBLDG
+0.002391 BLDGVAL-0.015216 BLDGELE+0.2735 ln(DELL)
-1.1877 ln(RREP)+1.1529 ln(TM)-0.58 ln(AVSD)+0.4278 ln(AR)
+0.2914 ln(ADTE)-2.69 ln(CC)-0.43 ln(Uemb)-0.4794 ln(Up)
+0.7344 ln(CM)+0.15 ln(Uoc)+0.10 ln(Udmg)

s.e.= 0.7665; r= 0.905; n= 73

Table 14.4(a) Predictive Equations for the LTEC Design Return Period for *Bridges* in *Rural Areas* Based on *Continuous* Design Return Period.

Rural / Mountainous Region / Bridges:

ln(T-1) = -10.980-0.2751 ln(D)-0.02 ln(Sl)-0.60 ln(Sc)-0.5085 ln(Np)+1.6888 ln(Nc)
+0.274 ln(DA)+1.59 ln(PR)-1.994 ln(Nl)+3.95 ln(Wp)+1.84 ln(BRIWID)
-3.538 ln(THICKPV)-0.06 ln(RATE)+0.4537 ln(LIFE)+0.035 NRES
+0.0005 BLDGVAL-0.0017 BLDGELE+0.2762 IndxI
+0.014258 (IndxC-1)+0.004 KFARM+0.17704 ln(DELL)-0.867 ln(RREP)
+0.81 ln(TM)-0.51 ln(AVSD)+0.72 ln(AR)+0.30 ln(ADTE)-1.138 ln(CC)
-0.8147 ln(Uemb)-0.4335 ln(Ubdg)-0.64 ln(Up)+0.56 ln(CM)
+0.61 ln(Uoc)+0.5197 ln(Udmg)

s.e.= 0.6006; r= 0.858; n=59

Rural / High Plain Region / Bridges:

ln(T-1) = -3.841+0.3007 ln(W)+0.3903 ln(D)+0.5516 ln(Sl)+0.7383 ln(Sc)
+0.63 ln(Np)+0.90 ln(Nc)-0.5831 ln(DA)-2.2274 ln(GF)-0.09 ln(Nl)
+0.43 ln(Wp)+0.6369 ln(THICKPV)-0.1592 ln(RATE)
+1.8325 ln(LIFE)+0.045 NRES+0.005 BLDGVAL-0.0017 BLDGELE
+0.3388 IndxI+0.01 (IndxC-1)+0.005 KFARM+0.15 ln(DELL)
-0.31 ln(RREP)+0.23 ln(TM)-0.15 ln(AVSD)+1.1 ln(AR)+0.176 ln(ADTE)
-1.895 ln(CC)-0.4917 ln(Uemb)-0.57 ln(Ubdg)-0.44 ln(Up)+0.51 ln(CM)
+0.45 ln(Uoc)+0.24 ln(Udmg)

s.e.= 0.5632; r= 0.880; n=59

Rural / Deserts / Bridges:

ln(T-1) = 4.27+1.0136 ln(D)-0.163 ln(Sr)-0.03 ln(Sc)+1.1776 ln(Np)+0.162 ln(Nc)
-0.28 ln(DA)+1.6782 ln(PR)-1.1169 ln(GF)+4.0 ln(Nl)+0.837 ln(Wp)
-8.226 ln(BRIWID)-2.4805 ln(RATE)+0.8058 ln(LIFE)+0.2421 NRES
+0.00025 BLDGVAL-0.0045 BLDGELE+0.5618 IndxI
+0.03549 (IndxC-1)+0.041 KFARM+0.1717 ln(DELL)-0.361 ln(RREP)
+0.6672 ln(TM)-0.6233 ln(AVSD)+0.88 ln(AR)+0.2015 ln(ADTE)
-1.0 IndxS-3.817 ln(CC)-2.04 ln(Uemb)-0.7612 ln(Ubdg)-2.0444 ln(Up)
+0.664 ln(CM)+0.5255 ln(Uoc)+2.3697 ln(Udmg)

s.e.= 0.6777; r= 0.902; n=56

Table 14.4(b) Predictive Equations for the LTEC Design Return Period for *Box Culverts* in *Rural Areas* Based on the *Continuous* Design Return Period.

Rural / Mountainous Region / Box Culverts:

ln(T-1) = 14.773+2.0032 ln(W)-0.4901 ln(D)+0.20529 ln(Sl)+0.48731 ln(Sr)
+0.1682 ln(Sc)-1.0185 ln(Nc)-0.3872 ln(DA)-0.8168 ln(PR)+4.1064 ln(Nl)
-2.7647 ln(COVERDEP)-3.2532 ln(RDWID)-0.16 ln(RATE)
+0.35 ln(LIFE)+0.13 NRES+0.015 BLDGVAL-0.0089 BLDGELE
+0.02 IndxI+0.01811 (IndxC-1)+0.022 KFARM+0.23 ln(DELL)
-0.7105 ln(RREP)+0.1787 ln(TM)-0.5224 ln(AVSD)+0.2846 ln(AR)
+0.23 ln(ADTE)-0.2422 IndxS-1.18 ln(CC)-0.5 ln(Uemb)
-1.9726 ln(Us)-2.361 ln(Uc)-0.4212 ln(Up)+1.27 ln(CM)+0.6765 ln(Uoc)
+0.17 ln(Udmg)

s.e.= 0.5679; r= 0.955; n= 58

Rural / High Plain Region / Box Culverts:

ln(T-1) = -3.369+0.52 ln(W)+2.1682 ln(D)-0.4025 ln(Sl)-0.3639 ln(Sr)
+0.9671 ln(Sc)-0.8517 ln(Np)-0.1814 ln(DA)-3.5641 ln(Nl)
+0.8968 ln(COVERDEP)+3.065 ln(RDWID)-1.5101 ln(THICKPV)
-0.11 ln(RATE)+0.6899 ln(LIFE)+0.11 NRES+0.008 BLDGVAL
-0.0114 BLDGELE+0.2561 IndxI+0.01871 (IndxC-1)+0.003 KFARM
+0.19 ln(DELL)-0.8619 ln(RREP)+0.24 ln(TM)-0.47 ln(AVSD)
+0.135 ln(AR)+0.4814 ln(ADTE)-0.6184 IndxS-1.525 ln(CC)
-0.2124 ln(Uemb)-0.30 ln(Us)-2.31 ln(Uc)-1.8596 ln(Up)+1.3712 ln(CM)
+0.9007 ln(Uoc)+0.4472 ln(Udmg)

s.e.= 0.6448; r= 0.956; n= 53

Rural / Deserts / Box Culverts:

ln(T-1) = -34.46+1.0267 ln(W)+0.8877 ln(D)+0.2068 ln(Sl) +0.3453 ln(Sc)
-2.3583 ln(Np)-0.98 ln(Nc)-0.35 ln(DA)-4.1261 ln(PR)+2.2849 ln(GF)
-6.482 ln(Nl)+0.9852 ln(COVERDEP)+6.719 ln(RDWID)-1.0469 ln(RATE)
+0.34 ln(LIFE)+0.2366 NRES+0.005 BLDGVAL-0.027 BLDGELE
+1.039 IndxI+0.023 (IndxC-1)+0.054 KFARM+0.2556 ln(DELL)
-0.908ln(RREP)+0.4524ln(TM)-0.25ln(AVSD)+0.674ln(AR)+0.03ln(ADTE)
-0.589 IndxS-0.14 ln(CC)-0.17 ln(Uemb)-2.78 ln(Us)-0.4462 ln(Uc)
-0.31 ln(Up)+1.21 ln(CM)+1.0874 ln(Uoc)+0.08107 ln(Udmg)

s.e.= 0.8351; r= 0.913; n= 54

Table 14.4(c) Predictive Equations for the LTEC Design Return Period for *Pipe Culverts* in *Rural Areas* Based on the *Continuous* Design Return Period.

Rural / Mountainous Region / Pipe Culverts:

ln(T-1) = 4.67+0.08 ln(W)-0.5511 ln(D)+0.3924 ln(Sl)-0.1274 ln(Sr)-0.2401 ln(Sc)
-0.6964 ln(Np)-0.7625 ln(Nc)-0.2 ln(DA)-1.5969 ln(PR)+0.06937 IndxP
-1.0066 ln(RDWID)-0.6882 ln(THICKPV)-0.3802 ln(RATE)
+0.8927 ln(LIFE)+0.007 NRES+0.0013 BLDGVAL-0.003 BLDGELE
+0.5411 IndxI+0.0146 (IndxC-1)+0.001 KFARM+0.3684 ln(DELL)
-1.21 ln(RREP)+1.551 ln(TM)-0.8063 ln(AVSD)+0.6475 ln(AR)
+0.05 ln(ADTE)-2.475 ln(CC)-1.7826 ln(Uemb)-1.8313 ln(Up)
+0.4278 ln(CM)+1.1459 ln(Uoc)+0.3506 ln(Udmg)

s.e.= 0.8682; r= 0.857; n= 69

Rural / High Plain Region / Pipe Culverts:

ln(T-1) = -3.443-0.9102 ln(W)+1.55 ln(D)-0.4332 ln(Sl)-0.4564 ln(Sr)+0.331 ln(Sc)
+0.2515 ln(Np)+0.1 ln(Nc)-0.09 ln(THICKPV)-0.14 ln(DA)-3.27 ln(GF)
-0.38 ln(RATE)+0.65 ln(LIFE)+0.013 NRES+0.0007 BLDGVAL
-0.0025 BLDGELE+0.3318 IndxI+0.0175 (IndxC-1)+0.0005 KFARM
-0.2279 IndxS+0.252 ln(DELL)+0.17 ln(TM)-0.7661 ln(AVSD)
+0.35 ln(AR)+0.14 ln(ADTE)-1.27 ln(CC)-0.25 ln(Uemb)-0.54 ln(Up)
+0.22 ln(CM)+0.43 ln(Uoc)+0.347 ln(Udmg)

s.e.= 0.7681; r= 0.949; n= 66

Rural / Deserts / Pipe Culverts:

ln(T-1) = -14.352+0.14 ln(W)+0.97 ln(D)+0.1576 ln(Sl)+0.1728 ln(Sc)
-0.52 ln(Np)+0.8263 ln(Nc)-0.4702 ln(DA)-2.814 ln(GF)-3.3368 ln(Nl)
-0.04353 IndxP+3.737 ln(RDWID)-0.3557 ln(THICKPV)-0.27 ln(RATE)
+1.1987 ln(LIFE)+0.019 NRES+0.0015 BLDGVAL-0.023 BLDGELE
+0.04 IndxI+0.0244 (IndxC-1)+0.003 KFARM+0.14527 ln(DELL)
-0.7068 ln(RREP)+0.9123 ln(TM)-0.6514 ln(AVSD)+0.2618 ln(AR)
+0.2355 ln(ADTE)-0.2944 IndxS-1.138 ln(CC)-0.8101 ln(Uemb)
-0.47 ln(Up)+0.535 ln(CM)+0.57 ln(Uoc)+0.275 ln(Udmg)

s.e.= 0.6922 ; r= 0.951; n= 70

dependent variable. Definitions of the variables in the predictive equations in Tables 14.1-14.4 are listed in Table 14.5. Once the value of dependent variable ln(T-1) is computed by an appropriate equation in Tables 14.1-14.4 for a specified site, the LTEC return period T can be obtained easily as

$$T = \exp[\ \ln(T-1)\ ] + 1 \tag{14.2}$$

14.2 COMPUTATION OF WEIGHTED LTEC DESIGN FREQUENCY FROM DISCRETE LTEC AND CONTINUOUS LTEC DESIGN FREQUENCIES

From the foregoing discussions about the discrete and continuous LTEC design frequencies, some discrepancies could exist between their values for a given site condition due to the interpolation. Such discrepancy will prevail through the use of empirical equations in Tables 14.1 and 14.3 for urban areas and in Tables 14.2 and 14.4 for rural areas. Although the LTEC design frequency obtained from the empirical equations using the discretized return periods could be different from that using the continuous return period, they are, nevertheless, two computed quantities for estimating the same LTEC design return period in question. Therefore, judgement must be made to reach a suggested LTEC return period for engineering design.

In this study, a procedure was employed to computed the weighted LTEC design frequency for a given site condition based on the two LTEC design frequencies. Let $Y_C=\ln(T_C-1)$ and $Y_D=\ln(T_D-1)$ be quantities computed from the empirical equations based on the discretized and continuous return periods, respectively. The weighted quantity, Y_W, is simply the weighted average of Y_C and Y_D as

$$Y_W = W\, Y_C + (1 - W)\, Y_D \tag{14.3}$$

in which W is the weighing factor with its value lying between 0 and 1. It is understood that the two quantities, Y_C and Y_D, computed from the empirical equations are not exact, but are subject to uncertainties. The associated

Table 14.5 Definitions of Variables in Predictive Equations for the LTEC Design Frequency.

ADTE = Avg. daily traffic count.	AR = accident ratio (acci/million vehicle miles)
AVSD = Average vehicle speed on detour (mph)	
BLDGELE = Avg. Bldg. height above channel bottom (ft)	BLDGVAL=Avg. Bldg. values ($1000)
	BRIWID = Total bridge width (ft)
CC = Cost adjustment factor	CM = Mobilization cost ($)
COVERDEP = Soil cover depth (ft)	
D = Bankfull channel depth (ft)	DA = Drainage area (sq. mi.)
DELL = Detour length (miles)	
GF = geographical factor	
IndxC = Crop type	IndxI = Irrigation type
IndxP = Pipe type (see Table 3.2)	IndxS = Soil index of embankment
KFARM = No. of farm houses.	
LIFE = Design project life (yrs)	
NBLDG = No. of buildings	Nc = Manning's roughness in main channel.
Nl = Number of lanes.	
Np = Manning's roughness on floodplain	NRES = No. of residential bldgs.
PR = Annual average precipitation (in.)	
RATE = Interest rate (in decimal)	RDWID = Total road width (ft)
RREP = Rate of repair (cu.yd/day)	
Sc = Longitudinal channel slope (ft/ft)	Sl = Transverse floodplain slope on the left (ft/ft)
Sr = Transverse floodplain slope on the right (ft/ft)	
T = LTEC return period (yrs.)	THICKPV = Pavement thickness (in)
TM = Mobilization time (hrs)	Ubdg = Unit bridge cost ($/sq. ft.)
Udmg = Unit damage cost ($/accid)	Uoc = Unit occupancy cost ($/person)
Uemb = Unit embankment cost ($/cu.yd)	Up = Unit pavement cost ($/cu.yd)
W = Channel width (ft.)	Wp = Bridge pier width (ft)

uncertainties are represented by the corresponding standard errors of the empirical equations for their calculations. Therefore, Y_C and Y_D can be treated as random variables each associated with the variances $Var(Y_C)$ and $Var(Y_D)$, respectively. These variances can be computed as the squared value of the standard error of the corresponding empirical equations.

Since Y_W is a function of Y_C and Y_D which are subject to uncertainties, therefore, Y_W is also subject to uncertainty expressible by its variance, $Var(Y_W)$, as

$$Var(Y_W) = W^2\,Var(Y_C) + (1 - W)_2\,Var(Y_D) \tag{14.4}$$

The weighing procedure used in this study is to determine the weighing factor W in such a way that minimizes the variance (or uncertainty) of the weighted LTEC design frequency. According to Eq.(14.4), it is easy to show that $Var(Y_W)$ is the concave function of W and its minimum can be obtained by solving $d[Var(Y_W)]/dW=0$. The resulting optimum weight, W*, that minimizes the uncertainty of Y_W is

$$W^* = \frac{Var(Y_D)}{Var(Y_D) + Var(Y_C)} \tag{14.5}$$

Substituting Eq.(14.5) to Eq.(14.3), the weighted log-transformed LTEC design frequency, Y_W, can be computed as

$$Y_W = \left(\frac{Var(Y_D)}{Var(Y_D) + Var(Y_C)}\right) Y_C + \left(\frac{Var(Y_C)}{Var(Y_D) + Var(Y_C)}\right) Y_D \tag{14.6}$$

Equation (14.6) can be alternatively expressed as

$$Y_W = \left(\frac{\frac{1}{Var(Y_C)}}{\frac{1}{Var(Y_D)} + \frac{1}{Var(Y_C)}}\right) Y_C + \left(\frac{\frac{1}{Var(Y_D)}}{\frac{1}{Var(Y_D)} + \frac{1}{Var(Y_C)}}\right) Y_D \tag{14.7}$$

which indicates that the weighing factor is proportional to the inverse of the variance of the estimate for the LTEC design frequency. The larger the value of the variance for an LTEC design frequency estimator, which corresponds to large uncertainty, the less weight will be given to that estimator. This is intuitively sensible. Once Y_W is obtained, the weighted LTEC design return period, T_W, can be computed as

$$T_W = \exp [Y_W] + 1 \tag{14.8}$$

14.3 DEVELOPMENT OF WORKING RELATIONSHIPS FOR THE EXTENDED-LTEC DESIGN FREQUENCY WITH SITE CONDITIONS AND INTANGIBLE FACTORS

The extended-LTEC design frequency is the one that, on the basis of the LTEC design frequency, incorporates intangible factors. Specifically, the intangible factors considered in this study for determining the design frequency of highway drainage structures in Wyoming are maintenance frequency, litigation potential, and public service. On the basis of questionnaire survey conducted in this study, elements affecting the extended-LTEC design frequency beyond the LTEC design frequency are the relative importance of each intangible factor as compared with economic factor, drainage structural type, traffic volume, detour length, and land use. More specifically,

$$T_{ext} = f(T_{ltec}, WT1, WT2, WT3, WT4, nADT, nFHT, nLAND, nDETR) \tag{14.9}$$

in which T_{ext} is extended-LTEC design return period; T_{ltec} is the LTEC design return period for the site; WT1 to WT4 are ratings indicating the relative importance of economic factor and three intangible factors, respectively; nADT is indicator for traffic volume class; nFHT is indicator for fill height category; nLAND is indicator for land use category; and nDETR is indicator for detour length category. The values of rating of relative importance and other site condition categories are given previously in Chapter 11 and are stated in Tables 13.5 and 13.6.

To generate the data base for the extended-LTEC design frequency and other relevant variables, the program FUZZY.FOR was applied after the LTEC design frequency is obtained from the program LTEC.FOR for each site condition in the data base. Originally, the extended-LTEC design return period in each synthetic site was computed by considering all three intangible factors simultaneously in the fuzzy decision-making framework (see Chapter 9). Two undesirable things were observed. They are (1) in practically all cases, the extended-LTEC design return period was pushed to a very large value far greater than 100-year; and (2) extensive computer time was required for each individual site which is not computationally practical when many synthetic sites are to be considered.

As an alternative, it was decided to determine the extended-LTEC design return period by pair-wise comparison of each of the three intangible factors with the tangible economic factor of total structural cost. In doing so, computation effort is significantly reduced and three extended-LTEC design return periods, each corresponds to the three intangible factors, will be obtained. The extended-LTEC design return period to be adopted will be the one that is the largest value of the three extended-LTEC design return periods, that is,

$$T_{ext} = \text{Max}\ \{T_{ext,MF},\ T_{ext,LP},\ T_{ext,PS}\} \tag{14.10}$$

in which T_{ext} is the suggested extended-LTEC design return period; $T_{ext,MF}$, $T_{ext,LP}$, $T_{ext,PS}$ are, respectively, the extended-LTEC design return periods considering maintenance frequency, litigation potential, and public service as they individually compare the tangible economic factor. Selecting the largest return period results in conservative design frequency for the remaining intangible factors.

Based on the generated data base containing various site conditions and the corresponding LTEC and extended-LTEC design frequencies, relationships for estimating the extended-LTEC design return period were developed separately for three different intangible factors, locations, hydrologic regions, and drainage structural types. Through many trials of different forms for dependent variable and predictors, it was found that the following form yielded the best statistical relationship:

$$\ln\left(\frac{T_{ext}}{T_{ltec}} - 1\right) = f(\ WT1,\ WT2,\ nADT,\ nFHT,\ nDETR,\ nLAND) \tag{14.11}$$

where WT1 is the relative importance of economic factor (1 - Not important; 2 -

Important; 3 - Very important); WT2 is the relative importance of maintenance frequency; WT3 is the relative importance of litigation potential; WT2 is the relative importance of public service; nADT is the average daily traffic at the site (1 for <750; 2 for 750-5000; 3 for >5000); nDTER is the length of detour (1 for < 5 miles; 2 for 5-20 miles; 3 for >20 miles); nFHT is the fill height of embankment (1 for <8ft; 2 for 8-20 ft; 3 for >20 ft); nLAND is the land use types (in urban area: 1 for rec. area w/o bldgs; 2 for 1 to 3 resid. bldgs; 3 for more than 3 resid. bldgs./ in rural area, 1 - desert or prairie; 2 - irrigation meadow; 3 - farm or ranch).

The final equations from the regression analysis are shown in Table 14.6 for urban areas and Table 14.7 for rural areas. Note that, in Tables 14.6 and 14.7, the dependent variable is $Y=\ln(T_{ext}/T_{ltec}-1)$ which does not directly yield the extended-LTEC return period. Hence, once the value of Y is computed, the extended-LTEC return period can be obtained as

$$T_{ext} = T_{ltec}\,(1 + e^{Y}) \tag{14.10}$$

14.4 COMMENTS ABOUT THE USE OF DEVELOPED WORKING RELATIONSHIPS

On the use of developed working models, equation sets in Tables 14.1-14.4 and Tables 14.6-14.7 should be used in tandem. In other words, one should use appropriate equations in Tables 14.1-14.2 (based on the discretized return periods) or 14.3-14.4 (based on the continuous return period) first to compute the LTEC design return period based on the hydraulic, economic, traffic, and structural conditions of the site. Ideally, it should be immaterial whether to use equations in Tables 14.1-14.2 or 14.3-14.3 to estimate the LTEC design frequency. However, for purpose of comparison about the consistency of the results, it is suggested that both equation sets are used. Furthermore, a computation of the weighted LTEC design frequency according to the procedure described in Section 14.2 is recommended. Once the LTEC design return period is computed, then equations in Tables 14.6-14.7 could be applied to determine the extended-LTEC design return period for the three intangible factors. The suggested extended-LTEC design return period will take the value which is the largest of the three associated with the intangible factors. Based on the empirical equation sets

Table 14.6(a) Predictive Equations for the Extended-LTEC Design Return Period for *Bridges* in *Urban Areas*

Urban / Mountainous Region / Bridges:

Maintenance Frequency $Y = -12.828 + 11.24\ WT1 - 2.3378\ WT1^2 + 0.42 WT2 - 0.641\ nFHT^2$
(s.e.= 1.620; r= 0.824; n= 34)

Litigation Potential $Y = -8.638 + 1.7582\ WT1 - 2.043\ nADT + 6.532\ nFHT + 0.3052\ WT2^2 - 2.0048\ nFHT^2 + 0.05365\ nLAND^2$
(s.e.=1.526; r= 0.755; n= 34)

Public Service $Y = -112.46 + 12.552\ WT1 + 0.44\ WT2 + 2.0761\ nADT - 1.8216\ nDETR + 12.3\ nLAND - 2.337\ WT1^2$
(s.e.= 1.121; r= 0.928; n= 28)

Urban / High Plain Region / Bridges:

Maintenance Frequency $Y = -25.347 + 16.513\ WT1 + 3.839\ WT2 + 4.745\ nFHT - 3.5663\ WT1^2 - 0.9927\ WT2^2 - 1.5872\ nFHT^2$
(s.e.=1.066; r = 0.851; n = 41)

Litigation Potential $Y = 4.084 + 7.831\ WT1 - 9.239\ WT2 - 11.171\ nADT - 1.5659\ WT1^2 + 2.625\ WT2^2 + 2.589\ nADT^2$
(s.e.= 2.564; r = 0.688; n = 39)

Public Service $Y = -20.948 + 14.721\ WT1 + 1.6598\ WT2 - 5.411\ nADT + 3.57\ nFHT - 3.0175\ WT1^2 + 1.141\ nADT^2 - 1.0566\ nFHT^2 + 0.05719\ nLAND^2$
(s.e. =1.185; r = 0.864; n = 36)

Urban / Desert Region / Bridges:

Maintenance Frequency $Y = -13.212 + 2.1314\ WT1 - 3.492\ WT2 - 1.4806\ nDETR + 2.145\ nLAND + 1.0527\ WT2^2 - 0.6572\ nFHT^2$
(s.e. = 1.124; r = 0.854; n = 33)

Litigation Potential $Y = -12.386 + 6.412\ WT1 - 4.54\ WT2 - 1.882\ nADT + 2.1155\ nLAND - 1.6088\ WT1^2 + 1.069\ WT2^2 - 0.4439\ nFHT^2$
(s.e. = 1.607; r = 0.819; n = 34)

Public Service $Y = -25.144 + 6.033\ WT1 + 3.462\ nFHT + 2.3293\ nLAND - 1.1468\ WT1^2 - 1.1724\ nFHT^2$
(s.e. = 1.251; r = 0.849; n = 33)

Note: Y : Dependent variable, $\ln(T_{ext}/T_{ltec} - 1)$

Table 14.6(b) Predictive Equations for the Extended-LTEC Design Return Period for *Box Culverts* in *Urban Areas*

Urban / Mountainous Region / Box Culvert:

Maintenance frequency $Y = -54.28+7.338\ WT1+0.5975\ WT2+0.3356\ nADT -4.8904\ nDETR -3.643\ nFHT+19.483\ nLAND-1.8163\ WT1^2+1.114\ nFHT^2 -1.698\ nLAND^2$ (s.e.=1.371; r= 0.775; n= 55)

Litigation potential $Y = -1.02+3.341\ WT1+4.76\ WT2-0.4504\ nADT+6.818\ nFHT-7.505\ nLAND -0.5455\ WT1^2-1.3356\ WT2^2-1.4418\ nFHT^2+0.797\ nLAND^2$
(s.e.= 1.611; r= 0.740; n = 54)

Public service $Y = -6.394+3.5879\ WT1+0.500\ WT2-1.6472\ nDETR+0.513\ nFHT -1.1259\ WT1^2+0.10639\ nLAND^2$
(s.e. = 0.622; r = 0.812; n = 46)

Urban / High Plain Region / Box Culvert:

Maintenance frequency $Y = -126.40+5.652\ WT1+0.3374\ nADT+0.9419\ nDETR+1.5351\ nFHT +41.1\ nLAND-0.993\ WT1^2+0.3556\ WT2^2-3.82\ nLAND^2$
(s.e. = 2.583; r = 0.748; n = 41)

Litigation potential $Y = -121.16+9.881\ WT1-5.504\ WT2+0.3173\ nADT+1.1043\ nFHT +40.75\ nLAND-1.866\ WT1^2+1.6522\ WT2^2-3.822\ nLAND^2$
(s.e. = 2.017; r = 0.858; n = 39)

Public service $Y = -123.66+6.199\ WT1-1.50\ WT2+0.6416\ nADT+43.05\ nLAND -1.01\ WT1^2-3.955\ nLAND^2$
(s.e.= 2.541; r = 0.749; n = 40)

Urban / Desert Region / Box Culvert:

Maintenance frequency $Y = -41.2+9.046\ WT1+3.5781\ WT2-1.608\ nADT-4.647\ nDETR+2.133\ nFHT +6.05\ nLAND-1.5827\ WT1^2-0.307\ nLAND^2$
(s.e. = 1.217; r = 0.715; n = 39)

Litigation potential $Y = -57.01+14.21\ WT1+4.354\ WT2-1.3445\ nADT+1.521\ nDETR +15.541\ nLAND-3.518\ WT1^2-1.0269\ WT2^2-1.7094\ nLAND^2$
(s.e. = 1.783; r = 0.865; n = 43)

Public service $Y = -37.55+11.596\ WT1+1.137\ WT2-1.6357\ nADT+0.707\ nDETR +7.842\ nLAND-2.9447\ WT1^2-0.654\ nLAND^2$
(s.e. = 1.391; r = 0.672; n = 43)

Note: Y : Dependent variable, $\ln(T_{ext}/T_{ltec} -1)$

Table 14.6(c) Predictive Equations for the Extended-LTEC Design Return Period for *Pipe Culverts* in *Urban Areas*

Urban/ Mountainous Region / Pipe Culvert:

Maintenance frequency

$$Y = -34.971+12.635\ WT1+7.295\ WT2+1.0344\ nDETR+14.286\ nFHT -0.5852\ nLAND-2.7641\ WT1^2-1.7704\ WT2^2-3.4425\ nFHT^2$$

(s.e. = 1.330; r = 0.739; n = 48)

Litigation potential

$$Y = 50.57+10.637\ WT1+0.3535\ WT2-0.8275\ nADT+2.514\ nDETR -27.08\ nLAND-3.0347\ WT1^2-0.2902\ nFHT^2+2.705\ nLAND^2$$

(s.e. = 2.413; r = 0.674; n = 47)

Public service

$$Y = 14.18+16.32\ WT1-1.4368\ WT2+0.6222\ nADT+1.787\ nDETR +4.064\ nFHT-15.17\ nLAND-4.0076\ WT1^2-1.3698\ nFHT^2+1.523\ nLAND^2$$

(s.e.= 1.531; r = 0.757; n = 46)

Urban / High Plain Region / Pipe Culvert:

Maintenance frequency

$$Y = 7.02+9.977\ WT1-6.291\ WT2+0.801\ nADT -0.6205\ nDETR-1.0315\ nFHT -6.48\ nLAND-2.5215\ WT1^2+2.3267\ WT2^2+0.5394\ nLAND^2$$

(s.e. = 0.978; r = 0.896; n = 39)

Litigation potential

$$Y = 22.85+8.082\ WT1-2.637\ WT2+0.5164\ nADT+5.812\ nFHT -16.786\ nLAND-2.2952\ WT1^2+0.8168\ WT2^2 -1.7655\ nFHT^2+1.8021\ nLAND^2$$

(s.e. = 1.275; r = 0.896; n = 39)

Public service

$$Y = -22.4+0.6106\ WT1-5.754\ WT2-0.6099\ nADT+1.0763\ nDETR -2.84\ nFHT +11.402\ nLAND+1.1737\ WT2^2+0.7173\ nFHT^2-1.1196\ nLAND^2$$

(s.e. = 1.201; r = 0.583; n = 41)

Urban / Desert Region / Pipe Culvert:

Maintenance frequency

$$Y = 5.67+13.739\ WT1+0.6127\ nADT-1.185\ nDETR-9.729\ nLAND -2.8308\ WT1^2-0.6472\ nFHT^2+1.0813\ nLAND^2$$

(s.e. =0.935; r = 0.849; n = 26)

Litigation potential

$$Y = 44.23+16.194\ WT1+0.7809\ nADT-2.50\ nDETR-26.29\ nLAND -3.845\ WT1^2+2.6907\ nLAND^2$$

(s.e. = 1.651; r =0.838; n = 27)

Public service

$$Y = 38.67+16.679\ WT1-11.927\ WT2+1.2232\ nADT-1.5504\ nDETR -8.4961\ nFHT-19.209\ nLAND-3.8822\ WT1^2+2.608\ WT2^2+2.26\ nLAND^2$$

(s.e. = 1.116; r =0.939; n = 24)

Note: Y : Dependent variable, $\ln(T_{ext}/T_{ltec} -1)$

Table 14.7(a) Predictive Equations for the Extended-LTEC Design Return Period for *Bridges* in *Rural Areas*

<u>Rural / Mountainous Region / Bridges:</u>

Maintenance Frequency

$Y = 5.21+3.01\ WT1-6.53\ WT2-9.41\ nADT+7.76\ nDETR-8.26\ nFHT -1.17\ nLAND+2.23\ WT2^2+2.09\ nADT^2-1.70\ nDETR^2+1.64\ nFHT^2$

(s.e. = 1.169; r = 0.913; n = 33)

Litigation Potential

$Y = -5.36+1.54\ WT1-7.14\ WT2-1.17\ nADT-0.735\ nDETR+5.27\ nFHT +0.639\ nLAND+2.00\ WT2^2-1.12\ nFHT^2$

(s.e. = 1.173; r = 0.775; n = 44)

Public Service

$Y = -9.47+5.17\ WT1-0.663\ nADT-1.02\ nDETR+1.28\ nFHT -0.796\ WT1^2+0.281\ WT2^2$

(s.e. = 1.204; r = 0.701; n = 42)

<u>Rural / High Plain Region / Bridges:</u>

Maintenance Frequency

$Y = 14.624+1.8993\ WT1-9.015\ WT2-1.091\ nADT-1.5747\ nDETR -8.744\ nFHT-0.7255\ nLAND+2.4757\ WT2^2+1.8522\ nFHT^2$

(s.e. = 1.449; r= 0.748; n=46)

Litigation Potential

$Y = 12.943-0.682\ WT1-2.988\ WT2-13.963\ nFHT-0.311\ nLAND+0.8659\ WT1^2 +0.8297\ WT2^2+2.9128\ nFHT^2$

(s.e. = 2.042; r = 0.796; n=48)

Public Service

$Y = 7.663+2.5301\ WT1+4.376\ WT2-1.1048\ nDETR-14.615\ nFHT -0.967\ nLAND-0.9384\ WT2^2+3.075\ nFHT^2$

(s.e. = 1.482; r = 0.714; n=44)

<u>Rural / Desert Region / Bridges:</u>

Maintenance Frequency

$Y = -7.823+1.553\ WT1-7.238\ WT2-5.856\ nADT+14.181\ nFHT+1.9583\ WT2^2 +1.405\ nADT^2-3.5616\ nFHT^2$

(s.e. = 1.182; r = 0.730; n=42)

Litigation

$Y = -12.924+2.2296\ WT1+1.0474\ WT2-0.4943\ nADT+6.004\ nFHT -1.5454\ nFHT^2$

(s.e. = 1.557; r = 0.782; n=40)

Public

$Y = -17.802+2.7253\ WT1+1.6504\ WT2-0.9859\ nDETR+10.116\ nFHT -0.405\ nLAND-2.4229\ nFHT^2$

(s.e. = 1.532; r = 0.728; n=42)

Note: Y : Dependent variable, $\ln(T_{ext}/T_{ltec} -1)$

Table 14.7(b) Predictive Equations for the Extended-LTEC Design Return Period for *Box Culverts* in *Rural Areas*

Rural / Mountainous Region / Box Culvert:

Maintenance Frequency $Y = 9.838+15.564\,WT1-10.825\,WT2+6.364\,nADT-10.422\,nDETR-9.21\,nFHT -6.902\,nLAND-3.8004\,WT1^2+2.7606\,WT2^2-1.6954\,nADT^2+2.91\,nDETR^2 +1.849\,nFHT^2+1.366\,nLAND^2$ (s.e. = 1.344; r = 0.878; n = 39)

Litigation Potential $Y = 14.953+3.122\,WT1-0.3698\,WT2+4.65\,nADT-29.695\,nDETR +3.4495\,nFHT-13.271\,nLAND-0.8086\,WT1^2-1.2134\,nADT^2 +8.1806\,nDETR^2+2.5296\,nLAND^2$ (s.e. =1.191; r = 0.945; n = 45)

Public Service $Y = -3.941+15.529\,WT1+13.028\,WT2+9.249\,nADT-22.966\,nDETR -7.933\,nFHT-1.9848\,nLAND-4.0311\,WT1^2-3.1238\,WT2^2-2.6328\,nADT^2 +5.767\,nDETR^2+1.524\,nFHT^2$ (s.e. = 1.090; r = 0.835; n = 40)

Rural / High Plain Region / Box Culvert:

Maintenence Frequency $Y = 12.923+17.002\,WT1-4.69\,WT2-9.309\,nADT-18.863\,nFHT-0.0988\,nLAND -3.7417\,WT1^2+1.2975\,WT2^2+3.0126\,nADT^2+3.7384\,nFHT^2$ (s.e. = 0.651; r = 0.983; n = 36)

Litigation Potential $Y = 0.059+10.351\,WT1-0.5881\,nADT+0.5311\,nDETR-16.529\,nFHT -2.6739\,WT2^2+3.4186\,nFHT^2-0.26075\,nLAND^2$ (s.e. = 1.171; r = 0.939; n = 42)

Public Service $Y = 6.242+19.122\,WT1+1.61\,WT2-10.184\,nADT-0.269\,nDETR-18.354\,nFHT -3.8365\,WT1^2-0.450\,WT2^2+3.2538\,nADT^2+3.6687\,nFHT^2-0.10619\,nLAND^2$ (s.e. = 0.717; r = 0.979; n = 38)

Rural / Desert Region / Box Culvert:

Maintenance Frequency $Y = 23.66+0.5723\,WT1-8.362\,WT2+1.7992\,nADT-8.88\,nDETR-16.802\,nFHT +1.0439\,nLAND+2.2757\,WT2^2+2.039\,nDETR^2+3.537\,nFHT^2$ (s.e. = 1.609; r = 0.702; n = 42)

Litigation Potential $Y = 32.744+9.951\,WT1+5.94\,nADT-26.294\,nDETR-36.425\,nFHT +2.7622\,nLAND-2.4439\,WT1^2+0.3719\,WT2^2-1.121\,nADT^2 +6.355\,nDETR^2+8.601\,nFHT^2$ (s.e. = 2.089; r = 0.773; n = 41)

Public Service $Y = 34.58+6.748\,WT1-3.82\,WT2-22.673\,nDETR-25.862\,nFHT +2.4366\,nLAND-1.3302\,WT1^2+1.0286\,WT2^2+0.7197\,nADT^2 +5.075\,nDETR^2+5.875\,nFHT^2$ (s.e. = 2.037; r = 0.769; n = 40)

Table 14.7(c) Predictive Equations for Extended-LTEC Design Return Period for *Pipe Culverts* in *Rural Areas*

<u>Rural / Mountainous Region / Pipe culvert:</u>

Maintenance Frequency

$Y = -15.43-5.55\ WT1-21.204\ WT2+22.963\ nADT-17.354\ nDETR +8.962\ nFHT+7.191\ nLAND+2.437\ WT1^2+5.802\ WT2^2-5.613\ nADT^2 +3.861\ nDETR^2-2.299\ nFHT^2-0.77\ nLAND^2$

(s.e. = 1.168; r = 0.863; n = 28)

Litigation Potential

$Y = -22.451+0.1797\ WT1+4.3163\ nADT+12.074\ nDETR-7.854\ nLAND +0.446\ WT2^2-2.939\ nDETR^2+0.2149\ nFHT^2+2.392\ nLAND^2$

(s.e. = 1.157; r = 0.832; n =32)

Public Service

$Y = -13.535+0.700\ WT1+0.183\ WT2+12.066\ nADT-1.2317\ nDETR -0.9368\ nFHT+1.017\ nLAND-3.007\ nADT^2$

(s.e. = 1.211; r = 0.645; n = 30)

<u>Rural / High Plain Region / Pipe Culvert:</u>

Maintenance Frequency

$Y = -12.825+1.1958\ WT1+1.5576\ WT2+1.2296\ nADT-0.935\ nDETR +1.10\ nFHT+0.4772\ nLAND$ (s.e. = 1.537; r = 0.633; n = 53)

Litigation Potential

$Y = -9.337+4.938\ WT1+2.1084\ WT2-0.7185\ nDETR-0.6229\ nLAND -0.7342\ WT1^2$ (s.e. = 2.766; r = 0.630; n = 50)

Public Service

$Y = -10.441+6.252\ WT1-1.269\ WT2+1.3958\ nADT-1.2716\ nDETR +5.13\ nFHT-1.4613\ WT1^2-1.2818\ nFHT^2$

(s.e. = 1.694; r = 0.610; n = 52)

<u>Rural / Desert Region / Pipe /Culvert:</u>

Maintenance Frequency

$Y = -14.683+14.487\ WT1-6.562\ WT2+0.5529\ nDETR+6.027\ nFHT -3.419\ WT1^2+1.47\ WT2^2-2.176\ nFHT^2$

(s.e. = 1.745; r = 0.639; n = 35)

Litigation Potential

$Y = -27.541+7.156\ WT1+0.426\ WT2+11.383\ nADT+0.8022\ nDETR +5.831\ nFHT+1.50\ nLAND-1.88\ WT1^2-3.273\ nADT^2-2.279\ nFHT^2$

(s.e. = 1.820; r = 0.799; n = 34)

Public Service

$Y = -28.111+13.85\ WT1+6.728\ WT2+7.296\ nFHT-3.254\ WT1^2 -1.471\ WT2^2-2.58\ nFHT^2$

(s.e. = 2.272; r = 0.694; n = 36)

Note: Y : Dependent variable, $\ln(T_{ext}/T_{ltec} -1)$

presented in this chapter, a computer program DSGNFREQ.FOR was developed to carry out the foregoing computations for estimating the LTEC and extended-LTEC design return periods.

The program DSGNFREQ.FOR consists of three types of subroutines: subroutines for computing the LTEC design return periods based on discretized return periods (Tables 14.1 and 14.2); subroutines based on the interpolated return periods (Tables 14.3 and 14.4); and subroutines for computing extended-LTEC design return periods based on Tables 14.6 and 14.7. Once the LTEC design frequencies based on discretized and interpolated return periods are computed, the weighted LTEC design frequency is calculated based on the procedure described in Section 14.2. For computing the extended-LTEC design return period, three subroutines were developed each of which considers the three intangible factors, i.e., maintenance frequency, litigation potential, and public service, respectively.

Inputs to the program DSGNFREQ.FOR consists of following groups:

(1) Location parameters: including location, hydrologic region, and type of drainage structure.
(2) Channel characteristics: including channel geometry and roughness coefficients.
(3) Basin characteristics: including drainage area, mean annual precipitation, and geographical factor.
(4) Roadway characteristics: including number of lanes, embankment height, embankment soil type, pavement thickness, road width, etc.
(5) Economic parameters: including interest rate, expected service life, number of buildings upstream of drainage structure and their values and elevation.
(6) Traffic characteristics: including detour length, rate of repairing embankment, mobilization time, average daily traffic, accident ratio, vehicle speed on detour.
(7) Cost parameters: including unit costs of bridge, steel, concrete, embankment, and pavement as well as cost per accident and mobilization cost.
(8) Preference judgement of relative importance of economic efficiency, maintenance frequency, litigation potential, and public service.

Detail descriptions of inputs have been described in various places in the report and are summarized in Appendix A.3.

It should be noted that the developed working models are designed for quick determination of the LTEC and extended-LTEC return periods for highway drainage structures in the State of Wyoming without having to resort to extensive hydraulics computation and the LTEC analysis. The final forms of the working models are results of several levels of simplifications including the use of hydraulic responses equations of Chapter 7 and simplified preference functions for evaluating relative importance and desirability about economic and intangible factors (see Chapter 11). Therefore, the working models are not perfect and contain certain degrees of uncertainty. The values of the LTEC and extended-LTEC return periods obtained from the working models should be interpreted as nominal values. For this reason, the program DSGNFREQ.FOR also computes the values plus and minus one standard deviation of the LTEC and extended-LTEC return periods provided from the working models. In other words, the program would compute, under a given site condition, three values for the LTEC and extended-LTEC return periods as

For LTEC return period: $[\ T_{ltec,-1},\ T_{ltec},\ T_{ltec,+1}\ ]$

For extend-LTEC return period: $[\ T_{ext,-1},\ T_{ext},\ T_{ext,+1}\ ]$

in which -1 and +1 in the subscripts represent, respectively. one standard deviation less, and one standard deviation more of the computed return periods from the working models. These intervals provide design engineers a range of return periods appropriate for the site condition under consideration. Design engineers could make a selection on the basis of their professional judgement or as might be dictated by the transportation agency's policy.

Outputs from the program DSGNFREQ.FOR are the mean of the LTEC return period along with plus and minus one standard deviation from the mean LTEC return period. Values of the LTEC return period based on discretized, interpolated, and weighted versions are printed. Furthermore, on the basis of mean LTEC return periods, the mean extended LTEC return periods along with plus and minus one standard deviation from it for the three intangible factors are printed. Inputs and outputs of some example applications obtained from the program DSGNFREQ.FOR are shown in Appendix A.3.

14.5 ESTIMATION OF LTEC DESIGN RETURN PERIOD FOR OTHER FLOOD FREQUENCY RELATIONSHIPS

Note that the LTEC design return period for a specified drainage structure site is a function of the flood frequency relationship selected for a site. In Wyoming, this selected flood frequency relationship for any highway drainage site could be obtained from the regional basin-characteristics method, the regional channel-geometry method, or a site specific frequency analysis when flood data are available. Consequently, a practical question is: what would be the LTEC design return period if the flood frequency relationship at the structure site is something other than that obtained from the basin-characteristics method which is the only base-line method currently included in DSGNFREQ.FOR?

The resulting working relationships presented in Tables 14.1-14.4 for the LTEC design frequency are functions of the drainage area, basin slope, annual average precipitation, and geographical factor as used in Wyoming's basin-characteristics method. These are variables in the basin-characteristic method defining the flood frequency relationship (see Table 5.1). Where it is preferred to use a unique, site specific flood frequency relationship at a drainage structure site, it is logical to assume that there is a 'hypothetical' basin having the basin characteristics that yield a flood frequency relationship very similar to this site specific relationship. The basin characteristics of this 'hypothetical' basin then can be used in the developed working relationships in Tables 14.1-14.4 to estimate the corresponding LTEC design return period.

Based on this logic, a simple procedure was developed that would allow the working relationships in Tables 14.1-14.4 to be used to estimate the LTEC design frequency for any unique, site specific flood frequency relationship a user might select. The procedure involves the following two steps:

Step 1 (Determine the equivalent basin characteristics) - This step determines the basin characteristics such as the drainage area, basin slope, annual average precipitation, and geographical factor which would result in a flood frequency relationship by using the basin-characteristics method for the hydrologic region (mountains, plains, and high deserts) that is close to the one the user selects for the site. The determination of such basin characteristics was made by employing an optimization technique with an objective function as

$$\text{Minimize} \sum_{\text{all } T} w_T \, (q_{BC,T} - q_{o,T})^2 \tag{14.11}$$

in which $q_{BC,T}$ is the T-year flood obtained by the basin-characteristics method, $q_{o,T}$ is the T-year flood to be adopted at the structure site, w_T is the weighting factor for each return period. The flood frequency relationship selected for the LTEC analysis, $q_{o,T}$, can be from the regional channel-geometry method, a unique site specific flood frequency relationship, or both. The decsion variables are modifie

The decision variables in Eq.(14.11) are drainage area, basin slope, annual average precipitation, and geographical factor which determine the values of $q_{BC,T}$ for T = 2-, 5-, 10-, 25-, 50-, 100-, and 200-year. Several types of weighting factors w_T can be used in Eq. (14.11) depending on the objective of the curve fitting. For the LTEC analysis, the entire flood frequency curve is important because of its role in computing the annual expected flood related damage costs. In this exercise, the weighting factor used in Eq.(14.11) is the non-exceedance probability associated with each return period, that is,

$$w_T = 1 - \frac{1}{T} \tag{14.12}$$

The optimization technique used to solve Eq.(14.11) is the Hooke-Jeeves algorithm described in Section 8.2. This algorithm is implemented in the program DSGNFREQ.FOR to force the flood frequency relationship defined by the basin-characteristics method to closely conform to the selected flood frequency relationship.

Step 2 (Determine the LTEC design frequency) - Once the best equivalent basin characteristics for the 'hypothetical' site are determined from the step-1, they are used in the working relationships in Tables 14.1-14.4 to determine the corresponding LTEC design return period for the adopted flood frequency relationship.

In the program DSGNFREQ.FOR, the LTEC design return periods based on the basin-characteristics method and channel-geometry method, along with their corresponding extended-LTEC design return periods, are provided automatically without a special request from the user. If the user adopts a flood frequency relationship from some other sources, it is necessary to input the flood discharges for 2-, 5-, 10-, 25-, 50-, 100-, and 200-year events. The input format requirement is described in Appendix A.3. In this case, the program would produce three LTEC design frequencies, along with the extended ones, for each flood frequency relationship. Examination of the various LTEC design return periods may give engineers some indication about the consisitency between the different flood frequency relationships. A small difference in the values of the LTEC design return periods indicates consistency between the flood frequency relationships. In case there is a significant discrepancy, engineers must exercise judgement in selecting the design flood frequency. Some example outputs from DSGNFREQ.FOR are shown in Appendix A.3.

14.6 APPLICATION OF DEVELOPED WORKING MODEL TO SITES WHERE LOCAL CHANNEL SLOPE IS LESS THAN THE BASIN SLOPE

Recall that, in Section 13.1, the generated synthetic site conditions for constructing the LTEC data base were that local channel slope at the structure site is the same as the basin slope. This simplification was made to reduce the amount of computations involved in the data base establishment. However, it is common that highway drainage structures are located at sites where the local channel slope is significantly flatter than the basin slope. This is especially the further road crossings are from the watershed divide. Under this situation, which slope should be used in the working model? The question is particularly crucial when the model is applied to Plains region in Wyoming because slope is used in determining the flood frequency curve at the structure site.

The answer to the above question is to use basin slope as the local channel slope in the working model because adopting local channel slope does not capture the true nature of the flood at the structure site and could significantly under-estimate the flood magnitude resulting in under-estimation of the potential damaging effect of the flood. Furthermore, when the developed working model is applied to sites of this nature, the resulting LTEC design return period would tend to be conservative. The rationale is the following.

Consider the Plains region in Wyoming, basin slope is a parameter in the regional flood frequency relation and it has a positive effect on the flood magnitude. Namely, steeper basin slope results in high flood peak discharge for a given return period when other basin characteristics remain the same. In case that basin slope is steeper than the local channel slope, using basin slope would yield larger floods than that using the local channel slope. When the flood frequency curve based on local channel slope is used in highway drainage structure design, the structure size will be smaller because the flood magnitudes are smaller. Therefore, the associated first cost would be lower. Hydraulically, local channel slope affects the storage upstream of the highway crossing structure. With a flatter local channel slope the storage effect is greater in which case water stage is less sensitive to change in discharge. This implies that the potential damaging effects of floods on highway crossing structures due to overtopping, traffic interruption, or upstream property damage would be less for a flat slope than for a steep slope. Consequently, both the first cost and the second cost for using a flatter slope would both be lower than those when a steeper slope is used (see Figure 14.2).

When a flatter slope is used in the Plains region of Wyoming, the slope of flood freqeuncy curve would also become flat. This indicates that incremental change in discharge would be less sensitive to change in the design return period for a flatter slope as compared with the case using a steeper slope. Consequently, incremental change in first cost with respect to design return period would be less for a flatter slope than a steeper slope. The difference in incremental change in first cost between two different slopes would increase as the design return period increases. On the other hand, the difference in incremental reduction in flood related damage would decrease between two didfferent slopes as the design return period increases.

Refer to Figure 14.2 and assume that the LTEC return period appears in the neighborhood of the intersection between the first and second cost curves (which is not a great violation from the truth in many cases). The use of a flatter local channel slope as the basin slope would yield a larger LTEC design freqeuncy (point A) than that of using a steeper basin slope as the local channel slope (point B). For the situation where the basin slope is steeper than the local channel slope, the associated first cost would lie between the two first cost curves but closer to the first cost curve than from using a steeper basin slope because structure size is primarily affected by the dischage. On the other hand, due the fact that flood damage is more dominated by the local storage effect, the second cost curve for the site with steeper basin slope and flatter local channel slope would be closer to the one associated with the flatter slope. The resulting LTEC design freqeuncy

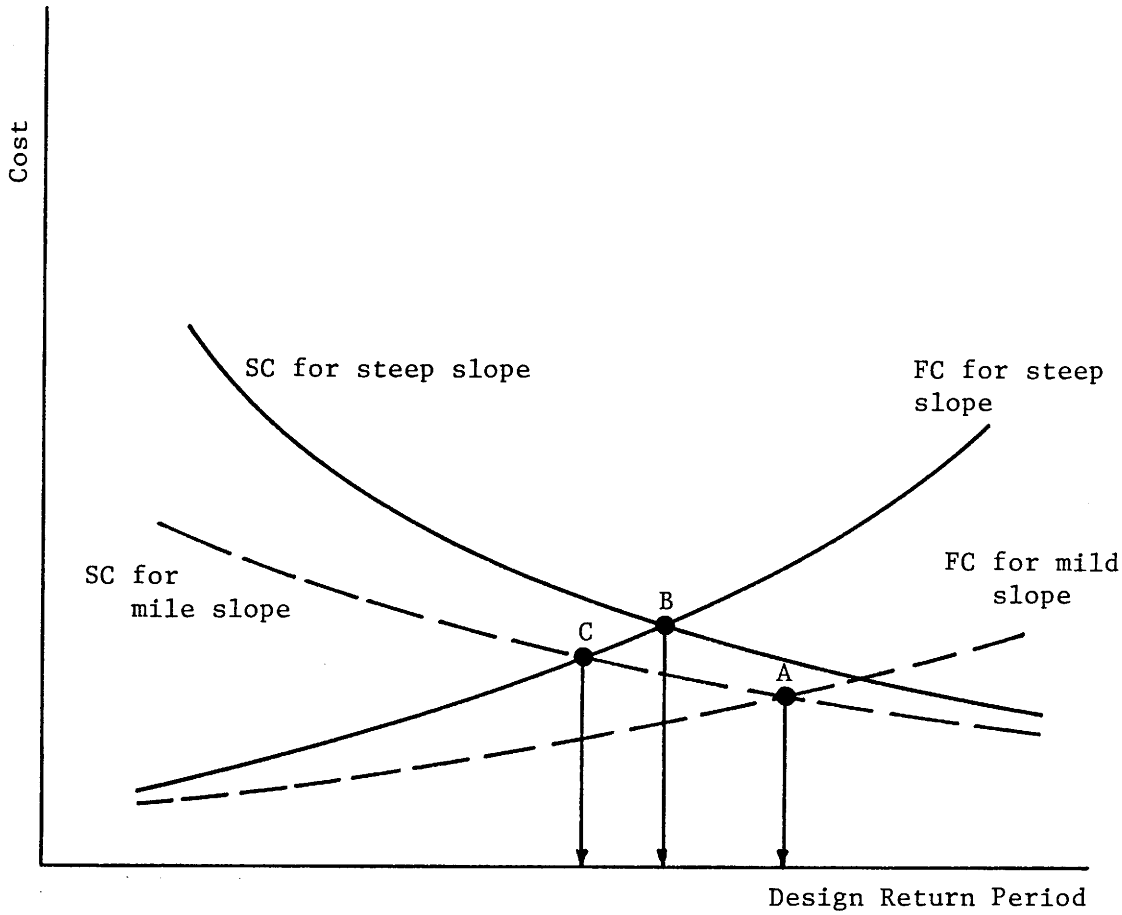


Figure 14.2 Variations of First Cost, Second Cost, and the LTEC Design Frequency Based on Different Slopes.

then would be in the neighborhood of point C which is smaller than the LTEC design frequency based entirely on using a steeper basin slope. Therefore, in hydrological areas such as the Plains region of Wyoming where basin slope is a significant hydrologic variable, using basin slope as the local channel slope in the working model would yield a conservative estimate of the LTEC and extended-LTEC design frequencies when the local channel slope at the highway drainage structure site is smaller than the basin slope, as usually occurs.

For the other areas where basin slope is not a significant variable, such as the two regions in Wyoming, namely, mountainous and high desert region, the basin slope is not used to compute the flood frequency curve making these concerns academic. In this case, there will be only one first cost curve that is independent of either basin slope or channel slope. Following the same arguments presented above about the effect of local channel slope on the second cost curve, one realizes that adopting a steeper basin slope as the local channel slope in the working model would again yield a conservative estimate of the LTEC and extended-LTEC design frequencies.

15.
SUMMARY, CONCLUSIONS, AND SUGGESTED FUTURE RESEARCH

15.1 SUMMARY

This report documents the cooperative research between the Wyoming Department of Transportation (WDT) and the Wyoming Water Resources Center (WWRC) for developing methodologies and data bases to produce a design procedure for quickly selecting a defensible design flood frequency for drainage sites in Wyoming and perhaps elsewhere. In this study, various new and innovative techniques were developed for producing the information that is needed to develop a sound, technically supported state-of-the-art methodology and computer program for quickly determining a reliable site specific design flood frequency. The methods devised for this purpose are considered to be highly defensible both from a scientific and legal standpoint. It is believed that the WDT *and others* will find the information contained in this report to be challenging and useful.

The intent of this research was to develop technically sound, defensible, easy to use, and reasonably accurate working models, based on the LTEC analysis framework, for determining an appropriate design flood frequency for three types of drainage structures (i.e., bridges, concrete box culverts and commercial pipe culverts) for drainage sites typical to Wyoming. Information was generously provided by the WDT on typical site characteristics as well as and structure configurations and costs for numerous drainage site conditions representative of Wyoming.

In the LTEC analysis, in addition to the initial construction cost of a highway drainage structure, the cost associated with the potential flood related damages during a structure's expected service life were also considered. This type of research normally requires an hydraulic analyses of the backwater effect due to the presence of roadway crossing structures. Due to the large number of synthetic (hypothetical) sites to be considered, the many detailed hydraulic simulations were found to be impracticable. As an alternative, detailed simulations were made using a limited number of data sets statistically selected to represent the complete data base of synthetic sites. These simulations provided empirical relationships between various hydraulic responses of flow and site characteristics for typical highway drainage structures. Such relationships were incorporated into the optimization model for determining the optimal layout of drainage structures and their corresponding LTEC design flood frequency.

Next, it was necessary to identify the effect of intangible factors on the design flood frequency selection process. Historically the decision-makers (design engineers) in this process have relied on traditional methods which have evolved over the years. Because of the intangible nature of some variables involved in these traditional methods, great dependence was necessarily placed on subjective and personal judgement of the decision-maker's predessors. In this study, along with the tangible cost factors, three intangible factors (i.e., maintenance frequency, litigation potential, and public service) were quantitatively considered. To remove as much subjectivity as possible in the decision-making process, a national survey was conducted. In this survey, relative importance and desirability of the various tangible and three intangible factors were rated by engineers holding different positions of responsibility in many federal, state, and county transportation agencies. The responses from the survey were examined and analyzed extensively. The primary objective in analyzing the survey responses was to develop models that would quantitatively simulate the decision-maker's preference rating.

Although the responses obtained from the national survey do not reflect the opinions of every engineer involved in highway drainage design, they did reflect the most representative information to date on the profession's views regarding the selection of a highway design flood frequency. Accordingly, this information can be viewed as the best consensus to date of the professionals involved in the practice of highway drainage design in the United States. In passing, those individuals or public transportation agencies who did not participate in the survey are encouraged to do so by completing the survey questionnaire in Appendix A.1. This will allow them to compare their opinions on the various intangible factors with the consensus afforded by this research. Further, such individuals are also encouraged to provide the authors with a completed questionnaire so their responses may be included in the WWRC data base for future research.

As expected, results from the national survey results clearly show that different degrees of variability exist in the preference ratings from the different survey respondents. To incorporate this inherent variability from the survey responses into the decision-making, fuzzy set theory in conjunction with the Simple

Additive Method was applied within the framework of Multiple Attribute Decision making. The consideration of tangible cost factors along with the three intangible factors resulted in rather lengthy computations using fuzzy set analysis. As an alternative, pair-wise comparison between the tangible cost factor and each of the intangible factors was made to determine the Extended-LTEC return period from the LTEC design frequency as it is affected by the intangible factor under consideration. The largest value among the three resulting Extended-LTEC design frequencies is suggested as being the appropriate design flood frequency where intangible factors are deemed appropriate; i.e., this would result in an 'over-design' for two of the three intangible factors considered in this research.

In the final stage of the study, data bases for the LTEC and Extended-LTEC flood design frequencies for different structure types under the different synthetic site conditions were established. From these data bases, working relationships were developed for quickly estimating the design flood frequency. It should be realized that due to the simplifications and idealizations used in this research, the derived working relationships possess certain degrees of uncertainty in estimating an average for the LTEC and Extended-LTEC design flood frequency. For this reason, intervals (standard deviations) about the average of the LTEC and Extended-LTEC frequencies were computed to provide decision-makers with a range of design return periods that would be defensible from a statistical viewpoint. From such information, decision-makers would exercise judgement or, better yet, rely on policy guidelines to select a design flood frequency for a drainage structure on a site specific basis.

The resulting working model involves uncertainty which might make its practical application in design less attractive to some decision-makers and engineers unfamiliar with this aspect of engineering design. However, the great majority of engineering design and analysis, regardless of the discipline, is plagued with uncertainties in the 'real world'. Decisions must be made under uncertainty. The major contribution of this research is that, with the aid of the resulting working model, the determination of a defensible design flood frequency for a highway drainage structure is technically based with much of the traditional subjectivity removed or statistically quantified.

The developed working model adopted the assumption that the local channel slope at the highway drainage structure site is identical to the basin slope. However, structure sites are often located on the lower portion of a drainage basin where the local channel slope is significantly smaller than the basin slope. It has been shown through a heuristic argument that the use of steeper basin slope for local channel slope, in all three hydrologic regions in Wyoming, would yield a conservative estimate of the LTEC and extended-LTEC design frequencies. Consideration should be given to using basin slope and channel slope as separate working model variables in future research.

No attempt was made to include loss of the bridge or culvert in the service life costs. The experience of the WDT indicated this cost would be of little significance as the structure is seldom lost due to floods. Should this ommission be of concern to others, two possibilities could be considered for including this cost. There could be others. One approach would be to consider devising a probability function for structure loss based on recorded history. However, it might be difficult to locate a representative sample showing the number of failures *as compared to the number of floods that have occurred at a site prior to the failure of a bridge*: this kind of data is probably an agency specific variable. Such an approach might also need a representative sample reflecting sites where there have been many floods and no failures. Additionally, the probability function would have to reflect certain site specific variables related to potential structure failure. In short, this approach of determining a probability function for potential drainage structure loss does not appear, at this time, as being very productive.

A more productive approach for considering potential structure losses might be the development of a working model for estimating when it would be reasonable to expect a structure (bridge or culvert) loss. Once scour and damage estimating practices become more reliable, then it may be useful to employ an approach similar to that used in this research. This approach would devise working models based on many hydraulic analyses of hypothetical but representative sites. Using this large hypothetical data base of known failure related site variables (along with the necessary site geometries to obtain the hydraulic variables at a site such as was assembled for this research), generate many analyses in order to identify a dependent variable that reflects the cost for the loss or damage of the drainage structure. This working model would then be intergrated into DSGNFREQ.FOR so as to include this secondary cost in the LTEC and Extended-LTEC analysis.

15.2 CONCLUSIONS

This study provided the means for the WDT to devise a more defensible and reliable means of quickly and easily selecting a design flood frequency at drainage sites in Wyoming. This methodology is based on the Least Total Economic Cost (LTEC) practices recommended by the Federal Highway Administration (FHWA) in 1979. LTEC, as a general economics practice traditionally applicable to all engineering disciplines, probably dates from the previous century and was found to be an excellent tool for this research to use in arriving at a means of selecting a design flood frequency. Previously perceived defects in the LTEC practice were resolved by using fuzzy set theory in conjunction with the Simple Additive Method. This was done within the architecture of Multiple Attribute Decision making which resulted in what is termed the Extended-LTEC design flood frequency. Also, a simplistic computer program (a programmable calculator might suffice) facilitates the use of the research findings.

This research, while directly applicable to Wyoming, was sufficiently broad based to where it might have application in other western states and possibly nationally. However, some modification of the input data might be necessary for the findings from this research to be used outside of Wyoming.

Several methods of interpolating the traditional LTEC and Extended-LTEC curve were developed: discrete, continuous, and weighted. DSGNFREQ.FOR provides all three interpolations as part of the output. The following are the conclusions regarding this interpolation.

(1) There can be a wide variance between the LTEC and Extended-LTEC design flood frequency obtained using the discrete and continuous interpolating methods.

(2) Because of the foregong variance the weighted method was developed and is suggested as the appropriate method at this time for selecting an LTEC or Extended-LTEC design flood frequency.

A sensitivity analysis provided some surprising results. In part these results may be due to some interdependence between the various regression variables. Table A.3.20 of Appendix A.3 indicates which variables were found to be significant, somewhat significant, and not significant.

The sensitivity analysis coupled with a limited exploration of how these research findings might be implemented proved most revealing and, in some cases, surprising: see Appendix A.3. *Caution*, the following findings are applicable to only one hydrologic region (plains) and are generalized in nature; i.e., they are not necessarily true for the following drainage structures in the plains hydrologic region of Wyoming. Additionally, this sensitivity analysis and implementation alternative are based on an early version of DSGNFREQ.FOR and, due to time and funding restraints, were not revised using the most current working model. As such, *these findings should not be used other than to examine the probable sensitivity of the variables and evaluate the policy approach to implementing this research.*

(1) Smaller and Moderate Size Culverts -- The traditional design flood frequency is generally too low except in urban areas where it is too high

(2) Large Culverts -- There is a wide variance as to whether the traditional design flood frequency is too low, too high, or about right depending on site specific circumstances.

(3) Very Large Culverts -- Except where there are litigation concerns related to traffic accidents or property damage due to a flood hazard, the traditional design flood frequency is generally too high

(4) Bridges -- The traditional design flood frequency is generally too high regardless of the site circumstances.

15.3 SUGGESTED FUTURE RESEARCH

There are several issues raised by this study that deserve further research. Some of these issues are directly related to the LTEC design of highway drainage structures and others are more general in terms of hydraulic analysis. These issues are listed below.

(1) This study clearly identified the feasibility of developing a more reliable means selecting a design flood frequency than the traditional subjective and often inaccurate practices. In this regard, this study should be considered as a pilot study for a more ambitious undertaking at the national level. As an example, given access to data from the midwest floods of 1993 regarding

such intangibles as drift, debris, scour potential, traffic delays, detour related delays and costs, public service concerns, and maintenance related problems the findings from this study could be greatly enhanced. Given this data and data from other transportation agencies, an engineering tool with broad, national application might emerge.

(2) Research on the hydraulic and hydrologic predictive models used in this research would be useful. Recalling the development of the hydraulic response equations for bridge structures in Section 7.3 of Chapter 7, the computer program WSPRO could successfully obtain results for 525 cases out of a total of 768 generated site conditions. This raises an issue regarding the performance of WSPRO, or any hydraulic simulation model and design procedure for that matter, regarding its range of applicability, sensitivity, uncertainty, and reliability. This becomes crucial when a hydraulic engineer select from many general purpose, computerized hydraulic models such as those for water surface profile computation, hydrologic rainfall-runoff analysis, or estimating sediment transport. What is their valid range of application? How sensitive are the model outputs to the change in model inputs and parameters over the parameter space? How do the uncertainties of inputs and parameters affect the model output uncertainty? The outcomes of a hydraulic engineering analysis and design, to a large extent, hinge on the model employed. Consequently, to obtain efficient and effective designs with high confidence, the users should understand the performance of the model.

(3) The present study considers design flood frequency as the sole design variable for which working relationships have been developed. This idea appears to be technically feasible for developing practicable working relationships that relate the optimum configurations of a highway drainage structure for a specified design return period to site specific conditions. This should be verified.

(4) Similar to issue 2, relationships could be established for various types of highway drainage structures, site conditions, and engineering judgement considering various factors. Such relationships, based on the knowledge of representative body of highway transportation engineers, would provide valuable guidelines for the selection of an appropriate drainage structure type. As an example, in this study the selection of drainage area as used in

Chapter 5 for the criterion is too simplistic and some other criterion should be explored such as one that perhaps reflects a dimensionless flood-frequency curve shape and some index discharge(s).

(5) It must be recognized that the flood discharge magnitudes obtained from the Wyoming regional regression equations such as those by Druse et al. (1988) or from other sources, are only estimates of the true but unknown discharges. They are associated with uncertainties indicated by their standard errors. Due to the computational intensiveness to include these hydrologic predictive standard errors, the implementation of such a refinement in this study was considered impracticable. However, a study by Tung (1987) indicates that under-design could occur without considering other uncertainties such as these, especially when such uncertainties are significant. The significance of this concern requires further study.

(6) In this study, the national survey assumed that the ratings of relative importance for the various factors were constants. It is likely that such ratings could be affected by the site characteristics. This issue should be clarified.

(7) This study considered only three intangible factors for determining the Extended-LTEC design flood frequency. Other intangible factors such as the availability of funds deserve consideration for inclusion in the selection of a design flood frequency. In this regard, further work is needed in simplifying the survey questionnaire to avoid placing an unnecessary burden on the potential respondents while gathering data on these other potentially significant intangible factors.

(8) It was noted that some of the selected variables reflected little significance in the selection of an LTEC or Extended-LTEC design flood frequency. Upon a closer examination it appeared that perhaps some of these variables might be inter-dependent. Future research should attempt to avoid inter-dependency in the variables.

(9) Attempts to devise a policy for routine application of this research without resorting to the routine use of DSGNFREQ.FOR was explored in Appendix A.3. This exploration indicated that, while feasible, more work is required in order address other hydrologic regions and to better reflect the sensitivity

of the significant variables.

(10) The research developed three methods for interpolating a design flood frequency from the traditional LTEC curve. Research is needed to ascertain which is the preferable interpolation method.

(11) Loss of the bridge or culvert was not included in the service life costs. Design criteria for new bridges may make this possiblility sufficiently remote to where it might generate an insignificant cost. Culverts may be a different matter. Never the less, research to verify this unsupported conclusion is warrented. This research might pursue defining a site sensitive probability function, or the development of a working model that indicates when failure or damage is to be expected, and the amount.

(12) Considering using channel slope and basin slope as separate variables in their true context where basin slope is only related to the flood-frequency relationships, and channel slope is only a site variable related to hydraulic performance. For a truely universal working model, it may be advisable to revise the working model to only use an input flood-frequency relationship thereby eliminatign all hydrology related variables.

REFERENCES

AASHTO, 1992. Highway Drainage Guidelines.

AASHTO, 1991. Model Drainage Manual.

Bao, Y., Y.K. Tung and V.R. Hasfurther, 1987. "Evaluation of Uncertainty in Flood Magnitude Estimator on Annual Expected Damage Costs of Hydraulic Structures," Water Resources Research, AGU, 23(11), pp. 2023-2029.

Bradley, J.N., 1973. "Hydraulics of Bridge Waterways," Federal Highway Administration, Hydraulic Design Series No. 1.

Chen, Y.H. and B.A. Anderson, 1987. "Development of a Methodology for Estimating Embankment Damage Due to Flood Overtopping," Federal Highway Administration, Report No. FHWA/RD-86/126, March.

Chow, V.T., 1959. Open Channel Hydraulics, McGraw-Hill, N.Y..

Colorado Conservation Board, 1986. "Colorado Flood Proofing Manual," October.

Corps of Engineers, 1980. Data of Flood Damage to Buildings, Department of the Army, Omaha District.

Corry, M.L., J.S. Jones and P.L. Thompson. 1980. "The Design of Encroachments on Flood Plains Using Risk Analysis," Hydraulic Engineering Circular, No. 17, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., July.

Craig, G.S. and J.C. Rankl, 1978. "Analysis of Runoff from Small Drainage Basins in Wyoming." Geological Survey, Water-Supply Paper 2056 in cooperation with the Wyoming Highway Department and the U.S. Department of Transportation, Federal Highway Administration.

Druse, S.A., H.W. Lowham, M.E. Cooley, and A.M. Wacker, 1988. Streamflow in Wyoming, Wyoming Highway Department.

Edgar, T.F. and Himmelblau, D.M., Optimization of Chemical Processes, McGraw-Hill Book Company, New York, NY. 1988.

Farraday, R.V. and F.G. Charlton, 1983. Hydraulic Factors in Bridge Design, Hydraulics Research Station, Ltd., Wallingford, England.

Federal Highway Administration, 1987. "Highways in the River Environment, Hydraulic and Environmental Design Considerations," Training and Design Manual, National Highway Institute.

Federal Highway Administration, 1984 ."Cost of Owning and Operating Automobiles and Vans 1984." U.S. Department of Transportation.

Henderson, F.M., Open Channel Flow, Macmillan, N.Y., 1966.

Hooke, R. and T.A. Jeeves, 1961. "Direct Search; Solution of Numerical and Statistical Problems," Journal of Computer, 8(2), April.

Klir, G.J. and Folger, T.A., 1988. Fuzzy Sets, Uncertainty, and Information, Prentice Hall, Inc., Englewood Cliffs, N.J.

Lowham, H.W., 1976. "Techniques for Estimating Flow Characteristics of Wyoming Streams." U.S. Geological Survey in cooperation with Wyoming Highway Department. November. Water Resources Investigation. 76-112.

Lowham, H.W., 1982. "Streamflows and Channels of the Green River Basin, Wyoming." U.S. Geological Survey Water Resources Investigation. 81-71. May.

Mays, L.W. and Y.K. Tung, 1992. Hydrosystems Engineering and Management, McGraw-Hill Book Co., New York, NY. 530pp.

Pritchett, H.D., 1964. "Application of the Principles of Engineering Economy to the Selection of Highway Culverts," Stanford University, Report EEP-13.

Scheider, V.R. and K.V. Wilson. 1980. "Hydraulic Design of Bridges with Risk Analysis," Technology Transfer Report, FHWA-TW-80-226, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., March.

Splett, D., 1987. "MCDM: A Probabilistic Approach and A Possibilistic Approach," M.S. Thesis, Department of Statistics, University of Wyoming, August.

SPSS Inc., 1988. SPSS/PC+ V2.0 Base Manual.

"Stanford Workshop on Risk-Based Approach to Dam Safety Assessment." February 4-5, 1985. Washington, D.C.

Tseng, M.T., A.J. Knepp and R.A. Schmalz, 1975. "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings," vol. IV economic risk analysis for design of bridge waterways, Report No. FHWA-RD-75-54, U.S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Washington, D.C..

Tung, Y.K., 1987. "Effects of uncertainties on optimal risk-based design of hydraulic structures," J. of Water Resour. Plan. and Mgmt., ASCE, 113(5): 709-722.

Tung, Y.K. and L.W. Mays, 1982. "Optimal risk-based hydraulic design of bridges," J. of Water Resources Planning and Management, ASCE, 108(WR2):191-203.

Tung, Y.K. and Bao, Y., 1990. "On the optimal risk-based design of highway drainage structures," J. of Stochastic Hydrology and Hydraulics, 4(4):311-324.

U.S. Bureau of Reclamation, 1986. Guidelines for Decision Analysis, March.

US Department of Agriculture, Statistical Reporting Service, 1985. "Wyoming Agricultural Statistics 1985."

U.S. Department of Transportation, 1970. "Economic Consequences of Automobile Accident Injuries." U.S. Am. Ins. and Compensation Study, Vol. 2, April.

Wyoming Construction, 1980 to 1985, "Weighted Average Bid Price."

Wyoming State Highway Department, 1984a. "Wyoming's Comprehensive Report on Traffic Accidents, 1983-1984", Highway Safety Branch Accident Data Management Section.

Wyoming State Highway Department. 1984b. "Vehicle Miles, 1984."

Wyoming State Highway Department. "Plan and Profile of Proposed State Highway."

Wyoming State Highway Department, 1984c. "Wyoming Construction Cost Index - Price Trends 1969-1984."

Young, G.K, R.S. Taylor and L.S. Costello, 1970. "Evaluation of the Flood Risk Factor in the Design of Box Culverts," Volume 1, Volume 2, U.S. Department of Transportation, Bureau of Public Roads.

Young, G.K. and M.R. Childrey. 1974. "Impact of Economic Risks on Box Culvert Design," An application to 22 Virginia sites, prepared for Federal Highway Administration, Final Report, August.

Zimmermann, H.J., 1991. Fuzzy Set Theory and Its Applications, 2nd edition, Kluwer Academic Publishers, Boston, MA.

APPENDIX A.1

SURVEY QUESTIONNAIRES

ECONOMIC RISK ANALYSIS

- Data Collection Survey -

Purpose -- The purpose of this survey is to obtain your views on flood and risk design criteria for drainage structures. This survey is for a research project undertaken by the Wyoming State Highway Department to try and simplify economic risk assessments and analyses required in drainage design.

Instructions -- How much of this survey you need to complete depends upon whether you are a highway agency's (1) Chief Administrator, (2) Staff Engineer for the Chief Administrator, (3) Branch or Department Head, (4) Hydraulic Design Engineer, or (5) Highway Engineer/Technician that is involved in drainage design on a part-time basis. Because of this, please read the following instructions carefully before you start. Administrators will require only a few minutes, technical people will require a longer time.

- If you feel comfortable in doing so, please complete the biodata below (page 1).
- All Respondents are to complete the Questionnaire for Part 1 (page 1-1).
- All Respondents are to complete the Questionnaire for Part 2 (page 2-1).
- Only those Respondents checking Current Position 1, 2, or 3 in Part 1 need complete the Questionnaire for Part 3 (page 3-2).
- Only those Respondents checking Current Position 2 or 3 in Part 1 need complete the Questionnaire for Part 4 (page 4-4).
- Return your completed portion of this survey to your Agency's Hydraulic Engineer. Make sure you have checked the one most appropriate **Current Position** and **Current Employer** in Part 1, page 1-1.

BIODATA -- Please complete the following if you feel comfortable in doing so. Note, later in this survey you will be asked to express your personal views on such sensitive issues as the value of human life.

Respondent ID # __________ (Leave Blank)

Respondent's Name, Title, and Address (Complete if you so desire.)

____
Name

____
Title

____
Agency

____
Address

____
City State Zip

PLEASE GO TO PART 1 OF THIS SURVEY.

PART 1 — RESPONDENT BACKGROUND INFORMATION

Purpose -- This part is to obtain background information on you as a respondent to this survey.

Instructions -- Check the **one** most appropriate block under **"Current Position"** and fill in any blank spaces for that position with an estimated value. Also, check the **one** most appropriate block under **"Current Employer"**.

Questionnaire -- Please complete part A and B below in accordance with the above instructions.

PART A — Current Position
(check only 1)

1. ___ **Highway engineer or technician** working ___% of the time in drainage design with about ___ years of total engineering technician experience.

2. ___ **Hydraulic engineer** with about ___ years of hydraulic engineering experience and about ___ years of total engineering experience.

3. ___ **Bridge structural engineer** with ___ years of structural bridge design experience.

4. ___ **Branch Head** of ______________ (Branch title) in a highway agency and directly responsible to an administrative staff engineer.

5. ___ **Administrative staff engineer** supervising several branch heads and directly responsible to an agency's Chief Engineer or Administrator.

6. ___ **Chief Engineer or Administrator** for a transportation agency.

7. ___ **Other** (describe) ______________
____
____
____

PART B — Current Employer
(check only 1)

___ Federal Government

___ State Government

___ County Government

___ City Government

___ Consulting Engineer*

___ Other (describe) ________
____
____
____

* Includes Consulting Engineers doing work for a highway agency and requested by the agency to complete these questionnaires.

PLEASE GO TO PART 2 OF THIS SURVEY.

PART 2 -- RATING THE RELATIVE IMPORTANCE OF FACTORS AFFECTING DRAINAGE DESIGN

Purpose -- This part of the survey is to obtain your opinion on the relative importance of several tangible and intangible factors commonly considered in designing a highway drainage structure.

Instructions -- Evaluate the relative importance of the seven factors listed below. Should you have any questions on these factors, they are described in more detail in Appendix A. Enter both a Verbal and a Numerical rating . A list of Verbal ratings is provided following the Questionnaire below. The same Numerical and/or Verbal rating may be used more than once to indicate equal importance of two or more factors.

For the Numerical ratings select an integer from 0 to 10, where 0 is for a factor that is **NOT AT ALL IMPORTANT,** and 10 is for a **MOST IMPORTANT FACTOR.** The same integer may be used more than once to indicate equal importance.

Questionnaire -- Please complete the Questionnaire for Part 2 indicating in your judgment, the relative importance of the following seven factors in highway drainage design.

Factors	Rating Verbal *	Numerical #
° **Drainage Structure Cost**	( )	( )
° **Costs Related to Flood Damage**	( )	( )
° **Maintenance Frequency**	( )	( )
° **Litigation Potential**	( )	( )
° **Public Service/Convenience Levels**	( )	( )
° **Risk for Loss of Human Life**	( )	( )
° **Uncertainty in Hydrologic Analysis**	( )	( )

* Enter: MI for "Most Important"; VI for "Very Important"; SI for "Somewhat Important"; I for "Important"; NI for "Not Important"; NV for "Not Very Important"; NA for "Not At All Important";

\# Enter an integer from 0 to 10 in accordance with the above instructions.

IF YOU CHECKED CURRENT POSITION 4, 5, or 6 IN PART 1, PLEASE STOP HERE AND RETURN ALL YOUR SURVEY FORMS TO YOUR AGENCY'S HYDRAULIC ENGINEER. YOU NEED NOT COMPLETE PART 3 or PART 4. THANK YOU FOR YOUR HELP.

IF YOU CHECKED CURRENT POSITION 1, 2 or 3 IN PART 1, PLEASE GO TO PART 3 OF THIS SURVEY.

PART 3 -- RATING OF DESIGN RETURN PERIOD VERSUS INTANGIBLE FACTORS

Purpose -- This part of the survey is to obtain your views on what you feel is the appropriate Design Return Period for each of the three common **Intangible Factors** listed in the attached Questionnaires for Part 3. Please take note that for each Questionnaire there are different site conditions. Further, the site conditions on your Questionnaire may differ from those provided to other Respondents.

Instructions -- Evaluate the relative desirability of the three **Intangible Factors** as they relate to the Design Return Period. Should you have any questions on these factors, they are described in more detail in Appendix B. Although similar to the descriptions in Appendix A, these factors attempt to focus more directly on the selection of a Design Return Period. Enter both Verbal and Numerical ratings. A list of Verbal ratings is provided following each Questionnaire. The same Numerical and/or Verbal rating may be used more than once to indicate equal importance of two or more factors.

For the Numerical rating select an integer from 0 to 10 where 0 is for a Design Return Period that is **NOT AT ALL DESIRABLE** and 10 is for a Design Return Period that is **MOST DESIRABLE.** The same rating may be used more than once.

The rating for a given Intangible Factor should increase or stay the same as the Design Return Period increases. In other words, referring to the Questionnaire of Part 3, the RATINGS with respect to a given Intangible Factor should STAY THE SAME OR INCREASE as your evaluation goes DOWNWARD. For example with say the **Maintenance Frequency** factor, your Numerical ratings for the eight Design Return Periods in the Questionnaire of Part 3 could, as an example be 2, 4, 6, 8, 10, 10, 10, 10, and the Verbal ratings ND, ND, NV, SD, D, VD, VD, MD.

For each individual site, consider each of the three different Intangible Factors **INDEPENDENTLY. DO NOT** consider how you rated the other two factors at an individual site.

PLEASE TURN THE PAGE AND COMPLETE YOUR FIRST PART 3 QUESTIONNAIRE TABLE.

QUESTIONNAIRE FOR PART 3

<u>Site Conditions</u> -- The site conditions to be considered at this site are listed below. Note, each Questionnaire for Part 3 has different site conditions, and your site conditions may also be different from those provided to other Respondents helping with this survey.

Location: ___ Urban Area, ___ Rural Area

Structure Type: ___ Bridge, ___ Culvert

Average Daily Traffic (ADT): ___ < 750, ___ 750 to 5000, ___ > 5000

Detour Length When Closed: ___ < 5 mi., ___ 5 to 20 mi., ___ > 20 mi.

Fill Height Where Overtopped: ___ < 8 ft., ___ 8 to 20 ft., ___ > 20 ft.

Floodplain Land Use Upstream of Roadway Crossing:

___ Desert or Prairie; i.e. lands tolerant of temporary inundation.
___ Agricultural crops, irrigated meadow, pasture, etc.
___ Farm or ranch buildings, or low value commercial buildings: low value contents. No residential occupancy.
___ Parks or recreational areas w/o buildings.
___ 1 to 3 residential buildings (farm or urban), or farm, ranch or commercial buildings: high value contents.
___ > 3 Residential or commercial buildings.

<u>Questionnaire</u> -- This part of the survey allows you to express your professional views regarding the Design Return Period vs. three common **Intangible Factors.**

Design Return Period	Maintenance Frequency		Litigation Potential		Public Svc/Convenience	
	Verbal*	Numer.#	Verbal*	Numer.#	Verbal*	Numer.#
2 yr	( )	( )	( )	( )	( )	( )
5 yr	( )	( )	( )	( )	( )	( )
10 yr	( )	( )	( )	( )	( )	( )
25 yr	( )	( )	( )	( )	( )	( )
50 yr	( )	( )	( )	( )	( )	( )
100 yr	( )	( )	( )	( )	( )	( )
200 yr	( )	( )	( )	( )	( )	( )
500 yr	( )	( )	( )	( )	( )	( )

* Enter: MD for "Most Desirable"; VD for "Very Desirable"; SD for "Somewhat Desirable"; D for "Desirable".; ND for "Not Desirable"; NV for "Not Very Desirable"; NA for "Not At All Desirable".

\# Enter an integer from 0 to 10 in accordance with the above instructions.

PLEASE GO TO THE NEXT QUESTIONNAIRE FOR PART 3. IF YOU HAVE COMPLETED ALL OF YOUR PART 3 QUESTIONNAIRES, PROCEED WITH THE FOLLOWING.

IF YOU CHECKED CURRENT POSITION 1 IN PART 1, PLEASE STOP HERE AND RETURN YOUR COMPLETED SURVEY FORMS TO YOUR AGENCY'S HYDRAULIC ENGINEER. YOU NEED NOT COMPLETE PART 4. THANK YOU FOR YOUR HELP.

IF YOU CHECKED CURRENT POSITION 2 OR 3 IN PART 1, PLEASE GO TO PART 4 OF THIS SURVEY.

PART 4 -- ECONOMIC DESIRABILITY OF SELECTING A NONOPTIMAL DESIGN RETURN PERIOD

Purpose -- This part of the survey is to obtain your view on the desirability, with respect to economics alone, of selecting a Design Return Period that is greater than the least economic cost return period (Optimal Return Period).

Background -- The total economic risk cost curve has the following generic shape.

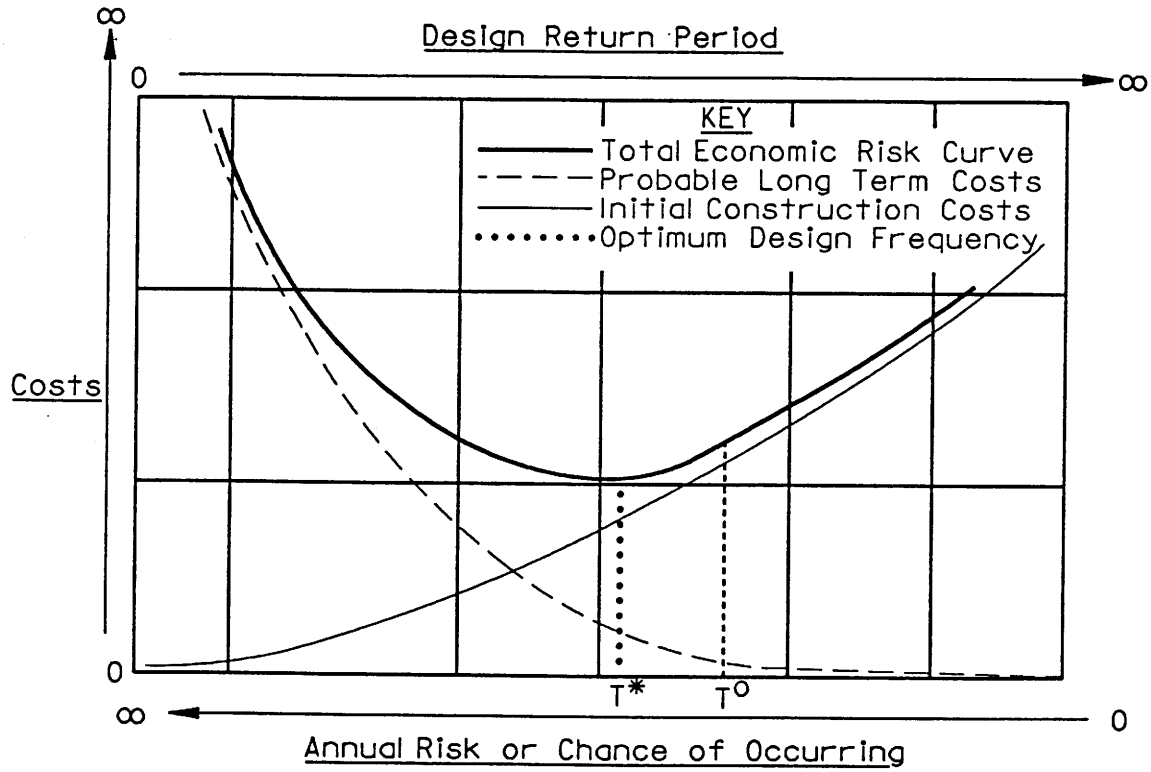


Figure 4-1 -- TOTAL RISK COST CURVE

T^* = Optimal Return Period
T° = Nonoptimal Return Period
Total Risk Cost = Initial Construction Cost + Long Term Risk Cost

From strictly an economic viewpoint, the Optimum Return Period (T^*) associated with the least Total Risk Cost is the most desirable one. This strictly economic viewpoint ignores such intangibles as the preferred level of service, moral concerns about human life, litigation avoidance, nuisance claims, etc. As the Design Return Period increases from T^* to T°, the

Total Risk Cost increases which would make the larger return period T° less **economically** attractive than T^*. You are to judge the relative desirability of selecting the Nonoptimal design return period T° on two bases: (1) the **additional** Total Risk Cost required over the least total risk cost associated with T^*, and (2) the **additional gain** in service, safety, decreased risk, etc. to be gained from adopting the larger return period T°.

In essence, the objective of this part of the survey is to seek your judgement on the relative desirability about paying extra costs to gain additional service and protection for a particular highway drainage structure.

Instructions -- Use both a Numerical and Verbal rating. For the Numerical rating select an integer from 0 to 10 where 0 is for a Nonoptimal Return Period (T°) that is for **NOT-AT-ALL-DESIRABLE** and 10 for a Nonoptimal Return Period that is **MOST DESIRABLE.** The Verbal ratings are listed with the figures in this part of the Questionnaire. Place your Numerical rating followed by the Verbal rating next to the points indicated by dots (see example below). The same Numerical and/or Verbal rating may be used more than once to indicate equal importance of two or more points.

Examples -- Note that the vertical ordinate is the change in percent between the Optimal Return Period Costs (T^*) and the Nonoptimal Return Period Costs (T°). Refer to site X on figure 4-2.

For the first example of site X, point A corresponds to the Optimum Return Period as the vertical ordinate is zero. This means that this must be the most desirable design return period from a strictly economical viewpoint and, therefore, a Numerical rating of 10 and a Verbal rating of MD (Most Desirable) must be assigned to point A. For Point A note that there is a 10% risk or chance of occurrance each year for a flood corresponding to the Optimum Return Period in this example. At point B the cost increase is 10% This means that with a 10% cost increase over the least total risk cost, the risk of incurring problems due to decreased safety, lower service complaints, litigation, etc. decrease from 10% chance of occurrance each year to a 4% chance of occurrance each year. Some of you might feel this is a worthwhile investment; others may not. Hence, a rating of (9; Very Desirable) might be awarded to point B by some of you, while others may feel that the rating should be (8; Very Desirable), or that perhaps it should be rated even lower.

Consider the second example shown on Figure 4-2 which is site Y. Again, Point A will be the Optimum Return Period having an annual risk of occurrance equal to 10%. Point C corresponds to the same Nonoptimal Return Period which has an annual risk of occurrance equal to 4%, the same as point B in example 1. Now however, the cost increase is 30% in order to reduce the annual risk or chance of occurance from 10% to 4%. Intuitively, ratings for point C should be lower than that for point B. Perhaps some of you would rate this higher cost required to decrease the risk to be only (7; Desirable), while others might feel it is only (5; Somewhat Desirable), or that perhaps it should be rated even lower.

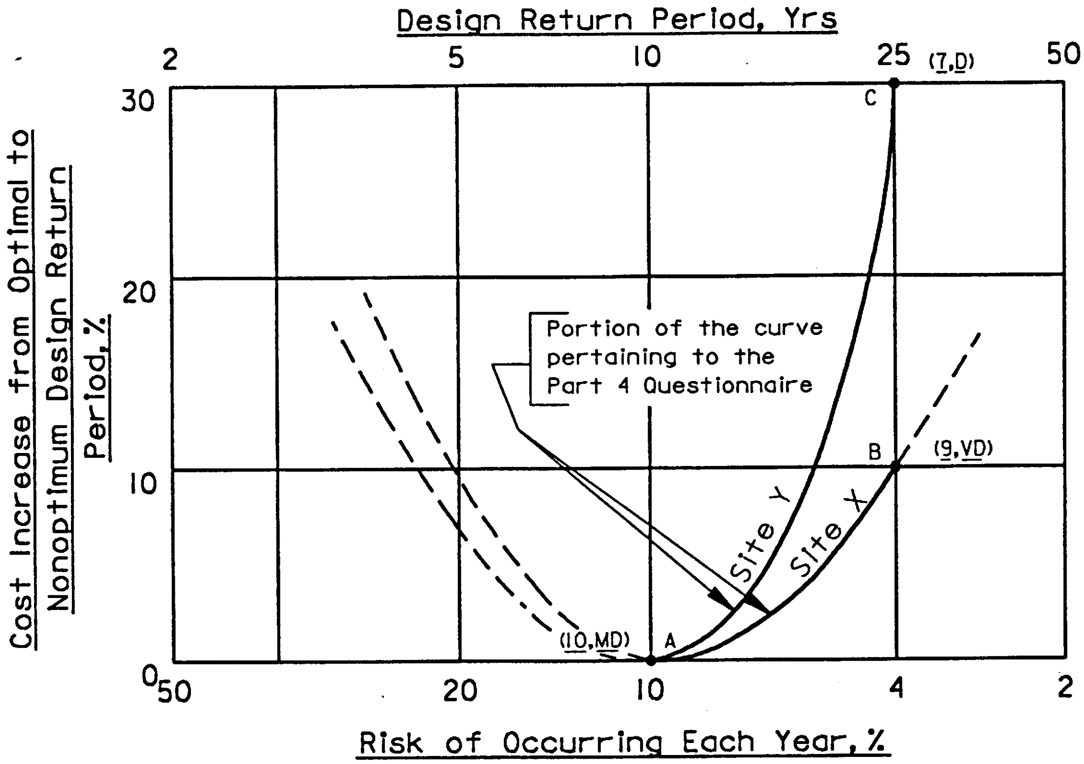


Figure 4-2 -- Example

To ensure consistency in your relative ratings, the following rules should be observed:

- For the same Nonoptimal Return Period considered for design, the rating must decrease as the percentage of incremental cost increases.
- For the same percentage of incremental cost, the rating could either stay the same or increase as the Nonoptimal Return Period considered for design increases.

Questionnaire -- The questionnaire for Part 4 is in the format of a figure (Figure 4-3). Given the data on your figure, enter your Verbal and Numerical ratings (Verbal; Numerical). Note, your figures for this questionnaire may differ from other respondants.

PLEASE TURN THE PAGE AND COMPLETE YOUR QUESTIONNAIRES FOR PART 4.

UPON COMPLETING THE QUESTIONNAIRE FOR PART 4, PLEASE RETURN ALL QUESTIONNAIRES TO YOUR AGENCY'S HYDRAULIC ENGINEER.

THANK YOU FOR YOUR ASSISTANCE.

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD

(Site Condition I)

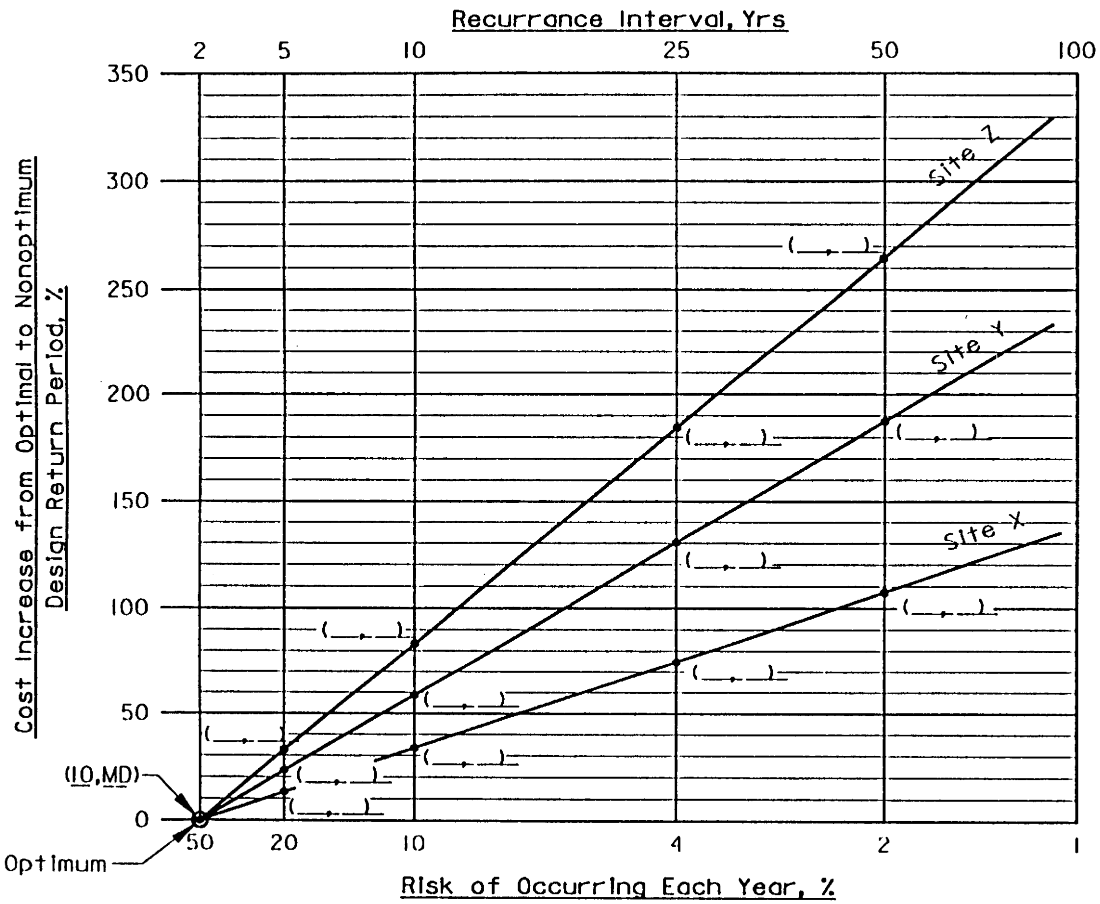


Figure 4-3 -- Questionnaire For Part 4

Ratings (a,b)

a = Numerical Ratings

Ratings are integers from 0 to 10 where:

0= Not at all Desirable

10= Most Desirable

b = Verbal Ratings

MD = Most Desirable

VD = Very Desirable

D = Desirable

SD = Somewhat Desirable

NV = Not Very Desirable

NA = Not At All Desirable

Instructions

- First, enter all the Numerical Ratings in the first blank.
- Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD

(Site Condition 2)

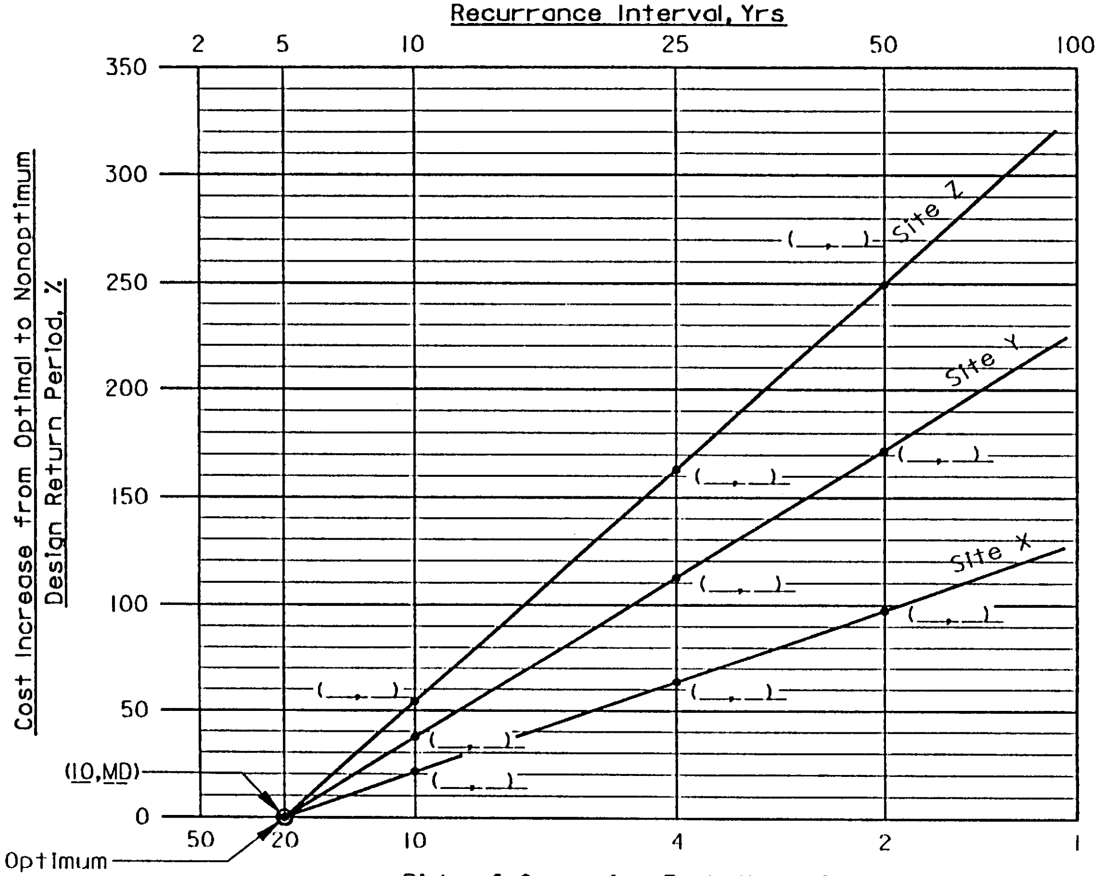


Figure 4-3 -- Questionnaire For Part 4

Ratings (a,b)

a = Numerical Ratings

Ratings are integers from 0 to 10 where:

0= Not at all Desirable

10= Most Desirable

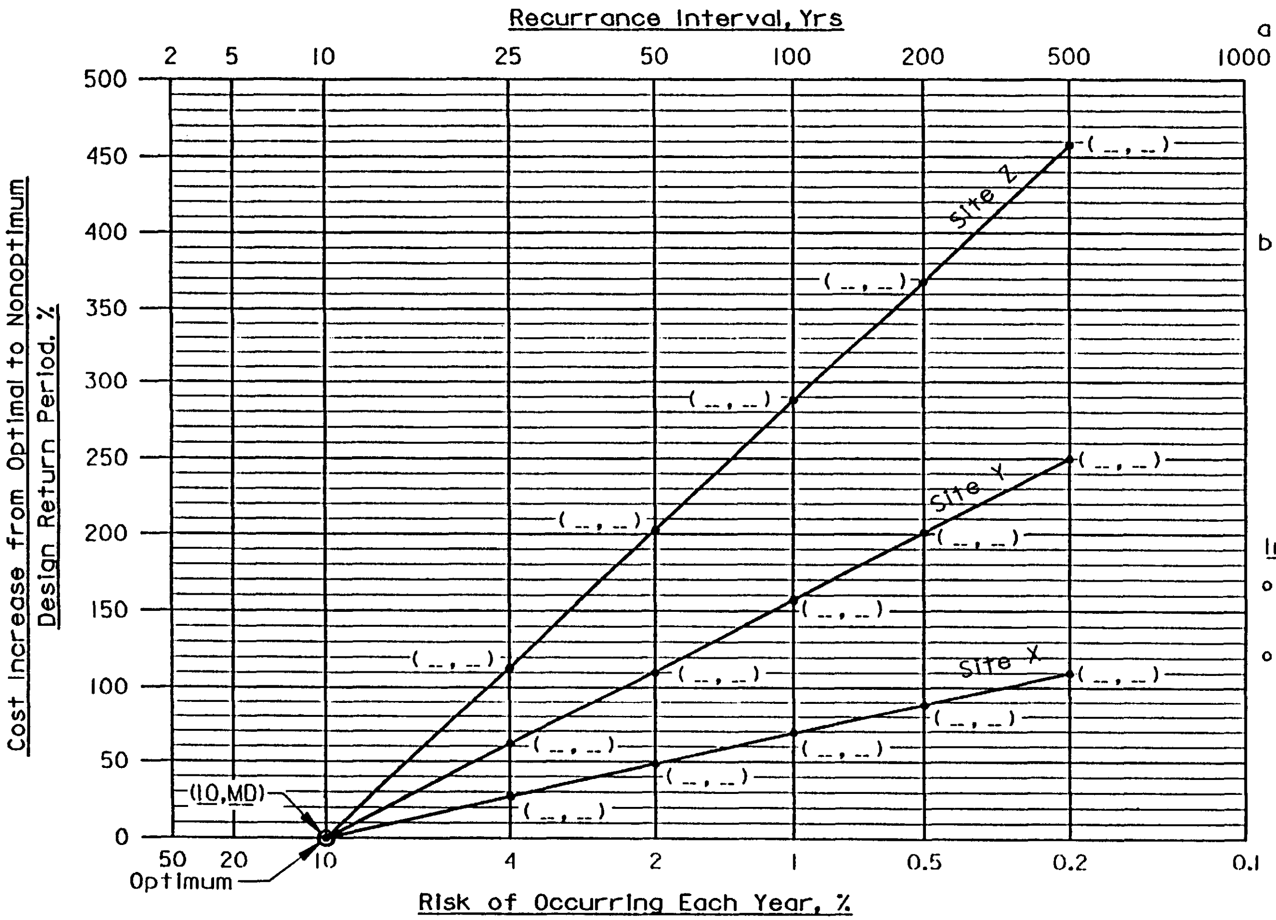
b = Verbal Ratings

MD = Most Desirable
VD = Very Desirable
D = Desirable
SD = Somewhat Desirable
NV = Not Very Desirable
NA = Not At All Desirable

Instructions

- First, enter all the Numerical Ratings in the first blank.
- Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD
(Site Condition 3)



Ratings (a,b)

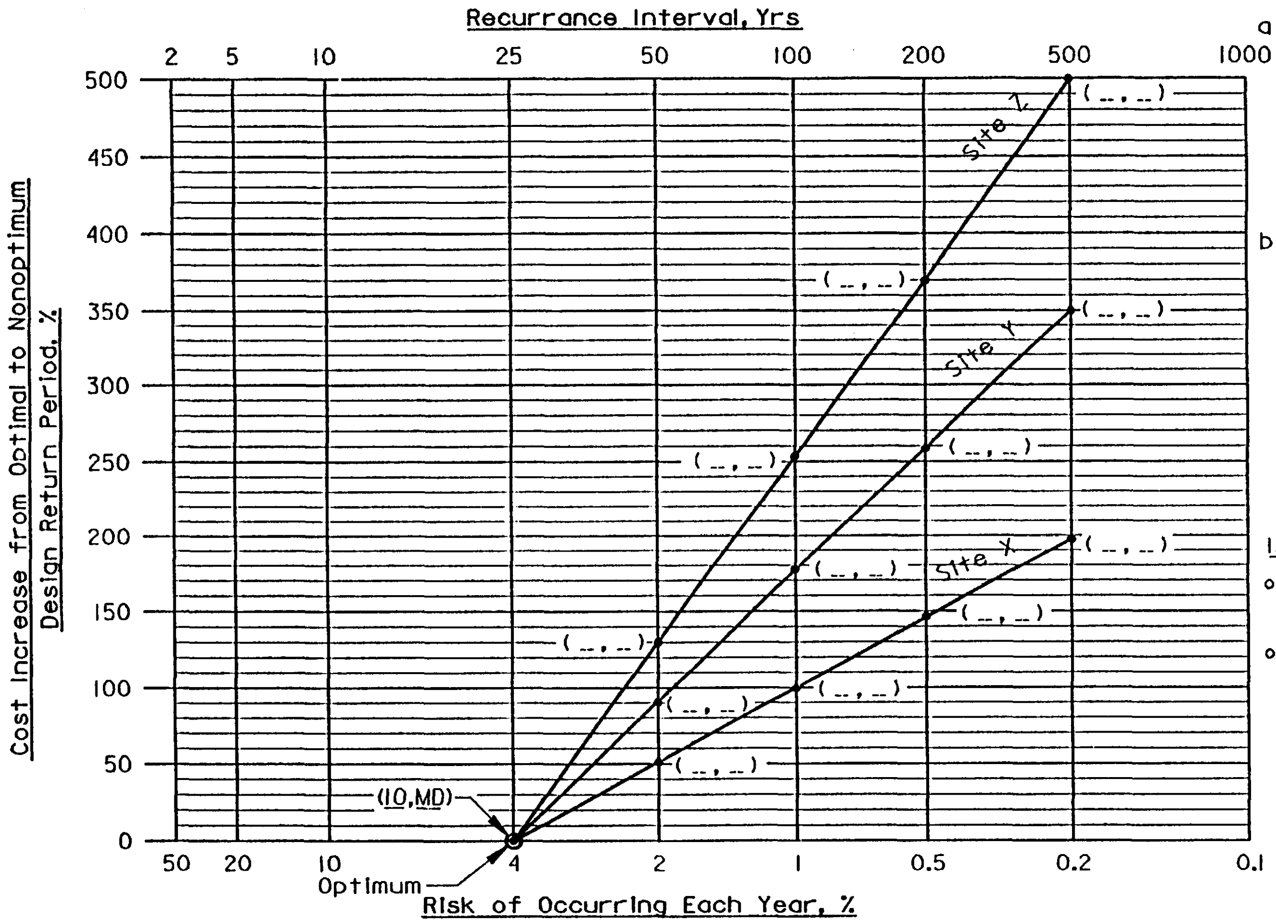
a = Numerical Ratings
Ratings are Integers from 0 to 10 where:
0= Not at all Desirable
10= Most Desirable

b = Verbal Ratings
MD = Most Desirable
VD = Very Desirable
D = Desirable
SD = Somewhat Desirable
NV = Not Very Desirable
NA = Not At All Desirable

Instructions
- First, enter all the Numerical Ratings in the first blank.
- Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

Figure 4-3 -- Questionnaire For Part 4

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD
(Site Condition 4)



Ratings (a,b)

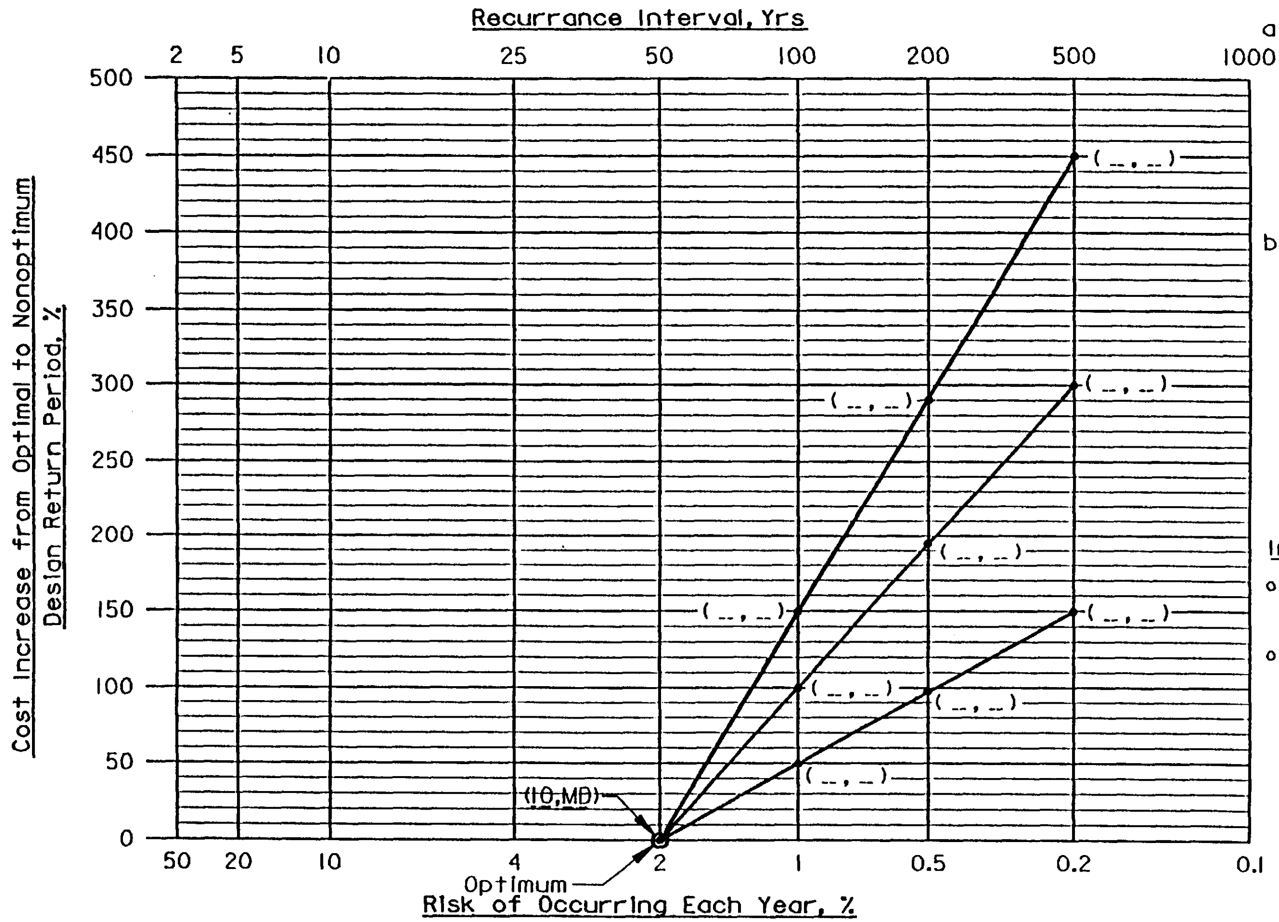
a = Numerical Ratings
Ratings are integers from 0 to 10 where:
0= Not at all Desirable
10= Most Desirable

b = Verbal Ratings
MD = Most Desirable
VD = Very Desirable
D = Desirable
SD = Somewhat Desirable
NV = Not Very Desirable
NA = Not At All Desirable

Instructions
- First, enter all the Numerical Ratings in the first blank.
- Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

Figure 4-3 -- Questionnaire For Part 4

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD
(Site Condition 5)



Ratings (a,b)

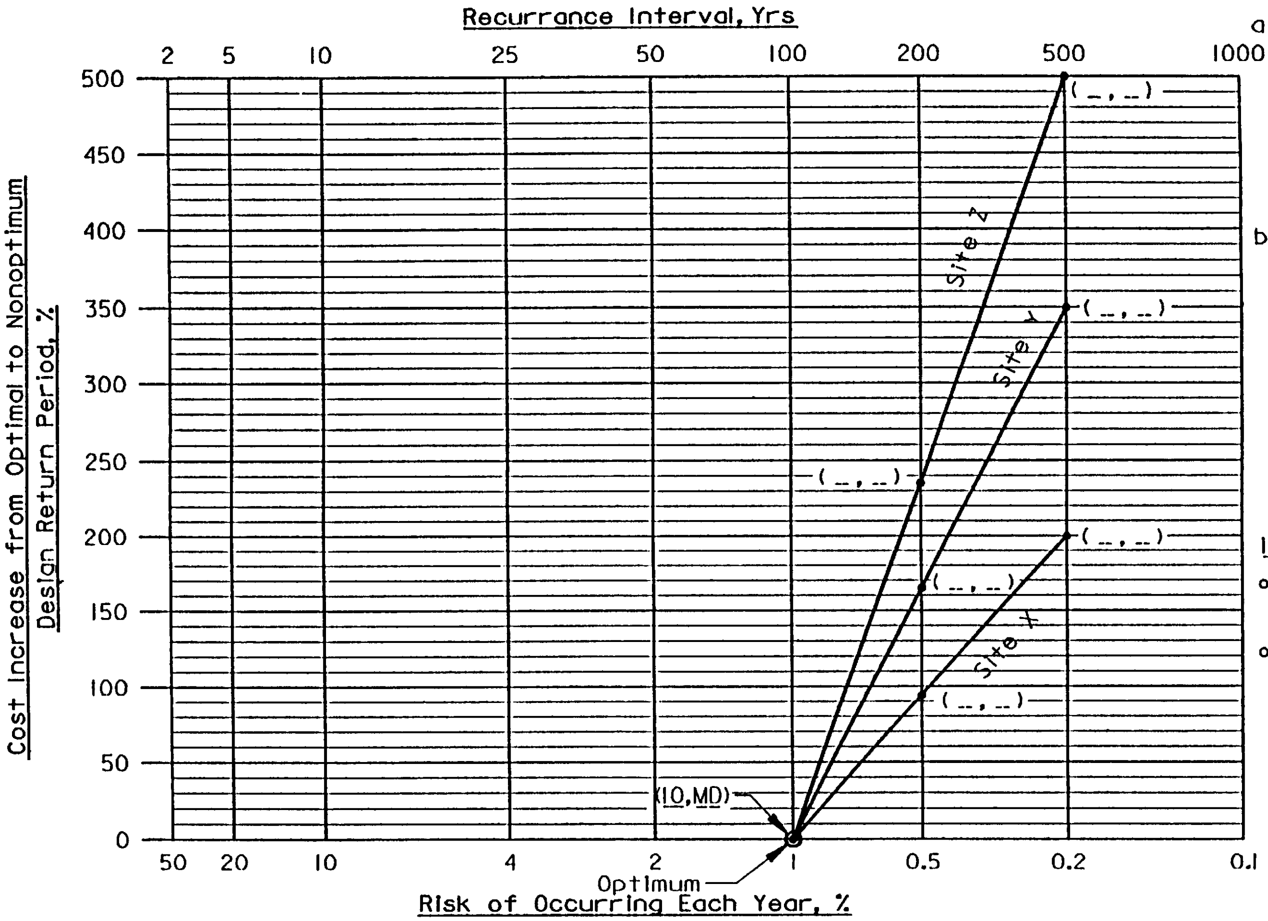
a = Numerical Ratings
Ratings are integers from 0 to 10 where:
0= Not at all Desirable
10= Most Desirable

b = Verbal Ratings
MD = Most Desirable
VD = Very Desirable
D = Desirable
SD = Somewhat Desirable
NV = Not Very Desirable
NA = Not At All Desirable

Instructions
- o First, enter all the Numerical Ratings in the first blank.
- o Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

Figure 4-3 -- Questionnaire For Part 4

PART 4 -- DESIRABILITY OF NONOPTIMAL RETURN PERIOD
(Site Condition 6)



Ratings (a,b)

a = Numerical Ratings

Ratings are integers from 0 to 10 where:

0= Not at all Desirable

10= Most Desirable

b = Verbal Ratings

MD = Most Desirable
VD = Very Desirable
D = Desirable
SD = Somewhat Desirable
NV = Not Very Desirable
NA = Not At All Desirable

Instructions

- First, enter all the Numerical Ratings in the first blank.
- Second, enter all the Verbal Ratings in the second blank ignoring your Numerical Ratings.

Figure 4-3 -- Questionnaire For Part 4

APPENDIX A -- DISCUSSION OF DRAINAGE DESIGN CRITERIA FACTORS

The Design factors for the Questionnaire of Part 2 are described below.

DRAINAGE STRUCTURE COST -- This factor includes only the **INITIAL CONSTRUCTION COST** for a highway drainage structure. See Figure 4-1.

COSTS RELATED TO FLOOD DAMAGE -- In addition to the **INITIAL CONSTRUCTION COST** there is a flood related **LONG TERM COST** (See Figure 4-1) that may occur during the structure's service life. These costs include the damages to (1) properties in the flood plain, (2) the drainage structure, and (3) the highway pavement and embankment, as well as those costs associated with (4) traffic delays and detours.

MAINTENANCE FREQUENCY -- This **LONG TERM COST** factor is for the concern some highway agencies have about having to frequently dispatch highway maintenance crews to repair only minor flood damage at a roadway crossing. Also included would be frequent nuisance complaints voiced by adjacent property owners. Not included in this factor would be major roadway crossing damage which would be repaired by contract, as these costs are to be considered part of the foregoing **COSTS RELATED TO FLOOD DAMAGE** factor. More specifically, **MAINTENANCE FREQUENCY** is to be rated only for minor flood damage repairable by your maintenance forces and to avoid continual minor complaints from nuisance flooding of adjacent lands. Major complaints by adjacent property owners that might lead to litigation are not to be considered here as they are to be included in the **LITIGATION POTENTIAL** factor below. Although your highway maintenance crews may technically be responsible for all maintenance associated with your highway system, the emphasis with this factor is only for the frequently recurring repair of a roadway crossing damaged by small floods, and to avoid having to continually respond to nuisance complaints.

LITIGATION POTENTIAL -- A highway or transportation agency can be involved in litigation due to flood related causes. The possibility of incurring this **LONG TERM COST** is usually considered intuitively in the design of a roadway crossing. Note that the economic losses or damages to the property, structure and roadway, as well as from traffic delays/detours are considered in the foregoing **COST RELATED TO FLOOD DAMAGE** factor. Accordingly, this factor is only for the potential inconvenience (hassle), legal costs and other court ordered awards that may be required to accommodate such things as pain, suffering, and reconstruction to a higher standard if a dispute cannot be resolved outside of the courts. It is impossible to precisely assess the chances that litigation relating to roadway crossing design might occur, so the question here is how intuitively important is this factor to you as compared with the other six factors considered in the design of a highway drainage structure.

PUBLIC SERVICE AND CONVENIENCE -- Since the advent of our modern highway system the traveling public has grown accustomed to a certain level of service regardless of what the initial cost may be. For the purpose of this survey, this **INITIAL COST** factor is primarily concerned with an increase in public inconvenience associated with traffic interruption due to floods overtopping the roadway should the optimum Design Return Period be less than that currently used. The magnitude of this inconvenience may depend on such things as the traffic volume, traffic types, availability of detours, and overall importance of the route. Note that the tangible aspect of traffic interruption (delay and detour cost) is included in the foregoing **COSTS RELATED TO FLOOD DAMAGE** factor; thus this factor is for the public inconvenience associated with flood related delays as well as the temporary interruption of access to private or commercial property. Also included in this factor are such things as the psychological effect on a highway user and the economic well-being of a community if traffic interruption occurs.

RISK FOR LOSS OF HUMAN LIFE -- A most difficult **LONG TERM COST** factor to rate. Undoubtedly there will be a wide and interesting range of ratings for the research team to evaluate. In the United States human life commonly carries a high value. However, when weighed against excessive costs to avoid any risks, many engineers begin to compromise -- probably in widely varying degrees. It is this degree of variance in which there is an interest. Certainly few, if any, engineers would elect to place a large number of lives at risk every year by selecting a low Design Return Period (say 2 years or there about) just to minimize the drainage structure's cost. Conversely, faced with limited resources, few engineers would advocate using say the Probable Maximum Flood or perhaps even the 500 or 100-year flood just to avoid **LITIGATION POTENTIAL,** or to decrease the **MAINTENANCE FREQUENCY.** Where do you really feel human life fits in this complex spectrum of Drainage Design Factors?

UNCERTAINTY IN HYDROLOGIC ANALYSIS -- Most engineers are well aware that there is some level of uncertainty in estimating the magnitude and frequency of floods. Even though the amount of uncertainty is often predictable, it is still there. Coupled with this flood predicting uncertainty is a lesser amount of variance in predicting the hydraulic performance of channels and drainage structures given a particular magnitude and frequency of flood. Because of these uncertainties, it may seem appropriate to you to rate this **LONG TERM RISK COST** factor higher just to "be safe". Conversely, given the higher costs associated with arbitrarily increasing the Design Return Period, you may wish to moderate your rating.

APPENDIX B — DESIGN RETURN PERIOD VS. INTANGIBLE FACTORS

The Design Return Period factors for the Questionnaire of Part 3 are described below.

MAINTENANCE FREQUENCY -- This factor is for the damage to a roadway crossing during a flood event due to the erosion of embankments and loss of pavements when floodwater overtops the roadway. The frequency that this occurs is related to the Design Return Period selected for a drainage structure. How often a highway maintenance crew must be dispatched or the repair let to contract to repair a flood damaged roadway crossing is related to the Design Return Period. Also, the magnitude of the damage is related to the Design Return Period.

To illustrate, the larger the flood, the larger (in years) is the selected Design Return Period, and the less frequent minor maintenance or the cost of a major contract will be; that is, for just maintenance considerations the level of desirability increases as a larger Design Return Period is used. However, you should attempt to respond to this survey objectively and not just from one point of view by, say, over-emphasizing the desirability of low maintenance costs.

LITIGATION POTENTIAL -- Litigation involving highway drainage structure design, in general, occurs after a flood event causes a death due to either a hazardous travel condition caused by overtopping floodwater, scoured bridges, or increased flood depths (backwater, diverted flows, etc.). Another source of potential litigation is excessive property damage caused by the backwater, or by diverted floodwaters. Conceivably there could be other damages that might be perceived as being due to the presence of the roadway crossing. The Design Return Period subjectively measures the likelihood of a highway agency getting involved in litigation regarding its drainage design practices. Stated another way, intuitively the use of a larger (in years) Design Return Period results in less chance of being involved in litigation.

PUBLIC SERVICE AND CONVENIENCE -- The criteria for public service and convenience of a roadway can again be subjectively measured by such things as the amount of traffic (ADT), the type of traffic delayed, and those activities associated with repairing flood damaged crossings that would inconvenience traffic (delays, detours, etc.). As before, selection of a larger Design Return Period (in years) would favor better public service because flood related inconveniences would be fewer during the service life of the drainage structure. Your rating is to indicate what you think this factor should be, not what the public has come to expect.

APPENDIX A.2

RAW DATA FROM SURVEY

ID	POSITION	EMPOLYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
1	6	2	VI	8	I	5	SI	7	NI	3	SI	7	VI	8	NI	3
2	5	2	I	5	VI	8	NI	4	SI	6	I	5	MI	10	NI	3
3	5	2	I	6	I	7	SI	5	I	7	VI	8	VI	9	SI	4
4	5	2	MI	10	SI	8	NI	6	NV	5	NV	5	SI	8	SI	8
5	4	2	VI	8	VI	8	SI	7	I	5	MI	10	MI	10	I	5
6	7	2	VI	8	I	6	SI	7	NI	4	VI	8	I	6	SI	7
7	7	2	I	7	VI	8	I	6	NV	2	I	5	VI	9	I	7
8	4	2	MI	9	MI	8	SI	5	VI	7	MI	9	VI	8	I	4
9	7	2	MI	1	I	3	VI	2	I	4	I	5	SI	6	I	7
10	1	2	SI	7	I	5	VI	8	SI	8	I	5	VI	8	I	6
11	7	2	I	5	SI	6	SI	7	I	5	VI	9	MI	10	I	5
12	7	2	SI	7	I	6	I	5	VI	8	VI	8	VI	9	SI	7
13	7	2	I	6	SI	7	I	6	NI	4	VI	8	MI	9	NI	3
14	7	2	SI	6	SI	6	SI	6	VI	8	I	5	MI	10	I	5
15	7	2	VI	2	SI	5	SI	4	I	7	VI	3	MI	1	I	6
16	7	2	VI	8	VI	9	VI	7	SI	8	VI	8	VI	10	SI	6
17	7	2	SI	6	I	9	I	8	I	8	SI	6	VI	10	I	8
18	7	2	VI	8	SI	7	VI	9	I	4	I	5	MI	10	SI	6
19	7	2	I	6	VI	9	VI	7	VI	8	NV	3	MI	10	I	5
20	7	2	SI	5	VI	9	SI	8	I	3	I	6	MI	10	NV	1
21	7	2	SI	7	VI	9	I	5	I	5	NI	2	MI	10	I	5
22	7	2	I	5	I	5	VI	8	I	5	SI	7	MI	10	I	5
23	7	2	SI	6	VI	8	NI	4	I	5	NV	3	MI	10	I	5
24	7	2	I	7	VI	9	SI	8	MI	9	I	6	MI	10	I	5
25	7	2	I	4	VI	7	VI	8	VI	6	VI	9	MI	9	I	6

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPLOYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
26	2	2	I	5	VI	9	I	5	VI	9	VI	9	MI	10	SI	7
27	2	2	MI	9	MI	10	VI	7	I	5	VI	8	VI	6	NI	4
28	2	2	MI	10	I	6	VI	8	VI	7	NI	4	MI	9	SI	5
29	2	2		5		3		2		5		2		9		3
30	1	2	SI	8	VI	9	I	7	VI	9	I	7	VI	9	VI	7
31	1	2	I	5	VI	8	I	7	VI	9	I	6	MI	10	I	5
32	3	2	SI	7	SI	7	I	6	VI	8	VI	8	MI	10	I	6
33	3	2	I	7	VI	8	VI	9	I	6	I	8	MI	10	I	7
34	1	2	VI	8	MI	9	SI	7	I	6	NI	4	I	6	I	5
35	1	2	VI	8	VI	8	I	5	SI	6	NI	4	MI	10	NV	2
36	1	2	SI	6	NI	4	NI	4	SI	7	SI	6	SI	7	NI	4
37	1	2	SI	7	NA	2	NV	4	VI	8	I	9	VI	8	NI	2
38	1	2	VI	9	I	8	I	7	I	7	I	8	MI	10	SI	6
39	1	2	NI	4	I	8	NI	3	SI	7	SI	7	VI	9	SI	8
40	1	2	MI	10	SI	7	SI	7	SI	7	SI	7	I	8	I	8
41	1	2	I	5	I	5	I	5	I	6	SI	6	VI	9	SI	6
42	1	2	I	7	VI	8	I	6	VI	8	VI	9	MI	10	I	5
43	1	2	I	6	VI	8	SI	6	SI	6	I	6	NI	9	SI	7
44	1	2	VI	8	MI	10	SI	8	I	5	SI	8	VI	10	I	5
45	1	2	VI	9	SI	7	NI	3	I	4	SI	7	VI	9	I	4
46	7	2	VI	8	SI	6	I	5	SI	6	SI	6	MI	10	VI	8
47	1	2	SI	7	MI	10	NI	4	SI	6	I	6	VI	8	NI	4
48	1	2	VI	8	I	6	I	6	I	6	I	6	VI	8	I	6
49	1	2	SI	5	VI	10	I	6	VI	5	I	5	MI	10	SI	5
50	1	2	SI	9	I	7	I	8	I	6	NI	4	MI	10	I	5

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPLOYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
51	3	2	VI	8	VI	8	SI	5	I	7	NV	4	MI	10	NV	4
52	3	2	VI	8	I	5	NI	4	NV	2	NI	3	NV	2	I	4
53	3	2	VI	8	VI	8	I	5	I	5	VI	8	VI	8	I	5
54	3	2	I	7	I	7	I	7	I	7	VI	9	MI	10	SI	8
55	1	2	I	5	VI	8	SI	4	SI	5	VI	7	VI	9	I	5
56	3	2	I	8	MI	10	SI	4	SI	5	I	7	I	9	SI	4
57	1	2	SI	5	SI	6	SI	5	VI	8	I	4	MI	10	I	4
58	3	2	SI	6	VI	8	VI	8	SI	8	MI	10	MI	10	VI	8
59	3	2	I	5	SI	7	SI	7	I	5	VI	9	MI	10	I	5
60	3	2	VI	7	VI	7	I	5	I	5	VI	7	I	5	I	5
61	3	2	MI	10	VI	9	SI	8	VI	9	VI	9	SI	8	SI	8
62	3	2	I	6	VI	8	I	6	I	7	I	7	MI	10	I	7
63	1	2	I	5	I	5	NI	4	SI	6	I	5	MI	10	I	5
64	4	2	I	8	I	8	NI	4	NI	3	VI	6	VI	6	I	7
65	3	2	VI	9	VI	8	I	5	SI	7	I	4	MI	10	I	4
66	5	2	I	6	SI	8	SI	7	I	6	VI	9	MI	10	I	5
67	2	2	VI	9	VI	9	VI	9	I	7	I	7	VI	9	I	7
68	1	2	I	6	VI	8	VI	8	VI	9	VI	9	MI	10	SI	6
69	4	2	I	7	VI	9	I	6	MI	10	VI	9	I	9	I	8
70	2	2	VI	8	SI	7	I	6	I	6	VI	8	MI	10	I	6
71	3	2	I	6	I	6	NI	4	NI	5	NV	3	VI	8	NI	4
72	3	2	VI	9	NI	4	VI	7	I	6	I	7	NI	3	NI	3
73	4	1	MI	10	MI	10	I	6	I	5	VI	7	MI	9	NI	0
74	4	2	SI	7	SI	7	NI	5	VI	8	I	7	MI	10	I	6
75	2	2	VI	8	MI	9	VI	7	VI	8	SI	6	MI	10	SI	6

Note:

Position: 1 - Highway engineer or technician;
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6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPLOYER	Drain. Struc. Cost V	Drain. Struc. Cost N	Flood Dmg. Cost V	Flood Dmg. Cost N	Maint. Freq. V	Maint. Freq. N	Litig. Poten. V	Litig. Poten. N	Publ. Svc. V	Publ. Svc. N	Loss of Human Life V	Loss of Human Life N	Hydro. Uncer. V	Hydro. Uncer. N
76	7	1	MI	10	VI	9	VI	7	VI	8	VI	8	MI	10	SI	6
77	7	1	VI	8	VI	8	I	6	I	6	SI	7	MI	10	NI	4
78	5	2	SI	5	VI	6	VI	6	I	4	SI	5	MI	10	I	4
79	2	2	SI	7	I	5	VI	8	I	5	VI	8	MI	10	I	5
80	4	2	SI	7	VI	9	SI	8	NI	5	MI	10	NI	6	I	4
81	1	2	VI	8	MI	10	I	6	I	6	NA	2	NA	2	SI	7
82	2	2	I	7	VI	9	VI	8	NV	3	MI	10	NV	1	NI	0
83	5	5	I	4	SI	6	SI	5	I	4	MI	9	MI	9	NI	3
84	3	5	VI	7	VI	9	I	5	VI	8	VI	7	MI	10	SI	6
85	3	5	VI	8	VI	8	SI	4	I	5	I	7	VI	9	NI	3
86	4	2	VI	8	SI	6	I	5	I	5	VI	8	MI	10	I	5
87	2	2	MI	10	I	5	I	5	NI	3	VI	6	VI	7	NI	4
88	2	2	VI	8	SI	7	I	6	SI	7	VI	8	MI	10	NV	2
89	6	1	I	4	VI	7	I	6	I	7	VI	8	MI	10	NI	0
90	2	1	SI	7	SI	7	I	5	VI	8	VI	8	VI	8	SI	6
91	2	2	VI	9	VI	7	SI	6	VI	9	VI	8	MI	10	I	5
92	4	2	I	7	I	7	I	6	VI	8	I	7	MI	10	I	7
93	1	2	I	7	VI	9	I	7	SI	8	VI	9	MI	10	MI	10
94	2	2	VI	8	VI	8	VI	8	VI	7	SI	6	MI	10	MI	10
95	2	2	MI	10	SI	8	NI	5	MI	9	NI	7	MI	9	I	7
96	2	2	I	8	VI	8	I	6	VI	9	I	4	MI	10	I	7
97	2	2	I	5	VI	7	I	7	VI	8	SI	7	MI	10	I	4
98	4	2	I	7	VI	8	I	7	VI	8	I	6	MI	10	NI	4
99	2	2	I	5	VI	9	VI	8	VI	8	MI	10	MI	10	SI	6
100	3	2	SI	6	I	5	SI	7	SI	8	VI	9	MI	10	NI	4

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPOLYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
101	4	2	I	4	VI	9	VI	8	MI	10	I	6	MI	10	SI	6
102	4	2	VI	6	VI	6	VI	7	I	5	SI	6	MI	10	SI	6
103	4	2	I	5	I	5	I	4	NI	3	VI	9	MI	10	SI	7
104	4	2	SI	7	I	6	NI	4	I	5	NV	2	SI	5	NV	2
105	4	2	I	5	VI	8	VI	8	VI	8	VI	8	MI	10	VI	8
106	4	2	I	5	VI	7	VI	7	VI	7	VI	8	MI	10	I	5
107	4	2	SI	7	VI	8	VI	8	VI	9	SI	7	MI	10	SI	7
108	4	2	I	6	VI	8	I	5	VI	8	SI	7	MI	10	NV	3
109	2	2	VI	9	SI	7	I	5	I	6	I	5	MI	10	SI	7
110	2	2	I	8	VI	10	I	8	VI	10	I	5	MI	10	SI	5
111	1	2	I	7	VI	8	I	6	VI	9	I	6	MI	10	I	7
112	1	2	VI	7	VI	7	I	5	I	5	VI	7	MI	10	I	5
113	2	2	I	6	VI	9	VI	9	I	7	SI	7	MI	10	MI	9
114	1	2	MI	9	MI	9	VI	7	NV	2	I	5	I	6	VI	8
115	2	2	I	5	SI	6	SI	6	VI	8	VI	8	MI	10	SI	6
116	1	2	VI	8	MI	10	SI	6	SI	6	I	4	I	4	SI	6
117	1	2	VI	9	MI	10	SI	6	SI	6	I	6	I	8	I	8
118	1	2	VI	8	SI	4	SI	5	VI	7	SI	4	VI	9	I	3
119	1	2	I	2	I	4	I	3	SI	6	I	5	MI	10	VI	7
120	2	2	I	6	VI	8	I	6	I	6	I	6	MI	10	NI	4
121	1	2	I	5	I	5	I	5	I	5	I	5	I	5	I	5
122	2	2	SI	9	VI	9	NV	5	NI	5	I	8	MI	10	NA	5
123	2	2	I	8	I	8	I	8	I	7	I	7	I	10	I	8
124	1	2	I	4	VI	8	I	4	I	6	I	5	VI	9	I	5
125	4	2	I	4	I	3	I	5	NV	7	VI	1	VI	1	NA	6

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPOLYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
126	1	2	I	5	MI	10	I	5	I	5	SI	7	VI	8	I	4
127	4	2	SI	7	VI	9	I	5	SI	7	I	5	I	5	I	5
128	2	2	VI	9	VI	9	SI	9	VI	9	VI	9	VI	9	SI	7
129	2	2	MI	10	VI	9	I	5	VI	9	VI	8	VI	9	SI	6
130	2	1	VI	9	VI	9	I	7	SI	8	I	7	MI	10	I	7
131	4	1	SI	7	SI	7	VI	8	NV	5	I	6	VI	9	VI	8
132	5	1	MI	10	I	7	VI	9	NI	3	I	6	I	8	NV	2
133	5	1	MI	9	MI	8	I	5	I	5	I	5	MI	10	I	5
134	5	1	SI	7	VI	9	I	6	VI	8	SI	7	MI	10	I	5
135	3	1	SI	3	SI	4	I	6	VI	2	I	7	MI	1	I	5
136	4	1	I	7	MI	10	VI	8	I	4	I	5	I	3	NI	1
137	3	1	VI	8	VI	7	MI	9	SI	7	VI	8	MI	9	SI	7
138	3	1		.		.		.		.		.		.		.
139	3	1	I	6	SI	8	I	6	I	6	SI	8	MI	10	I	6
140	4	2	MI	10	NV	2	NV	2	NV	2	I	5	I	5	VI	8
141	5	2	I	8	VI	10	VI	9	VI	10	VI	10	MI	10	VI	10
142	2	2	I	5	VI	8	I	5	SI	7	VI	8	MI	10	I	5
143	5	2	I	5	MI	9	SI	5	VI	8	VI	6	MI	10	VI	7
144	5	2	I	5	VI	8	I	5	VI	8	SI	7	MI	10	NI	4
145	2	2	SI	7	VI	8	VI	8	I	5	MI	10	MI	10	NV	3
146	2	2	I	7	I	7	I	5	I	7	I	7	VI	10	VI	10
147	2	2	VI	6	VI	7	I	4	MI	10	VI	9	MI	10	I	5
148	2	2	SI	8	VI	9	SI	7	I	5	SI	6	MI	10	I	5
149	1	2	I	5	VI	7	SI	5	MI	10	VI	8	MI	10	I	5
150	1	2	VI	9	VI	8	I	3	SI	6	I	4	MI	10	SI	5

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

ID	POSITION	EMPLOYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
151	4	1	SI	7	SI	7	I	6	I	6	VI	8	MI	10	I	5
152	2	1	I	8	I	7	I	6	I	5	VI	8	MI	10	NI	3
153	3	1	VI	9	I	7	VI	8	I	6	MI	10	I	7	NI	3
154	3	1	VI	9	VI	9	SI	6	I	5	NI	3	MI	10	SI	7
155	3	1	SI	6	VI	8	SI	6	SI	6	VI	8	MI	10	SI	6
156	3	1	VI	7	SI	6	SI	6	VI	8	VI	8	MI	10	NV	1
157	4	2	MI	10	VI	7	I	3	I	2	I	2	VI	8	I	2
158	2	2	VI	8	VI	8	VI	8	SI	6	I	5	MI	10	SI	6
159	1	2	VI	9	VI	9	SI	7	I	6	SI	8	MI	10	I	5
160	1	2	I	6	MI	10	NV	5	SI	8	I	6	I	6	VI	10
161	3	1	VI	8	VI	8	I	6	SI	7	I	5	MI	10	I	5
162	3	1	NV	3	SI	6	VI	8	VI	8	VI	8	MI	10	SI	6
163	1	1	SI	7	VI	8	I	6	VI	8	SI	7	VI	8	I	6
164	1	1	VI	8	VI	7	SI	5	I	5	I	5	VI	8	I	5
165	4	1	SI	8	VI	9	VI	8	VI	10	I	7	MI	10	I	7
166	2	1	MI	10	MI	10	VI	9	VI	9	I	7	SI	8	I	6
167	4	1	MI	8	VI	7	SI	6	I	5	VI	6	I	4	I	3
168	5	1	VI	9	SI	7	I	6	NI	4	I	5	MI	10	I	5
169	2	2	VI	9	VI	9	I	7	VI	8	VI	8	MI	10	SI	6
170	1	2	VI	9	VI	8	SI	8	VI	7	SI	7	VI	8	SI	7
171	.	.		.		.		.		.		.		.		.
172	4	2	SI	6	VI	8	VI	8	I	5	I	5	MI	10	I	5
173	2	2	VI	9	VI	9	SI	8	SI	8	SI	8	MI	10	SI	8
174	2	2	SI	4	VI	7	SI	3	VI	8	VI	8	MI	10	VI	6
175	2	2	I	5	MI	10	SI	8	VI	9	VI	9	MI	10	I	5

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
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5 - Consulting engineer;
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ID	POSITION	EMPLOYER	Drain. Struc. Cost V	N	Flood Dmg. Cost V	N	Maint. Freq. V	N	Litig. Poten. V	N	Publ. Svc. V	N	Loss of Human Life V	N	Hydro. Uncer. V	N
176	1	2	NV	5	VI	8	VI	9	I	7	VI	9	VI	10	VI	10
177	3	2	SI	6	VI	8	I	5	NI	4	VI	7	MI	10	I	5
178	3	2	SI	7	MI	10	VI	8	MI	10	VI	10	MI	10	SI	5
179	2	2	SI	7	MI	10	SI	6	I	5	VI	8	MI	10	I	5
180	4	2	VI	8	VI	8	I	5	NI	4	NI	4	MI	10	I	5
181	2	1	I	7	I	8	SI	6	SI	5	VI	9	MI	10	SI	6
182	7	1	I	9	SI	8	I	8	SI	5	I	7	MI	10	NI	3
183	5	1	I	7	VI	8	I	7	SI	5	I	7	MI	10	NI	4
184	4	1	SI	8	VI	9	I	5	I	6	I	4	MI	10	SI	7
185	2	2	NI	3	MI	9	NI	3	I	5	MI	10	MI	10	I	5
186	2	2	NI	2	MI	10	NV	2	I	4	MI	9	MI	10	I	5
187	4	3	SI	7	VI	8	SI	6	I	5	VI	9	MI	10	I	5
188	2	3	NI	4	VI	8	NI	4	NI	5	SI	6	MI	10	SI	7
189	1	3	SI	7	VI	8	SI	7	SI	6	MI	10	VI	9	I	5
190	2	2	I	7	I	6	SI	5	I	6	VI	8	MI	10	I	6
191	4	2	SI	6	VI	4	VI	5	VI	2	VI	3	MI	1	I	7
192	2	2	I	7	SI	8	I	6	VI	9	I	6	MI	10	NI	5

Note:

Position: 1 - Highway engineer or technician;
2 - Hydraulic engineer;
3 - Highway structural engineer;
4 - Branch head;
5 - Administrative staff engineer;
6 - Chief Engineer or administrator;
7 - Other.

Employer: 1 - Federal government;
2 - State government;
3 - County government;
4 - City government;
5 - Consulting engineer;
6 - Other.

APPENDIX A.3
USERS' MANUAL FOR DSGNFREQ.FOR

Appendix A.3 provides guidance on estimating LTEC and Extended LTEC design frequencies using the program DSGNFREQ.FOR. This is done primarily for Wyoming's Basin characteristics hydrology[1] but, as illustrated with Example 4, other flood-frequency relationships can be considered following some manipulation of the input data. Example 5 shows how this manipulation can be circumvented using DSGNFREQ.FOR.

Guidance and example problems are set forth below in five sections.

- Program Loading Instructions
- Program Codes and Code Values
- User Instructions and Examples for DSGNFREQ.FOR
- Sensitivity Analysis
- Application of Research Findings and Policy Example

A.3.1 PROGRAM LOADING INSTRUCTIONS

To use the program DSGNFREQ.FOR, first load the programs. Generally this is done as follows for 386 and 486 personal computers, and may vary some where a different configuration is used. The program has been compiled and executed successfully using Micro-Soft compiler.

Step 1 -- Copy DSGNFREQ.FOR into a hard disk of a computer.

Step 2 -- Compile the program using appropriate fortran compiler to create an executable file, DSGNFREQ.EXE.

Step 3 -- Create an input file, DSGNFREQ.DAT, according to the user instructions described in Section A.3.3.

[1] Reference Druse, S. A., et. al, "Floodflow Characteristics of Wyoming Streams -- A Compilation of Previous Reports", 1988, available from the Accounting Program, Wyoming Department of Transportation, P.O. Box 1708, Cheyenne, WY. 82003-1708, for $20. This publication addresses Wyoming's Basin Characteristics and Channel Geometry Method. For use in other states, input the flood-frequency relationship (Second Case).

Step 4 -- Run program at DOS prompt c:\> by typing DSGNFREQ, then RETURN. The program will echo print the input data on the screen requesting the user to verify the inputs. When all data is confirmed correct, the program will execute to produce an output file, DSGNFREQ.OUT, containing the LTEC and extended - LTEC design frequencies.

Step 5 -- Optional step: Print output at DOS prompt c:\> by typing PRINT DSGNFREQ.OUT, then RETURN.

Step 6 -- Optional step: For another site, repeat steps 1-4. (Note, overstriking will eliminate previous DSGNFREQ.DAT unless file names are used and stored.)

Step 7 -- Exit with editor of choice.

A.3.2 PROGRAM CODES AND CODE VALUES

A 'snapshot' of the codes and their of reliable input values used in DSGNFREQ.FOR are shown in Tables A.3.1 through A.3.7. There are no default values; the program will not run unless a value is entered. Further, using values beyond the ranges in these tables, the hydraulics engineer risks some unknown amount of error. The format for in-putting these values is shown in Tables A.3.8a and A.3.8b.

Table A.3.1 Pipe Culvert Codes (INDXP)

Type of Pipe (Bid Item)	Code
Pipe	1
RCP (Installed)	2
CMP (Installed)	3
RCP Arch	4
Pipe (Installed)	5
CMP Arch	6
RCP w/F.E.	7
CMP w/F.E.	8
Pipe w/F.E.	9
Pipe w/F.E (Installed)	10
CMP Arch w/F.E. (Installed)	11
Relaying Pipe	12
CMP	13
RCP Arch	14

There is no default value. The program will not run unless a value is entered.

Table A.3.2 Predominate Crop Type Codes (INDEXC)

Crop Type*	Code	Crop Type*	Code
Desert	1	Alfalfa	6
Range	2	Barley	7
Hay	3	Corn	8
Oats	4	Beans	9
Wheat	5	Beets	10

Table A.3.3 Summary of Code Limits for Hydraulic/Hydrologic Variables

Variable Code	Bridge Sites	Box Culvert Sites	Pipe Culvert Sites
W (ft.)	20 300	7 - 130	3-270
D (ft.)	2 - 30	2 - 15	1 - 12
S_i (ft/ft)	0.002 - 0.400	0.001 - 0.600	0.001 - 0.650
S_r (ft/ft)	0.002 - 0.400	0.001 - 0.600	0.001 - 0.650
S_c (ft/ft)	0.005 - 0.1500	0.01 - 0.200	0.006 - 0.300
N_p	0.035 - 0.150		
N_c	0.30 - 0.100		
DA (sq. mi.)	15 - 6000	0.4 - 100	0.01 - 6.00
PR (in.)	10 - 40	5 - 40	5 - 40
GF	0.5 - 1.6		

*There is no default value. The program will not run unless a value is entered.

Table A.3.4 Summary of Code Limits for Structural Geometric Variables

Variable Code	Bridges	Box Culverts	Pipe Culverts
NL	2 - 4		
WP (ft)	4 - 6	N/A	N/A
BRIWID (ft)	25 - 65	N/A	N/A
HEMB (ft)			
THICKPV (in)	4 - 8		
INDXS	1 - 3		
COVERDEP (ft)	N/A	2 - 4	
RDWID (ft)	N/A	30 - 80	
INDXP	N/A	N/A	1 - 14

*There is no default value. The program will not run unless a value is entered.

Table A.3.5 Summary of Code Limits for Economic Variables

Variable Code	Bridge Sites	Box Culvert Sites	Pipe Culvert Sites
RATE	2 - 4		
LIFE (yrs)	40 - 100	20 - 100	
NBLDG[a]	0 - 40	0 - 30	
NRES[b]	0 - 5	0 - 5	
BLDGVAL ($1000)	0 - 500		
BLDGELE (ft)	0 - 150	0 - 200	0 -150
KFARM[b]	0 - 5		
OMDXO[b]	0 - 1		
INDXC[b]	1 - 10		

a: For urban areas only.
b: For rural areas only.
* There is no default value. The program will not run unless a value is entered.

Table A.3.6 Summary of Code Limits for Traffic Related Variables

Variable Code	URBAN AREAS	RURAL AREAS
DELL (miles)	0.3 - 10	0.3 - 50
RREP (yd^3/day)	40 - 80	
TM (hrs)	8 - 16	
ASVD (mph)	20 - 65	
AR	200 - 500	100 - 300
ADTE	1000 - 12000	150 - 6000

* There is no default value. The program will not run unless a value is entered.

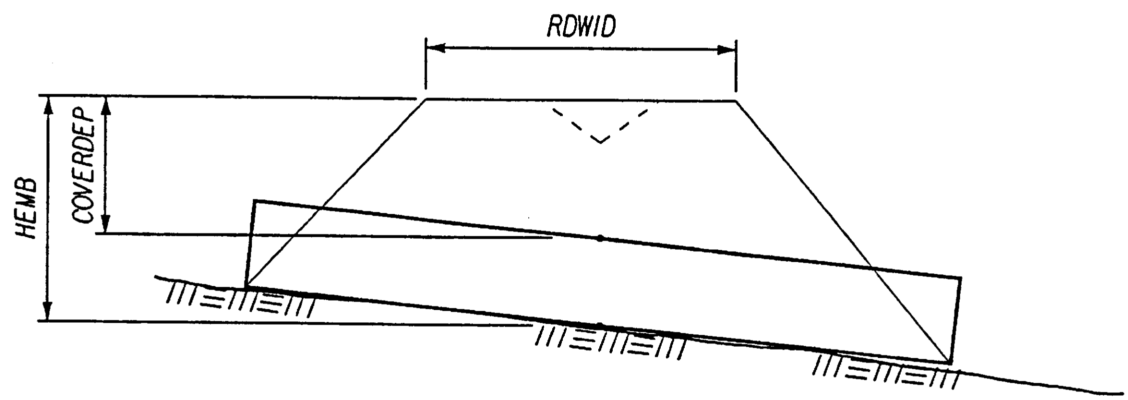


Figure A.3.1 Sketch for Structure and Road Codes

A.3.3 USER INSTRUCTIONS AND EXAMPLES FOR DSGNFREQ.FOR

A tabular format named DSGNFREQ.DAT is used to provide input to DSGNFREQ.FOR. These input formats are shown in Tables A.3.8a and A.3.8b to facilitate editing or creating the input file DSGNFREQ.DAT. The ranges of input variables are shown in Tables A.3.1 through A.3.7. Tables A.3.8a and A.3.8b quickly identify the data for the input file, DSGNFREQ.DAT. The table is also useful should the hydraulics engineer wish to create another input file without (overstriking) the previous DSGNFREQ.DAT file.

Table A.3.8a Input Codes Structure for DSGNFREQ.DAT Without User Defined Flood Frequency Curve

Feature	Feature Codes							
Location, Region, Type LINE 1	LOC Location 1 = Urban 2 = Rural I8	IREGION Hydrol. Region 1 = Mountains 2 = High Plains 3 = Desert I8	IST Structural Type 1 = Bridges 2 = Box Culverts 3 = Pipe Culverts I8	USRCURVE 0	(blank)	(blank)	(blank)	(blank)
Channel Characteristics LINE 2 (Table A.3.3)	W Main Channel Top Width F8.0	D Main Channel Depth F8.0	S_l Floodplain Slope Lt, ft/ft F8.0	S_r Floodplain Slope Rt, ft/ft F8.0	S_o Ave. Channel Slope, ft/ft F8.0	N_p Ave. Mannings n, Floodplain F8.0	N_o Ave. Mannings n, Main Channel F8.0	(blank)
Basin Characteristics LINE 3 (Table A.3.3)	DA Drainage Area, sq mi F8.0	PR Ave Annual Precip Depth, In F8.0	GF Geographic Factor F8.0	(blank)	(blank)	(blank)	(blank)	(blank)
Structure and Road LINE 4 (Table A.3.4)	Bridges (IST = 1)							
	NL Total No. of Traffic Lanes, F8.0	WP Pier Width, ft, Struct. Thickness F8.0	BRIWID Bridge Width, ft, out-to-out F8.0	HEMB Embankment Height, ft F8.0	THICKPV Pavement Thickness, in. F8.0	INDXS Fill Cohesion, 1 = None 2 = Low 3 = High	(blank)	(blank)
	RC Box Culverts (IST = 2)							
	NL (same as above)	COVERDEP Min. Cover Over Culvert, ft F8.0	RDWID Road Template Width, ft. F8.0	HEMB (same as above)	THICKPV (same as above)	INDXS (same as above)	(blank)	(blank)
	Pipe Culverts (IST = 3)							
	NL (same as above)	COVERDEP (same as above)	RDWID (same as above)	HEMB (same as above)	THICKPV (same as above)	INDXS (same as above)	INDXP Pipe Culv Type (Table A.3.2) I8	(blank)
Economic Factors LINE 5 (Table A.3.5)	RATE F8.0	LIFE I8	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)

Table A.3.8a Input Codes Structure for DSGNFREQ.DAT Without User Defined Flood Frequency Curve (Continued)

Feature	Feature Codes							
Property Data LINE 6 (Table A.3.5)	**Urban (Location = 1)**							
	NBLDG No. of Flood Prone Bldgs, Upstream I8	**BLDGVAL** Ave. Bldg Value, $1000 F8.0	**BLDGELE** Ave. Threshold Elev. Above Ch. Bottom, Ft. F8.0	(blank)	(blank)	(blank)	(blank)	(blank)
	Rural (Location = 2)							
	NRES Number of Flood Prone Residences Upstream I8	**BLDGVAL** (same as above)	**BLDGELE** (same as above)	**INDXI** Irrigated Lands Upstream 0 = No; 1 = Yes I8	**INDXC** Predominate Crop Type I8	**KFARM** Number of Flood Prone Farm Type Outbldgs Upstream I8	(blank)	(blank)
Traffic Data LINE 7 (Table A.3.6)	**DELL** Detour Travel Distance, mi. F8.0	**RREP** Embankment & Pavement Repair Rate, CY/day F8.0	**TM** Mobilization Time, hrs F8.0	**ASVD** Ave. Vehicle Speed on Detour, mph F8.0	**AR** Accident Ratio, accidents/100 million vehicle mi. F8.0	**ADTE** Average Daily Traffic (ADT), vehicle/day F8.0	(blank)	(blank)
Cost Data LINE 8 (Table A.3.7)	**Bridges (IST = 1)**							
	CC Cost Adjustment Factor, 1977 is Base Year F8.0	**CM** Mobilization Cost, $ F8.0	**UEMB** Unit Embankment Cost, $/CY F8.0	**UBRDG** Unit Bridge Cost $/sq. ft. F8.0	**UPAVE** Unit Pavement Cost, $/CY F8.0	**UOC** Unit Occupancy Cost, $/person/hr F8.0	**UDAMG** Unit Damage Cost, $/claim F8.0	(blank)
	Box Culverts (IST = 2)							
	CC (same as above)	**CM** (same as above)	**UEMB** (same as above)	**US** Unit Steel Cost $/lb F8.0	**UC** Unit Concrete Cost, $/CY F8.0	**UPAVE** (same as above)	**UOC** (same as above)	**UDAMG** (same as above)
	Pipe Culverts (IST = 3)							
	CC (same as above)	**CM** (same as above)	**UEMB** (same as above)	**UPAVE** (same as above)	**UOC** (same as above)	**UDAMG** (same as above)	(blank)	(blank)

Table A.3.8a Input Codes Structure for DSGNFREQ.DAT Without User Defined Flood Frequency Curve (Continued)

Feature	Feature Codes							
Intangible Factors LINE 9 1 = Less Important 2 = Important 3 = Very Important	**WT1** Project Cost F8.0	**WT2** Maintenance Frequency F8.0	**WT4** Provide High Level of Public Service F8.0	(blank)	(blank)	(blank)	(blank)	(blank)

Table A.3.8b Input Codes Structure for DSGNFREQ.DAT With User Defined Flood Frequency Curve

Feature	Feature Codes							
Location, Region, Type LINE 1	**LOC** Location 1 = Urban 2 = Rural I8	**IREGION** Hydrol. Region 1 = Mountains 2 = High Plains 3 = Desert I8	**IST** Structural Type 1 = Bridges 2 = Box Culverts 3 = Pipe Culverts I8	**USRCURVE** 0	(blank)	(blank)	(blank)	(blank)
Channel Characteristics LINE 2 (Table A.3.3)	**W** Main Channel Top Width F8.0	**D** Main Channel Depth F8.0	**S_l** Floodplain Slope Lt, ft/ft F8.0	**S_r** Floodplain Slope Rt, ft/ft F8.0	**S_c** Ave. Channel Slope, ft/ft F8.0	**N_p** Ave. Mannings n, Floodplain F8.0	**N_c** Ave. Mannings n, Main Channel F8.0	(blank)
Basin Characteristics LINE 3 (Table A.3.3)	**DA** Drainage Area, sq mi F8.0	**PR** Ave Annual Precip Depth, In F8.0	**GF** Geographic Factor F8.0	(blank)	(blank)	(blank)	(blank)	(blank)
User Defined Flood Frequency Curve LINE 4	**Q_2** F8.0	**Q_5** F8.0	**Q_{10}** F8.0	**Q_{25}** F8.0	**Q_{50}** F8.0	**Q_{100}** F8.0	**Q_{200}** F8.0	(blank)

Table A.3.8b Input Codes Structure for DSGNFREQ.DAT With User Defined Flood Frequency Curve (Continued)

Feature	Feature Codes							
Structure and Road LINE 5 (Table A.3.4)	Bridges (IST = 1)							
	NL Total No. of Traffic Lanes, F8.0	WP Pier Width, ft, Struct. Thickness F8.0	BRIWID Bridge Width, ft, out-to-out F8.0	HEMB Embankment Height, ft F8.0	THICKPV Pavement Thickness, in. F8.0	INDXS Fill Cohesion, 1 = None 2 = Low 3 = High	(blank)	(blank)
	RC Box Culverts (IST = 2)							
	NL (same as above)	COVERDEP Min. Cover Over Culvert, ft F8.0	RDWID Road Template Width, ft. F8.0	HEMB (same as above)	THICKPV (same as above)	INDXS (same as above)	(blank)	(blank)
	Pipe Culverts (IST = 3)							
	NL (same as above)	COVERDEP (same as above)	RDWID (same as above)	HEMB (same as above)	THICKPV (same as above)	INDXS (same as above)	INDXP Pipe Culv Type (Table A.3.2) I8	(blank)
Economic Factors LINE 6 (Table A.3.5)	RATE F8.0	LIFE I8	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)
Property Data LINE 7 (Table A.3.5)	Urban (Location = 1)							
	NBLDG No. of Flood Prone Bldgs, Upstream I8	BLDGVAL Ave. Bldg Value, $1000 F8.0	BLDGELE Ave. Threshold Elev. Above Ch. Bottom, Ft. F8.0	(blank)	(blank)	(blank)	(blank)	(blank)
	Rural (Location = 2)							
	NRES Number of Flood Prone Residences Upstream I8	BLDGVAL (same as above)	BLDGELE (same as above)	INDXI Irrigated Lands Upstream 0 = No; 1 = Yes I8	INDXC Predominate Crop Type I8	KFARM Number of Flood Prone Farm Type Outbldgs Upstream I8	(blank)	(blank)

Table A.3.8b Input Codes Structure for DSGNFREQ.DAT With User Defined Flood Frequency Curve (Continued)

Feature	Feature Codes							
Traffic Data LINE 8 (Table A.3.6)	**DELL** Detour Travel Distance, mi. F8.0	**RREP** Embankment & Pavement Repair Rate, CY/day F8.0	**TM** Mobilization Time, hrs F8.0	**ASVD** Ave. Vehicle Speed on Detour, mph F8.0	**AR** Accident Ratio, accidents/100 million vehicle mi. F8.0	**ADTE** Average Daily Traffic (ADT), vehicle/day F8.0	(blank)	(blank)
Cost Data LINE 9 (Table A.3.7)	**Bridges (IST = 1)**							
	CC Cost Adjustment Factor, 1977 is Base Year F8.0	**CM** Mobilization Cost, $ F8.0	**UEMB** Unit Embankment Cost, $/CY F8.0	**UBRDG** Unit Bridge Cost $/sq. ft. F8.0	**UPAVE** Unit Pavement Cost, $/CY F8.0	**UOC** Unit Occupancy Cost, $/person/hr F8.0	**UDAMG** Unit Damage Cost, $/claim F8.0	(blank)
	Box Culverts (IST = 2)							
	CC (same as above)	**CM** (same as above)	**UEMB** (same as above)	**US** Unit Steel Cost $/lb F8.0	**UC** Unit Concrete Cost, $/CY F8.0	**UPAVE** (same as above)	**UOC** (same as above)	**UDAMG** (same as above)
	Pipe Culverts (IST = 3)							
	CC (same as above)	**CM** (same as above)	**UEMB** (same as above)	**UPAVE** (same as above)	**UOC** (same as above)	**UDAMG** (same as above)	(blank)	(blank)
Intangible Factors LINE 10 1 = Less Important 2 = Important 3 = Very Important	**WT1** Project Cost F8.0	**WT2** Maintenance Frequency F8.0	**WT4** Provide High Level of Public Service F8.0	(blank)	(blank)	(blank)	(blank)	(blank)

Example 1 -- The use of DSGNFREQ.FOR is illustrated with this example which has the following site characteristics and design considerations.

A *bridge* is to be considered in an *urban area* which is located in the *mountainous region* of Wyoming. The flood-frequency method selected for this example was the Basin Characteristics Method. The average low flow (Q_2) channel width of 4.5 feet was obtained away from the site at the entrance and exit of several bendways in accordance with Druse (Druse, et. al. 1988). This was done in case it was decided to use the channel geometry method to determine the flood frequency relationship.

Based on the format guidance provided by Table A.3.8, the screen will have the following appearance when the coding is completed and prior to running DSGNFREQ.FOR. Since this screen currently is difficult to quickly interpret, frequent reference to Table A.3.8 is recommended to avoid input errors.

```
URBAN BRIDGE MOUNTAINOUS REGION
     1       1       1       0
  90.0     4.5    0.03    0.03      0.012      0.04      0.035
 350.0    12.0     1.1
     2       3    40.0    16.0       14.5         3
 0.042      50
     5     100     9.0
   5.0    60.2    15.2    30.0      265.7      1000
  1.32   450.0     3.0    50.0       40.0      20.0     6250.6
     2       2       2       2
```

Run the program as described in Step 3 of the foregoing User Instructions. The output file, DSGNFREQ.OUT, would have the following appearance in which the channel characteristics, basin characteristics, and other relevant information for the site condition are first repeated as shown below.

```
LOCATION: Urban Area
REGION: Mountainous Region
DRAINAGE STRUCTURAL TYPE: Bridges

CHANNEL CHARACTERISTICS:
Bankfull channel width = 90.0 ft
Bankfull channel depth = 4.5 ft
Transverse floodplain slope on the left = .0300
Transverse floodplain slope on the right = .0300
Longitudinal channel slope = .0120
Manning roughness on floodplain = .0400
Manning roughness in main channel = .0350
```

BASIN CHARACTERISTICS:
Drainage area = 350.0 sq. miles
Annual average precipitation = 12.00 inches
Geographic factor = 1.1

FLOOD FREQUENCY BY BASIN CHARACTERISTIC METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
972.2	1676.8	2235.9	3157.6	4030.0	4823.7	5900.5

FLOOD FREQUENCY BY CHANNEL GEOMETRY METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
2374.1	3230.2	3758.6	4322.3	4825.4	5489.9	7093.8

HYPOTHETICAL SITE CHARACTERISTICS TO MATCH THE CHANNEL GEOMETRY FLOOD FREQUENCY CURVE:
Drainage area = 405.13 square miles
Channel slope = .0120 feet/feet
Annual avg. precipitation = 21.96 inches
Geographical factor = 1.10

ROADWAY CHARACTERISTICS:
No. of lanes = 2
Design width of pier = 3.00 ft
Bridge deck width = 40.00 ft
Design embankment height = 16.00 ft
Pavement thickness = 14.50 in
Embankment soil types = Low cohesive

ECONOMIC PARAMETERS:
Interest rate = .0420
Design project life = 50.0 years
No. of buildings = 5
Building values = 100.000 ($1000)
Building elevation above
channel bottom at the drainage structure site = 9.00 ft

TRAFFIC CHARACTERISTICS:
Detour length = 5.00 miles
Rate of repair = 60.20 cu. yd./hr
Mobilization time = 15.20 hrs
Average vehicle speed on detour = 30.00 mph
Accident ratio = 265.70 per million veh-miles
Avg. daily traffic count = 1000.00

UNIT COST CHARACTERISTICS:
Cost adjustment factor = 1.32
Mobilization cost ($) = 450.00
Unit embankment cost ($/cu. yd.) = 3.00
Unit bridge cost ($/sq. ft.) = 50.00
Unit pavement cost ($/cu. yd.) = 40.00
Unit cost of occupant ($/person) = 20.00
Unit damage cost ($/accident) = 6250.60

Following the echo prints of input data, the resulting LTEC design return periods corresponding to the site condition by using different methods are computed and tabulated as follows on the printout.

LTEC DESIGN RETURN PERIOD & DESIGN DISCHARGE

(BY BASIN-CHARACTERISTICS METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	12.0 YRS	24.1 YRS	49.3 YRS
	2401.2 CFS	3114.0 CFS	4011.3 CFS

CONTINUOUS	13.7 YRS	26.5 YRS	52.3 YRS
	2521.4 CFS	3227.2 CFS	4087.7 CFS
WEIGHTED	15.7 YRS	25.3 YRS	41.4 YRS
	2652.1 CFS	3173.2 CFS	3787.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. RETURN PERIOD
(BY CHANNEL-GEOMETRY METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	18.4 YRS	37.3 YRS	77.0 YRS
	4113.4 CFS	4604.4 CFS	5203.5 CFS
CONTINUOUS	20.7 YRS	40.6 YRS	80.6 YRS
	4192.9 CFS	4665.2 CFS	5249.1 CFS
WEIGHTED	23.9 YRS	39.0 YRS	64.1 YRS
	4291.1 CFS	4636.3 CFS	5033.0 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. RETURN PERIOD

Following the LTEC return periods, the output prints the relative importance of the four factors as specified by the hydraulic engineer: the last line of input file as shown in Table A.3.8. Then, three tables of the extended-LTEC design return periods based on the mean extended-LTEC design return period by three different methods are presented on the printout. In each table, the mean extended-LTEC design return periods, along with the values plus and minus one standard deviation, for each intangible factor, as compared with the total cost factor, are tabulated.

RATING OF FACTORS AFFECTING DESIGN FREQUENCY:
ECONOMIC EFFICIENCY: IMPORTANT
MAINTENANCE FREQUENCY: IMPORTANT
LITIGATION POTENTIAL: IMPORTANT
PUBLIC SERVICE: IMPORTANT

INTERVALS OF *EXTENDED-LTEC* DESIGN RETURN PERIODS
AND DESIGN DISCHARGES:

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	25.2 YRS	29.9 YRS	53.4 YRS
	3168.2 CFS	3371.7 CFS	4112.5 CFS
LITIG. POTEN.	26.0 YRS	32.8 YRS	64.4 YRS
	3203.0 CFS	3489.6 CFS	4337.1 CFS
PUBLIC SRVC.	24.1 YRS	24.1 YRS	24.1 YRS
	3112.2 CFS	3112.2 CFS	3112.2 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD
(BY CHANNEL-GEOMETRY METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	39.1 YRS	46.3 YRS	82.8 YRS
	4638.5 CFS	4766.0 CFS	5277.0 CFS
LITIG. POTEN.	40.3 YRS	50.9 YRS	99.9 YRS
	4660.3 CFS	4840.1 CFS	5488.3 CFS
PUBLIC SRVC.	37.3 YRS	37.3 YRS	37.3 YRS
	4605.0 CFS	4605.0 CFS	4605.0 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD
(BY BASIN-CHARACTERISTICS METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	27.8 YRS	32.9 YRS	58.8 YRS
	3283.0 CFS	3492.1 CFS	4230.5 CFS
LITIG. POTEN.	28.6 YRS	36.2 YRS	70.9 YRS
	3318.8 CFS	3612.6 CFS	4446.1 CFS
PUBLIC SRVC.	26.5 YRS	26.5 YRS	26.5 YRS

	- STDEV	MEAN	+STDEV
	3229.9 CFS	3229.9 CFS	3229.9 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD
(BY CHANNEL-GEOMETRY METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	42.5 YRS	50.3 YRS	90.0 YRS
	4700.0 CFS	4830.7 CFS	5366.1 CFS
LITIG. POTEN.	43.8 YRS	55.3 YRS	108.5 YRS
	4722.4 CFS	4907.2 CFS	5594.8 CFS
PUBLIC SRVC.	40.6 YRS	40.6 YRS	40.6 YRS
	4666.1 CFS	4666.1 CFS	4666.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD
(BASIN-CHARACTERISTICS METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	26.5 YRS	31.4 YRS	56.2 YRS
	3228.2 CFS	3434.7 CFS	4175.2 CFS
LITIG. POTEN.	27.3 YRS	34.6 YRS	67.8 YRS
	3263.6 CFS	3554.1 CFS	4395.0 CFS
PUBLIC SRVC.	25.3 YRS	25.3 YRS	25.3 YRS
	3173.8 CFS	3173.8 CFS	3173.8 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD
(CHANNEL-GEOMETRY METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	40.9 YRS	48.4 YRS	86.5 YRS
	4670.7 CFS	4799.9 CFS	5323.2 CFS
LITIG. POTEN.	42.1 YRS	53.2 YRS	104.3 YRS
	4692.8 CFS	4875.2 CFS	5543.2 CFS
PUBLIC SRVC.	39.0 YRS	39.0 YRS	39.0 YRS
	4637.1 CFS	4637.1 CFS	4637.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD

Note, the output repeats the input file in an easily read format followed by the output containing the estimated LTEC design frequency and related statistics. Next and in a similar manner, the *Extended* LTEC input is provided for checking followed by the Extended LTEC output. The hydraulics engineer should check to insure the desired data has been input correctly.

Discussion for example 1 is addressed in the following three sub-sections.

- Discrete and Continuous Findings
- Statistical Margin of Error
- Extended LTEC Findings

Discrete and Continuous Findings -- Referring to Section 14.1, two types of LTEC design return periods are used in the data base: those at selected discretized values and those continuous values obtained through quadratic interpolation. Outputs from the program LTEC.FOR provide both types of LTEC design return periods. Due to the potential inconsistency in the discrete and continuous LTEC data, the *weighted* LTEC is also provided based on the procedure described in Section 14.2.

Statistical Margin of Error -- For each of three LTEC design return periods, the *mean* flood frequency is provided. However, since the *mean* is only an estimate based on data, it is desirable to provide the hydraulics engineer with estimates reflecting the margin of error to be expected. This is done using the standard deviation. As a quick review, the margin of statistical error associated with one, two and three standard deviations is shown in Table A.3.9, and the use of this table is illustrated below.

Table A.3.9 Standard Deviation vs. Margin of Error

Standard Deviation	Chance*, Percent
One	66.7
Two	95.0
Three	99.9

* Chance that the true mean is within one, two, or three standard deviations either side of the mean.

Table A.3.9 allows the hydraulics engineer to use judgement in selecting a design flood frequency. As noted above, the output for DSGNFREQ.FOR provides only the findings for one standard deviation. If findings for the second and third standard deviation are desired, they must be computed using hand computations with proper recognition given to the logrithmetic nature of the standard deviation. An example of how to better focus the example findings in light of Table A.3.9 as well as how to compute the second and third standard deviation range follows.

Referring to the discretized LTEC design frequency in the above example, based on the empirical equation in Table 14.1(a) for urban/mountain/bridge, we have $Y = \ln(T - 1) = 4.162$ with a standard deviation $S_y = 0.738$. Therefore, the following three quantities are obtained

$$Y_{-1} = Y - S_Y + 4.162 - 0.738 = 3.424$$
$$Y = 4.162$$
$$Y_{+} = Y + S_Y = 4.162 + 0.738 = 4.900$$

in which Y_{-1} and Y_{+1} are the values of log-transformed LTEC design frequency with minus and plus one standard deviation. Then, the corresponding values of LTEC design frequency in the original scale are

$T = \exp(Y) + 1 = \exp(4.162) + 1 = 65$ years (Mean)
$T_{+} = \exp(Y_{+1}) + 1 = \exp(4.900) + 1 = 135$ years (+1 Standard deviation)
$T_{-} = \exp(Y_{-1}) + 1 = \exp(3.424) + 1 = 32$ years (-1 Standard deviation)

This means that about 67% of the time the correct answer will lie somewhere between 32 years and 135 years with the mean being 65 years.

Similarly, for the two standard deviation range can be calculated as

$$Y_{-2} = Y - 2S_y = 4.162 - 2(0.738) = 2.686$$
$$Y_{+2} = Y + 2S_Y = 4.162 + 2(0.738) = 5.638$$

The limits for two standard deviations would be

$T_{+2} = \exp(Y_{+2}) + 1 = \exp(5.638) + 1 = 282$ years (+1 Standard deviation)
$T_{-2} = \exp(Y_{-2}) + 1 = \exp(2.686) + 1 = 16$ years (- Standard deviation)

This means that about 95% of the time the correct answer will lie somewhere between 16 years and 282 years with the mean being 65 years.

The computation procedures illustrated above for computing the margin of error range for the estimated LTEC design return period are identical for the continuous LTEC design frequency based on Tables 14.3 and 14.4. However, the computation is a little more complicated for the LTEC design frequency. To compute the range of interval for the weighted LTEC design frequency, one has to first calculate the weighing factor, W*, according to Eq.(14.5), based on the squared errors associated with the discretized and continuous LTEC frequency equations. Once W* is obtained, the weighted log-transformed LTEC design return period, $Y_W = \ln(t_W - 1)$, and its associated variance, $Var(Y_W)$, can be computed by Eq.(14.3) and Eq.(14.4), respectively. Note that standard deviation of Y_W is the square root of $Var(Y_W)$. The computation of interval range of different confidence levels for the weighted LTEC design return period can be calculated in the same manner as demonstrated above.

Refer to the example output regarding the three types of LTEC design return periods. One can observe that the mean weighted LTEC design frequency lies between those of discretized and continuous LTEC design frequency. Because the weighting factor is determined in such a manner as to minimize the variance of Y_W, the interval range for the weighted LTEC design return period is tighter than the other two LTEC design return periods. It is generally recommended that the weighted LTEC design return period be used because it is more statistically reliable then the other two competitors.

Extended LTEC Findings -- Note that the estimated LTEC design return periods in output file DSGNFREQ.OUT are based on only the *tangible,* cost related factors and ignores the following three important judgmental in *intangible* factors that this research has *quantified* using "Fuzzy Logic" theory.

- Maintenance frequency
- Litigation potential
- Public service

As described in Section 12.5, the extended-LTEC design return periods are calculated when considering the relative importance between the tangible economic factor along with each of the three above intangible factors. More specifically, based on the estimated mean LTEC design frequency, three extended-LTEC design return periods are calculated, respectively, by considering total cost factor versus maintenance frequency, litigation potential, and public service. Furthermore, for each of the above three intangible factors, the extended-LTEC design frequencies are estimated based on the mean LTEC design return periods from the discretized, continuous, and weighted cases. Like the estimated LTEC design frequencies, the mean value of the extended-LTEC design return period, along with the interval range of plus and minus one standard deviation, are presented.

Refer to the last block of output file of the above example containing the extended-LTEC design frequencies. Note that each *Extended*-LTEC line for an intangible factor reflects the *estimated* design flood return period based on the *tangible*, cost related factors; i.e., the same as for the foregoing LTEC design flood return period estimate. However, in this instance the *estimated* design flood return periods have been increased to reflect the hydraulics engineer's concerns for *each* of the foregoing three quantified *intangible* factors: maintenance frequency; litigation potential; and public service. This was done in accordance with the hydraulics engineer's input assessment of the importance of these factors on the last line of input file as shown in Table A.3.8. Normally the selected design flood return period is that corresponding to the *larger of the* mean *yearly* values as this would obviously provide a conservative return period for the remaining two factors.

Example 2 -- The use of DSGNFREQ.FOR is illustrated with this example which has the following site characteristics and design considerations.

A *box culvert* is to be considered in a *rural area* which is located in the *high desert region* of Wyoming. The flood-frequency method selected for this analysis was the Basin Characteristics Method. The average low flow (Q_2) channel width of 90.0 feet was obtained away from the site at the entrance and exit of several bendways in accordance with Druse (Druse, et. al. 1988). This was done in case it was decided to use the channel geometry method to determine the flood frequency relationship.

The channel characteristics, basin characteristics, and other relevant information for this example are listed below in the first eight sections of the output for the LTEC analysis. The Extended LTEC input is found in the last section of the output. Based on the format guidance provided by Table A.3.8 the screen will have the following appearance when the coding is completed and prior to running DSGNFREQ.FOR. Since this screen currently is difficult to quickly interpret, frequent reference to Table A.3.8 is recommended to avoid input errors.

RURAL BOX CULVERTS DESERT REGION

2	3	2	0				
90.0	4.5	0.0300	0.0300	0.0120	0.0400	0.0350	
350.0	12.00	1.1					
2.0	3.0	40.0	16.0	14.5	3		
0.042	50						
2	100.00	9.00	0	2	1		
15.0	60.2	15.2	30.0	265.7	1000.0		
1.32	450.00	3.00	0.55	400.0	40.0	10.00	6250.60
2	2	2	2				

Run the program as described in Step 3 of the foregoing User Instructions. Output for this example would have the following appearance.

LOCATION: Rural Area
REGION: Desert Region
DRAINAGE STRUCTURE TYPE: Box Culverts

CHANNEL CHARACTERISTICS:
Bankfull channel width = 90.0 ft
Bankfull channel depth = 4.5 ft
Transverse floodplain slope on the left = .0300
Transverse floodplain slope on the right = .0300
Longitudinal channel slope = .0120
Manning roughness on floodplain = .0400
Manning roughness in main channel = .0350
BASIN CHARACTERISTICS:
Drainage Area = 350.0 sq. miles
Annual Average Precipitation = 12.00 inches
Geographic Factor = 1.1

FLOOD FREQUENCY BY BASIN CHARACTERISTIC METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
590.8	1367.4	2119.7	3294.9	4322.0	5514.0	6930.9

FLOOD FREQUENCY BY CHANNEL GEOMETRY METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
1454.7	2969.4	4332.0	6134.1	6134.1	9082.3	10765.3

HYPOTHETICAL SITE CHARACTERISTICS TO MATCH THE CHANNEL GEOMETRY FLOOD FREQUENCY CURVE:

Drainage area = 874.84 square miles
Channel slope = .0120 feet/feet
Annual precip = 12.05 inches
Geograp. Fac. = 1.32

ROADWAY CHARACTERISTICS:

No. of lanes = 2
Soil cover depth = 3.00 ft
Road width = 40.00 ft
Design embankment height = 16.00 ft
Pavement thickness = 14.50 in
Embankment soil type = Low cohesive

ECONOMIC PARAMETERS:

Interest rate = .0420
Design project life = 50.0 years

No. of buildings = 2
Building values = 100.000 ($1000)
Building elevation above
channel bottom at the drainage structure site = 9.00 ft
No. of farm houses = 1
Non-irrigated land
Range Land

TRAFFIC CHARACTERISTICS:

Detour length = 15.00 miles
Rate of repair = 60.20 cu. yd./hr
Mobilization time = 15.20 hrs
Average vehicle speed on detour = 30.00 mph
Accident ratio = 265.70 per million veh-miles
Avg. daily traffic count = 1000.00

UNIT COST CHARACTERISTICS:

Cost adjustment factor = 1.32
Mobilization cost ($) = 450.00
Unit embankment cost ($/cu. yd.) = 3.00
Unit steel cost ($/lb.) = 0.55
Unit concrete cost ($/sq. yd.) = 400.00
Unit pavement cost ($/cu. yd.) = 40.00
Unit cost of occupant ($/person) = 10.00
Unit damage cost ($/accident) = 6250.60

LTEC DESIGN RETURN PERIOD & DESIGN DISCHARGE

(BY BASIN-CHARACTERISTICS METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	6.8 YRS	13.9 YRS	29.7 YRS
	1677.3 CFS	2519.3 CFS	3538.6 CFS
CONTINUOUS	7.1 YRS	15.1 YRS	33.4 YRS
	1729.0 CFS	2623.1 CFS	3708.3 CFS
WEIGHTED	8.5 YRS	14.4 YRS	25.0 YRS
	1934.7 CFS	2568.8 CFS	3292.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	7.1 YRS	14.6 YRS	31.3 YRS
	3665.2 CFS	5063.9 CFS	6599.2 CFS
CONTINUOUS	7.6 YRS	16.2 YRS	36.1 YRS

	3801.1 CFS	5271.4 CFS	6905.3 CFS
WEIGHTED	9.0 YRS	15.3 YRS	26.6 YRS
	4137.8 CFS	5163.1 CFS	6259.8 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD

RATING OF FACTORS AFFECTING DESIGN FREQUENCY:
Economic Efficiency: Important
Maintenance Frequency: Important
Litigation Potential: Important
Public Service: Important

INTERVALS OF EXTENDED-LTEC DESIGN RETURN PERIODS:
(BY BASIN-CHARACTERISTICS METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	13.9 YRS	13.9 YRS	14.0 YRS
	2519.8 CFS	2521.8 CFS	2532.1 CFS
LITIG. POTEN.	13.9 YRS	13.9 YRS	13.9 YRS
	2519.3 CFS	2519.6 CFS	2521.7 CFS
PUBLIC SRVC.	13.9 YRS	13.9 YRS	14.1 YRS
	2519.6 CFS	2521.6 CFS	2537.0 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	14.6 YRS	14.6 YRS	14.7 YRS
	5064.7 CFS	5067.8 CFS	5083.7 CFS
LITIG. POTEN.	14.6 YRS	14.6 YRS	14.6 YRS
	5063.9 CFS	5064.3 CFS	5067.6 CFS
PUBLIC SRVC.	14.6 YRS	14.6 YRS	14.8 YRS
	5064.3 CFS	5067.5 CFS	5091.5 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	15.1 YRS	15.1 YRS	15.2 YRS
	2623.6 CFS	2625.7 CFS	2636.0 CFS
LITIG. POTEN.	15.1 YRS	15.1 YRS	15.1 YRS
	2623.1 CFS	2623.4 CFS	2625.5 CFS
PUBLIC SRVC.	15.1 YRS	15.1 YRS	15.3 YRS
	2623.4 CFS	2625.4 CFS	2641.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	16.2 YRS	16.3 YRS	16.4 YRS
	5272.2 CFS	5275.4 CFS	5291.4 CFS
LITIG. POTEN.	16.2 YRS	16.2 YRS	16.3 YRS
	5271.5 CFS	5271.9 CFS	5275.2 CFS
PUBLIC SRVC.	16.2 YRS	16.2 YRS	16.5 YRS
	5271.9 CFS	5275.1 CFS	5299.2 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	14.4 YRS	14.5 YRS	14.6 YRS
	2569.4 CFS	2571.4 CFS	2581.7 CFS
LITIG. POTEN.	14.4 YRS	14.4 YRS	14.5 YRS
	2568.9 CFS	2569.1 CFS	2571.3 CFS
PUBLIC SRVC.	14.4 YRS	14.5 YRS	14.6 YRS
	2569.1 CFS	2571.2 CFS	2586.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	15.4 YRS	15.4 YRS	15.5 YRS
	5163.9 CFS	5167.1 CFS	5183.1 CFS
LITIG. POTEN.	15.3 YRS	15.4 YRS	15.4 YRS
	5163.2 CFS	5163.6 CFS	5166.9 CFS
PUBLIC SRVC.	15.4 YRS	15.4 YRS	15.6 YRS
	5163.6 CFS	5166.8 CFS	5190.8 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

Note, the first part of the output again repeats the site conditions specified in the input file followed by the output containing the estimated LTEC design frequency and related statistics. The hydraulics engineer should check to insure the desired data has been input correctly. Next and in a similar manner, the *Extended* LTEC input is provided for checking followed by the Extended LTEC output.

Discussion for Example 2 is generally the same as Example 1, but the manual computations for the standard deviations would reflect different values and thus, perhaps, a different interpretation.

Example 3 -- The use of DSGNFREQ.FOR is illustrated with this example which has the following site characteristics and design considerations.

Pipe culverts are to be considered in an *urban area* which is located in the *high desert region* of Wyoming. The flood-frequency method selected for this analysis was the Basin Characteristics Method. The average low flow (Q_2) channel width of 90 feet was obtained away from the site at the entrance and exit of several bendways in accordance with Druse (Druse, et. al. 1988). This was done in case it was decided to use the channel geometry method to determine the flood frequency relationship.

The channel characteristics, basin characteristics, and other relevant information for this example are listed below in the first eight sections of the output for the LTEC analysis. The Extended LTEC input is found in the last section of the output. Based on the format guidance provided by Table A.3.8 the screen will have the following appearance when the coding is completed and prior to running DSGNFREQ.FOR. Since this screen currently is difficult to quickly interpret, frequent reference to Table A.3.8 is recommended to avoid input errors.

URBAN PIPE CULVERTS DESERT REGION

1	3	3	0			
90.0	4.5	0.0300	0.0300	0.0120	0.0400	0.0350
350.0	12.00	1.1				
2.0	3.0	40.0	16.0	14.5	3	2
0.042	50					

2	100.00	9.00			
15.0	60.2	15.2	30.0	265.7	1000.0
1.30	450.00	3.00	40.0	10.00	6250.60
2	2	2	2		

Run the program as described in Step 3 of the foregoing User Instructions. Output for this example, would have the following appearance.

LOCATION: Urban Area
REGION: Desert Region
DRAINAGE STRUCTURAL TYPE: Pipe Culverts

CHANNEL CHARACTERISTICS:
Bankfull channel width = 90.0 ft
Bankfull channel depth = 4.5 ft
Transverse floodplain slope on the left = .0300
Transverse floodplain slope on the right = .0300
Longitudinal channel slope = .0120
Manning roughness on floodplain = .0400
Manning roughness in main channel = .0350

BASIN CHARACTERISTICS:
Drainage area = 350.0 sq. miles
Annual average precipitation = 12.00
Geographic factor = 1.1

FLOOD FREQUENCY BY BASIN CHARACTERISTIC METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
590.8	1367.4	2119.7	3294.9	4322.0	5514.0	6930.9

FLOOD FREQUENCY BY CHANNEL GEOMETRY METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
1454.7	2969.4	4332.0	6134.1	7393.9	9082.3	10765.3

HYPOTHETICAL SITE CHARACTERISTICS TO MATCH
THE CHANNEL GEOMETRY FLOOD FREQUENCY CURVE:
Drainage area = 874.84 square miles
Channel slope = .0120 feet/feet
Annual precip = 12.05 inches
Geograp. Fac. = 1.32

ROADWAY CHARACTERISTICS:
No. of lanes = 2
Soil cover depth = 3.00 ft
Pipe culvert type = 3
Road width = 40.00 ft
Design embankment height = 16.00 ft
Pavement thickness = 14.50 in
Embankment soil type = High cohesive

ECONOMIC PARAMETERS:
Interest rate = .0420
Design project life = 50.0 years
No. of buildings = 2
Building values = 100.000 ($1000)
Building elevation above
channel bottom at the drainage structure site = 9.00 ft

TRAFFIC CHARACTERISTICS:
Detour length = 15.00
Rate of repair = 60.20 cu. yd./hr
Mobilization time = 15.20 hrs
Average vehicle speed on detour = 30.00 mph
Accident ratio = 265.70 per million veh-miles
Avg. daily traffic count = 1000.00
UNIT COST CHARACTERISTICS:
Cost adjustment factor = 1.30
Mobilization cost ($) = 450.00
Unit embankment cost ($/cu. yd.) = 3.00
Unit pavement cost ($/cu. yd.) = 40.00
Unit cost of occupant ($/person) = 10.00
Unit damage cost ($/accident) = 6250.60

LTEC DESIGN RETURN PERIOD & DESIGN DISCHARGE

(BY BASIN-CHARACTERISTICS METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	7.4 YRS	13.6 YRS	25.9 YRS
	1767.6 CFS	2492.1 CFS	3343.7 CFS
CONTINUOUS	6.0 YRS	11.7 YRS	24.0 YRS
	1542.2 CFS	2305.6 CFS	3237.1 CFS
WEIGHTED	8.0 YRS	12.7 YRS	20.5 YRS
	1865.0 CFS	2408.7 CFS	3023.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	9.1 YRS	17.0 YRS	32.7 YRS
	4148.8 CFS	5366.4 CFS	6692.1 CFS
CONTINUOUS	5.8 YRS	11.4 YRS	23.5 YRS
	3285.2 CFS	4590.8 CFS	6004.6 CFS
WEIGHTED	9.0 YRS	14.3 YRS	23.1 YRS
	4119.7 CFS	5018.8 CFS	5970.9 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YRS. OF RETURN PERIOD

RATING OF FACTORS AFFECTING DESIGN FREQUENCY:

Economic Efficiency:	Important
Maintenance Frequency:	Important
Litigation Potential:	Important
Public Service:	Important

(BY BASIN-CHARACTERISTICS METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	13.7 YRS	14.0 YRS	14.6 YRS
	2506.5 CFS	2528.6 CFS	2583.3 CFS
LITIG. POTEN.	13.6 YRS	13.6 YRS	13.7 YRS
	2492.5 CFS	2494.2 CFS	2503.0 CFS
PUBLIC SRVC.	13.6 YRS	13.6 YRS	13.6 YRS
	2492.1 CFS	2492.1 CFS	2492.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	17.2 YRS	17.5 YRS	18.3 YRS
	5389.1 CFS	5423.7 CFS	5509.6 CFS
LITIG. POTEN.	17.0 YRS	17.1 YRS	17.2 YRS
	5367.0 CFS	5369.7 CFS	5383.6 CFS
PUBLIC SRVC.	17.0 YRS	17.0 YRS	17.0 YRS
	5366.4 CFS	5366.4 CFS	5366.4 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)			
(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	11.8 YRS	12.0 YRS	12.6 YRS
	2319.7 CFS	2341.2 CFS	2394.6 CFS
LITIG. POTEN.	11.7 YRS	11.7 YRS	11.8 YRS
	2306.0 CFS	2307.7 CFS	2316.3 CFS
PUBLIC SRVC.	11.7 YRS	11.7 YRS	11.7 YRS
	2305.6 CFS	2305.6 CFS	2305.7 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD			

(BY CHANNEL-GEOMETRY METHOD)			
(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	11.6 YRS	11.8 YRS	12.3 YRS
	4613.2 CFS	4647.2 CFS	4731.4 CFS
LITIG. POTEN.	11.4 YRS	11.5 YRS	11.5 YRS
	4591.4 CFS	4594.1 CFS	4607.8 CFS
PUBLIC SRVC.	11.4 YRS	11.4 YRS	11.4 YRS
	4590.8 CFS	4590.8 CFS	4590.8 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD			

(BY BASIN-CHARACTERISTICS METHOD)			
(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	12.8 YRS	13.1 YRS	13.7 YRS
	2423.0 CFS	2444.8 CFS	2499.0 CFS
LITIG. POTEN.	12.7 YRS	12.7 YRS	12.8 YRS
	2409.1 CFS	2410.8 CFS	2419.6 CFS
PUBLIC SRVC.	12.7 YRS	12.7 YRS	12.7 YRS
	2408.7 CFS	2408.7 CFS	2408.7 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD			

(BY CHANNEL-GEOMETRY METHOD)			
(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	14.4 YRS	14.7 YRS	15.3 YRS
	5041.3 CFS	5075.6 CFS	5160.5 CFS
LITIG. POTEN.	14.3 YRS	14.3 YRS	14.4 YRS
	5019.4 CFS	5022.1 CFS	5035.9 CFS
PUBLIC SRVC.	14.3 YRS	14.3 YRS	14.3 YRS
	5018.8 CFS	5018.8 CFS	5018.8 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD			

Note, in the first part of the output again repeats the site conditions specified in the input file followed by the output containing the estimated LTEC design frequency and related statistics. The hydraulics engineer should check to insure the desired data has been input correctly. Next, and in a similar manner, the *Extended* LTEC input is provided for checking, followed by the Extended LTEC output.

Discussion for Example 3 is generally the same as Example 1, but the manual computations for the standard deviations would reflect different values and thus, perhaps, a different interpretation.

Example 4 -- The use of DSGNFREQ.FOR for a unique flood-frequency relationship not defined by the Wyoming Basin Characteristics Method (such as a Log Pearson III analysis, the Wyoming Channel Geometry Method, SCS TR-20, etc) is illustrated with this problem. With this analysis the Basin Characteristics flood-frequency curve is transformed to the unique flood-frequency curve applicable to this site. The average low flow (Q_2) channel width of 35 feet was obtained away from the site at the entrance and exit of several bendways in accordance with Druse (Druse, et. al. 1988). This was done in case it was decided to use the channel geometry method to determine the flood frequency relationship.

In this example the transformation was accomplished manually, outside DSGNFREQ.FOR. The accuracy of the LTEC and Extended LTEC findings is a function of how well the user is able to make this manual transformation. In order to make this transformation it is necessary that the user be able to plot Wyoming's Basin Characteristics curve. This curves can be plotted from the equations provided in the following table.

Table 1 -- Basin Characteristics Flood-Frequency Equations

Equation	Acceptable Range
Curve No. 1 -- Mountain Hydrologic Region	
$Q_2 = 0.51\ A^{0.81}\ PR^{1.13}$	$A^{0.02}\ PR^{0.35} < 4.6275$
$Q_5 = 2.36\ A^{0.79}\ PR^{0.78}$	$A^{0.01}\ PR^{0.19} < 2.2671$
$Q_{10} = 5.35\ A^{0.78}\ PR^{0.59}$	$A^{0.01}\ PR^{0.19} < 2.5233$
$Q_{25} = 13.5\ A^{0.77}\ PR^{0.38}$	$PR^{0.13} < 1.7630$
$Q_{50} = 23.8\ A^{0.77}\ PR^{0.25}$	$A^{0.01}\ PR^{0.12} < 1.7100$
$Q_{100} = 40.7\ A^{0.76}\ PR^{0.13}$	$A^{0.01}\ PR^{0.13} < 1.7960$
$Q_{200} = 73.1\ A^{0.75}\ PR^{-0.001}$	$A^{0.01}\ PR^{0.149} < 1.8601$
$Q_{500} = 136\ A^{0.74}\ PR^{-0.15}$	--
Curve No. 2 -- Plains Hydrologic Region	
$Q_2 = 41.3\ A^{0.60A^{-0.05}}\ GF$	$SB^{-0.09} < 1.5422$
$Q_5 = 63.7\ A^{0.60A^{-0.05}}\ SB^{0.09}\ GF$	$A^{0.010}\ SB^{-0.05} < 1.2073$
$Q_{10} = 76.9\ A^{0.59A^{-0.05}}\ SB^{0.14}\ GF$	$SB^{-0.05} < 1.2250$
$Q_{25} = 94.2\ A^{0.59A^{-0.05}}\ SB^{0.19}\ GF$	$A^{0.010}\ SB^{-0.04} < 1.1889$
$Q_{50} = 112\ A^{0.58A^{-0.05}}\ SB^{0.23}\ GF$	$SB^{-0.02} < 1.1608$
$Q_{100} = 130\ A^{0.58A^{-0.05}}\ SB^{0.25}\ GF$	$A^{0.010}\ SB^{-0.01} < 1.4000$
$Q_{200} = 182\ A^{0.57A^{-0.05}}\ SB^{0.26}\ GF$	$SB^{-0.01} < 1.3461$
$Q_{500} = 245\ A^{0.57A^{-0.05}}\ SB^{0.27}\ GF$	--
Curve No. 3 -- High Desert Hydrologic Region	
$Q_2 = 6.66\ A^{0.59A^{-0.03}}\ PR^{0.60}\ GF$	$A^{0.03V}\ PR^{-0.21} < 1.5916$
$Q_5 = 10.6\ A^{0.56A^{-0.03}}\ PR^{0.81}\ GF$	$A^{0.01V}\ PR^{-0.09} < 1.3019$
$Q_{10} = 13.8\ A^{0.55A^{-0.03}}\ PR^{0.90}\ GF$	$A^{0.02V}\ PR^{-0.08} < 1.4059$
$Q_{25} = 19.4\ A^{0.53A^{-0.03}}\ PR^{0.98}\ GF$	$A^{0.01V}\ PR^{-0.04} < 1.2473$
$Q_{50} = 24.2\ A^{0.52A^{-0.03}}\ PR^{1.02}\ GF$	$A^{0.01V}\ PR^{-0.03} < 1.2438$
$Q_{100} = 30.1\ A^{0.51A^{-0.03}}\ PR^{1.05}\ GF$	$PR^{-0.02} < 1.1960$
$Q_{200} = 36.0\ A^{0.51A^{-0.03}}\ PR^{1.07}\ GF$	$A^{0.01V}\ PR^{-0.02} < 1.3082$
$Q_{500} = 47.1\ A^{0.50A^{-0.03}}\ PR^{1.09}\ GF$	--

A = Drainage Area, Square Miles
PR = Average Annual Precipitation, inches
SB = Slope of the Basin, feet/mile
U = $A^{-0.05}$
V = A

For this example a unique flood-frequency relationship was determined by some method other than Wyoming's Basin Characteristics Method. This unique flood-frequency relationship is listed in Table 2.

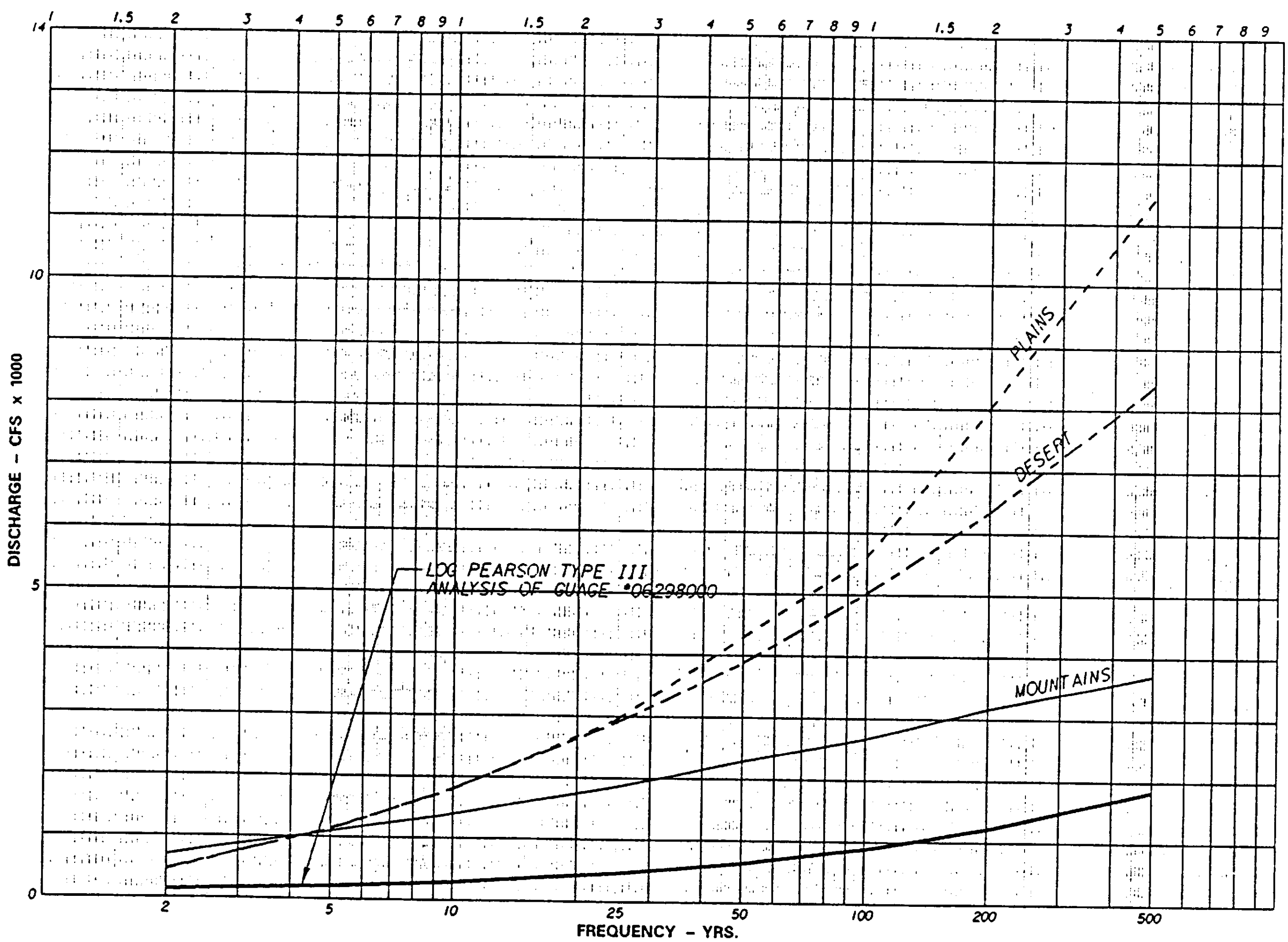
Table 2 -- Comparison of Unique Flood-Frequency Curve Data to USGS Regional Equations Curve 1

Frequency (yrs)	Guage Q, cfs	D.A. = 100 Pf = 12		D.A. = 80 Pf = 10		D.A. = 60 Pf = 8		D.A. = 40 Pf = 8	
		Q (cfs)	Diff (%)	Q (cfs)	Diff (%)	Q (cfs)	Diff (%)	Q (cfs)	Diff (%)
2	117	352	201.2	239	104.6	147	25.9	106	-9.3
5	196	623	218.0	453	131.3	303	54.8	220	12.4
10	280	842	200.5	635	126.8	445	58.8	324	15.8
25	443	1203	171.7	946	113.5	696	57.1	509	15.0
50	623	1536	146.5	1236	98.4	937	50.3	685	10.0
100	871	1862	113.7	1534	76.2	1198	37.5	880	1.1
200	1207	2306	91.0	1951	61.6	1573	30.3	1160	-3.9
500	1829	2829	54.7	2465	34.8	2060	12.6	1526	-16.6

D.A. = Drainage Area (square miles)
Pf = Precipitation Factor (inches)

It is necessary to plot the three flood-frequency relationships from Table 1 as shown in Figure 1 for this example.

In Table 2, the first column lists the return frequency of the different discharges and the second column lists the discharges determined by a Log-Pearson III analysis of the gauge data. These discharges are the ones DSGNFREQ.FOR will try and match. The headers on the following pairs of columns list the different trials for four different drainage areas and precipitation factors. These results are the resultant discharges using the Wyoming Basin Characteristics Method for the Mountainous Region. Also shown are corresponding deviations from the guage analysis (in percent).



DISCHARGE - CFS x 1000
FREQUENCY - YRS.
LOG PEARSON TYPE III ANALYSIS OF GUAGE *06298000
PLAINS
DESERT
MOUNTAINS

Figure 1

On Figure 1 of this example plot the selected unique flood-frequency curve from Table 1. Compare these four plots and choose one of the three Wyoming Basin Characteristics curves that is closest in replicating the selected unique flood-frequency curve. Adjust the variables in the selected Basin Characteristics Curve (Curve 1 in this example) until it more closely replicates the selected flood-frequency curve; i.e., force the selected Wyoming Basin Characteristics Curve to "move over" to the unique flood-frequency curve from Table 1. Table 1 also reflects the accuracy of this replication as the deviations (Diff) from the selected flood-frequency which relationship vary for -16.6% to +15.8%. In order to obtain this transformation, it was necessary to change the actual drainage area from 152 square miles to a hypothetical value of 40 square miles. Similarly, the precipitation factor was changed from 16 inches to a hypothetical value of 8 inches.

Continuing with the example as before, This site is located in a rural area where a bridge is being considered. Based on the format guidance provided in Table A.3.8a and the foregoing hypothetical drainage area and precipitation factor, the screen will have the following appearance when the coding is completed and prior to running DSGNFREQ.FOR. Since this screen is currently difficult to quickly interpret, frequent reference to Table A.3.8a is recommended to avoid input errors. Note, this screen and the subsequent output reflects the hypothetical hydrological region and hypothetical basin characteristics developed to replicate the selected flood-frequency curve shown on Figure 1.

2	1	1	0			
35.0	2.5	0.009	0.009	0.0050	0.04	0.035
40.0	8.0	1.0				
2	3	32.0	5.0	7.0	1	
0.040	50					
0	50	4.0	0	3	0	
0.25	60.0	15.0	30.0	265.0	20	
1.60	450.0	3.0	50.0	40.0	20.0	6000.0
2	2	2	2			

Run the program as described in Step 3 of the foregoing User Instructions. Output for this example would have the following appearance.

LOCATION: Rural Area
REGION: Mountainous Region
DRAINAGE STRUCTURAL TYPE: Bridges

CHANNEL CHARACTERISTICS:
Bankfull channel width = 35.0 ft
Bankfull channel depth = 2.5 ft
Transverse floodplain slope on the left = 0.0090
Transverse floodplain slope on the right = 0.0090
Longitudinal channel slope = 0.0050
Manning roughness on floodplain = 0.0400
Manning roughness in main channel = 0.0350

BASIN CHARACTERISTICS:
Drainage Area = 40.0 sq. miles
Annual Average Precipitation = 8.00 inches
Geographic Factor = 1.0

FLOOD FREQUENCY BY BASIN CHARACTERISTIC METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
106.1	220.3	324.2	509.4	685.4	880.2	1160.3

FLOOD FREQUENCY BY CHANNEL GEOMETRY METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
533.9	805.9	992.4	1219.2	1413.5	1654.4	2220.0

HYPOTHETICAL SITE CHARACTERISTICS TO MATCH THE CHANNEL GEOMETRY FLOOD FREQUENCY CURVE:
Drainage area = 89.22 sq. miles
Channel slope = 0.0050 feet/feet
Annual precip = 15.99 inches
Geograp. Fac. = 1.00

ROADWAY CHARACTERISTICS:
No. of lanes = 2
Design width of pier = 3.00 ft
Bridge deck width = 32.00 ft
Design embankment height = 5.00 ft
Pavement thickness = 7.00 in
Embankment soil type = Non cohesive

ECONOMIC PARAMETERS:
Interest rate = .0400 (decimal)
Design project life = 50.0 years
No. of residential buildings = 0
Building values = 50.000 ($1000)
Building elevation above
channel bottom at the drainage structure site = 4.00 ft
No. of farm house = 0
Non-irrigated land
Other hays

TRAFFIC CHARACTERISTICS:
Detour length = 0.25 miles
Rate of repair = 60.00 cu. yd./hr
Mobilization time = 15.00 hrs
Average vehicle speed on detour = 30.00 mph
Accident ratio = 265.00 per million veh-miles
Avg. daily traffic count = 20.00

UNIT COST CHARACTERISTICS:
Cost adjustment factor = 1.60
Mobilization cost ($) = 450.00
Unit embankment cost ($/cu. yd.) = 3.00
Unit bridge cost ($/sq. ft.) = 50.00
Unit pavement cost ($/cu. yd.) = 40.00
Unit cost of occupant ($/person) = 20.00
Unit damage cost ($/accident) = 6000.00

LTEC DESIGN RETURN PERIOD (IN YEARS)
(BY BASIN-CHARACTERISTICS METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	16.4 YRS	28.5 YRS	49.9 YRS
	416.6 CFS	540.5 CFS	684.9 CFS
CONTINUOUS	8.8 YRS	15.3 YRS	27.1 YRS
	303.9 CFS	402.6 CFS	528.5 CFS
WEIGHTED	14.2 YRS	21.1 YRS	31.4 YRS
	388.3 CFS	470.2 CFS	565.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	59.8 YRS	105.7 YRS	187.6 YRS
	1468.9 CFS	1678.6 CFS	2106.2 CFS
CONTINUOUS	30.4 YRS	54.6 YRS	98.7 YRS
	1271.6 CFS	1440.4 CFS	1649.0 CFS
WEIGHTED	51.1 YRS	76.9 YRS	116.1 YRS
	1419.9 CFS	1553.4 CFS	1722.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

RATING OF FACTORS AFFECTING DESIGN FREQUENCY:

Economic Efficiency: Important
Maintenance Frequency: Important
Litigation Potential: Important
Public Service: Important

INTERVALS OF EXTENDED-LTEC DESIGN RETURN PERIODS AND DESIGN DISCHARGES:
(BY BASIN-CHARACTERISTICS METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	28.8 YRS	29.7 YRS	32.5 YRS
	543.8 CFS	551.0 CFS	573.1 CFS
LITIG. POTEN.	28.5 YRS	28.6 YRS	29.1 YRS
	541.0 CFS	542.1 CFS	545.6 CFS
PUBLIC SRVC.	30.2 YRS	34.2 YRS	47.7 YRS
	555.0 CFS	586.6 CFS	673.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	107.2 YRS	110.4 YRS	120.6 YRS
	1684.6 CFS	1698.0 CFS	1741.2 CFS
LITIG. POTEN.	106.0 YRS	106.4 YRS	108.0 YRS
	1679.5 CFS	1681.5 CFS	1687.9 CFS
PUBLIC SRVC.	112.2 YRS	127.2 YRS	177.4 YRS
	1705.6 CFS	1769.6 CFS	2030.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	15.5 YRS	16.0 YRS	17.5 YRS
	405.3 CFS	411.2 CFS	429.5 CFS
LITIG. POTEN.	15.3 YRS	15.4 YRS	15.6 YRS
	403.0 CFS	403.9 CFS	406.7 CFS
PUBLIC SRVC.	16.2 YRS	18.4 YRS	25.7 YRS
	414.5 CFS	440.8 CFS	515.8 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	55.3 YRS	57.0 YRS	62.3 YRS
	1444.6 CFS	1453.7 CFS	1482.0 CFS
LITIG. POTEN.	54.7 YRS	54.9 YRS	55.7 YRS
	1441.0 CFS	1442.4 CFS	1446.8 CFS
PUBLIC SRVC.	57.9 YRS	65.7 YRS	91.6 YRS

	- STDEV	MEAN	+STDEV
	1458.9 CFS	1499.5 CFS	1618.6 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	21.4 YRS	22.0 YRS	24.0 YRS
	473.2 CFS	479.8 CFS	500.3 CFS
LITIG. POTEN.	21.1 YRS	21.2 YRS	21.5 YRS
	470.6 CFS	471.6 CFS	474.9 CFS
PUBLIC SRVC.	22.4 YRS	25.4 YRS	35.4 YRS
	483.6 CFS	512.8 CFS	594.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	78.0 YRS	80.3 YRS	87.7 YRS
	1558.2 CFS	1568.7 CFS	1601.9 CFS
LITIG. POTEN.	77.1 YRS	77.4 YRS	78.5 YRS
	1554.1 CFS	1555.7 CFS	1560.8 CFS
PUBLIC SRVC.	81.6 YRS	92.5 YRS	129.0 YRS
	1574.7 CFS	1622.7 CFS	1777.4 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

Note, the first part of the output again repeats the input, but in this instance the hypothetical basin variables. This is followed by the output containing the estimated LTEC design frequency and related statistics. The hydraulics engineer should check to insure the desired data has been input correctly. Next and in a similar manner the *Extended* LTEC input is provided for checking followed by the Extended LTEC output.

Discussion for Example 4 is generally the same as Example 1, but the manual computations for the standard deviations would reflect different values and thus perhaps a different interpretation. Also, the marginal errors reflected in Table 1 would have some unknown effect on the estimated LTEC and Extended LTEC design frequencies. A reasonable replication of the selected flood-frequency curve would probably have little significant effect on the accuracy of the estimated LTEC and Extended LTEC design frequencies given the accuracy of the site data.

Example 5 -- DSGNFREQ.FOR can accept unique, site specific flood-frequency curve as input. This alternative avoids the manual transformation illustrated with Example 4. The average low flow (Q_2) channel width of 35 feet was obtained away from the site at the entrance and exit of several bendways in accordance with Druse (Druse, et. al. 1988). This was done in case it was decided to use the channel geometry method to determine the flood frequency relationship.

Using the site of Example 4 and inputting the flood-frequency data from Table 2 of that example as described in Table A.3.8 results in the following input screen.

2	1	1				
35.0	2.5	0.009	0.009	0.0050	0.04	0.035
152.0	16.0	1.0				
117.0	196.0	280.0	443.0	623.0	871.0	1207.0
2	3	32.0	5.0	7.0	1	
0.040	50					
0	50	4.0	0	3	0	
0.25	60.0	15.0	30.0	265.0	20	
1.60	450.0	3.0	50.0	40.0	20.0	6000.0
2	2	2	2			

Run the program as described in Step 3 of the foregoing User Instructions. Output would have the following appearance.

LOCATION: Rural Area
REGION: Mountainous Region
DRAINAGE STRUCTURAL TYPE: Bridges

CHANNEL CHARACTERISTICS:
Bankfull channel width = 35.0 ft
Bankfull channel depth = 2.5 ft
Transverse floodplain slope on the left = 0.0090
Transverse floodplain slope on the right = 0.0090
Longitudinal channel slope = 0.0050
Manning roughness on floodplain = 0.0400
Manning roughness in main channel = 0.0350

BASIN CHARACTERISTICS:
Drainage Area = 152.0 sq. miles
Annual Average Precipitation = 16.00 inches
Geographic Factor = 1.0

FLOOD FREQUENCY BY BASIN CHARACTERISTIC METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
684.7	1085.9	1382.4	1853.2	2278.4	2656.6	3155.7

FLOOD FREQUENCY BY CHANNEL GEOMETRY METHOD:

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
533.9	805.9	992.4	1219.2	1413.5	1654.4	2220.0

HYPOTHETICAL SITE CHARACTERISTICS TO MATCH THE CHANNEL GEOMETRY FLOOD FREQUENCY CURVE:
Drainage area = 88.16 sq. miles
Channel slope = 0.0050 feet/feet
Annual precip = 16.94 inches
Geograp. Fac. = 1.00

USER SPECIFIED FLOOD FREQUENCY CURVE (IFLOOD = 1):

2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	200-YR
117.0	196.0	280.0	443.0	623.0	871.0	1207.0

ROADWAY CHARACTERISTICS:
No. of lanes = 2
Design width of pier = 3.00 ft
Bridge deck width = 32.00 ft
Design embankment height = 5.00 ft
Pavement thickness = 7.00 in
Embankment soil type = Non cohesive

ECONOMIC PARAMETERS:
Interest rate = 0.0400 (decimal)
Design project life = 50.0 years
No. of residential buildings = 0
Building values = 50.000 ($1000)
Building elevation above
channel bottom at the drainage structure site = 4.00 ft
No. of farm house = 0
Non-irrigated land
Other hays

TRAFFIC CHARACTERISTICS:
Detour length = 0.25 miles
Rate of repair = 60.00 cu. yd./hr
Mobilization time = 15.00 hrs
Average vehicle speed on detour = 30.00 mph
Accident ratio = 265.00 per million veh-miles
Avg. daily traffic count = 20.00

UNIT COST CHARACTERISTICS:
Cost adjustment factor = 1.60
Mobilization cost ($) = 450.00
Unit embankment cost ($/cu. yd.) = 3.00
Unit bridge cost ($/sq. ft.) = 50.00
Unit pavement cost ($/cu. yd.) = 40.00
Unit cost of occupant ($/person) = 20.00
Unit damage cost ($/accident) = 6000.00

LTEC DESIGN RETURN PERIOD (IN YEARS)

(BY BASIN-CHARACTERISTICS METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	72.2 YRS	127.9 YRS	227.0 YRS
	2471.0 CFS	2817.0 CFS	3262.7 CFS
CONTINUOUS	35.1 YRS	63.1 YRS	114.2 YRS
	2065.3 CFS	2400.7 CFS	2741.1 CFS
WEIGHTED	60.4 YRS	91.0 YRS	137.5 YRS
	2377.8 CFS	2599.9 CFS	2867.8 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

	- STDEV	MEAN	+STDEV
DISCRETE	64.9 YRS	114.9 YRS	203.9 YRS
	1495.5 CFS	1716.8 CFS	2262.9 CFS
CONTINUOUS	33.1 YRS	59.6 YRS	107.8 YRS
	1295.1 CFS	1467.7 CFS	1687.0 CFS
WEIGHTED	55.6 YRS	83.7 YRS	126.4 YRS
	1445.8 CFS	1584.2 CFS	1766.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY USER SPECIFIED FLOOD FREQUENCY CURVE)

	- STDEV	MEAN	+STDEV
DISCRETE	18.9 YRS	32.9 YRS	57.8 YRS
	385.5 CFS	507.3 CFS	668.7B CFS
CONTINUOUS	9.8 YRS	17.1 YRS	30.3 YRS
	277.2 CFS	366.2 CFS	486.9 CFS
WEIGHTED	16.1 YRS	23.9 YRS	35.8 YRS
	356.1 CFS	433.5 CFS	528.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

RATING OF FACTORS AFFECTING DESIGN FREQUENCY:
Economic Efficiency: Important
Maintenance Frequency: Important
Litigation Potential: Important
Public Service: Important

INTERVALS OF EXTENDED-LTEC DESIGN RETURN PERIODS AND DESIGN DISCHARGES:

(BY BASIN-CHARACTERISTICS METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	129.6 YRS	133.4 YRS	145.8 YRS
	2826.3 CFS	2846.8 CFS	2910.4 CFS
LITIG. POTEN.	128.1 YRS	128.7 YRS	130.5 YRS
	2818.4 CFS	2821.5 CFS	2831.4 CFS
PUBLIC SRVC.	135.7 YRS	153.8 YRS	214.5 YRS
	2858.4 CFS	2949.8 CFS	3214.2 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	116.4 YRS	119.9 YRS	131.0 YRS
	1723.4 CFS	1738.1 CFS	1786.1 CFS
LITIG. POTEN.	115.1 YRS	115.6 YRS	117.3 YRS
	1717.8 CFS	1720.0 CFS	1727.0 CFS
PUBLIC SRVC.	121.9 YRS	138.2 YRS	192.7 YRS
	1746.5 CFS	1818.2 CFS	2149.4 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY USER FLOOD SPECIFIED FREQUENCY CURVE)

(DISCRETE)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	33.3 YRS	34.3 YRS	37.5 YRS
	510.7 CFS	518.1 CFS	541.3 CFS
LITIG. POTEN.	33.0 YRS	33.1 YRS	33.6 YRS
	507.8 CFS	508.9 CFS	512.5 CFS
PUBLIC SRVC.	34.9 YRS	39.6 YRS	55.2 YRS
	522.3 CFS	555.7 CFS	653.7 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	64.0 YRS	56.9 YRS	72.0 YRS
	2407.7 CFS	2422.8 CFS	2469.3 CFS
LITIG. POTEN.	63.2 YRS	63.5 YRS	64.4 YRS
	2401.7 CFS	2404.0 CFS	2411.4 CFS
PUBLIC SRVC.	66.9 YRS	75.9 YRS	2692.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	60.4 YRS	62.2 YRS	67.9 YRS
	1472.0 CFS	1481.4 CFS	1510.6 CFS
LITIG. POTEN.	59.7 YRS	59.9 YRS	60.8 YRS
	1468.3 CFS	1469.7 CFS	1474.3 CFS
PUBLIC SRVC.	63.2 YRS	71.7 YRS	99.9 YRS
	1486.7 CFS	1528.7 CFS	1654.1 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY USER FLOOD SPECIFIED FREQUENCY CURVE)

(CONTINUOUS)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	17.3 YRS	17.8 YRS	19.4 YRS
	368.7 CFS	374.1 CFS	391.1 CFS
LITIG. POTEN.	17.1 YRS	17.2 YRS	17.4 YRS
	366.6 CFS	367.4 CFS	370.0 CFS
PUBLIC SRVC.	18.1 YRS	20.5 YRS	28.6 YRS
	377.2 CFS	401.6 CFS	473.5 CFS

NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY BASIN-CHARACTERISTICS METHOD)

(WEIGHTED)	- STDEV	MEAN	+STDEV
MAINT. FREQ.	92.2 YRS	95.0 YRS	103.8 YRS

```
                          2607.8 CFS   2625.3 CFS   2679.8 CFS
LITIG. POTEN.               91.2 YRS     91.6 YRS     92.9 YRS
                          2601.1 CFS   2603.7 CFS   2612.2 CFS
PUBLIC SRVC.                96.5 YRS    109.5 YRS    152.7 YRS
                          2635.2 CFS   2713.7 CFS   2944.1 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY CHANNEL-GEOMETRY METHOD)
(WEIGHTED)                 - STDEV        MEAN        +STDEV
MAINT. FREQ.                84.9 YRS     87.4 YRS     95.5 YRS
                          1589.2 CFS   1600.3 CFS   1635.3 CFS
LITIG. POTEN.               83.9 YRS     84.3 YRS     85.5 YRS
                          1584.9 CFS   1586.6 CFS   1592.0 CFS
PUBLIC SRVC.                88.8 YRS    100.7 YRS    140.5 YRS
                          1606.6 CFS   1657.5 CFS   1828.5 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD

(BY USER FLOOD SPECIFIED FREQUENCY CURVE)
(WEIGHTED)                 - STDEV        MEAN        +STDEV
MAINT. FREQ.                24.3 YRS     25.0 YRS     27.3 YRS
                           436.4 CFS    442.8 CFS    462.7 CFS
LITIG. POTEN.               24.0 YRS     24.1 YRS     24.4 YRS
                           433.9 CFS    434.9 CFS    438.0 CFS
PUBLIC SRVC.                25.4 YRS     28.8 YRS     40.1 YRS
                           446.4 CFS    475.1 CFS    559.6 CFS
NOTE: 500 IMPLIES EXCEEDING 500-YR RETURN PERIOD
```

The accuracy of the LTEC and Extended LTEC frequencies obtained from the manual transformation of Example 4 and the transformation provided by DSGNFREQ.FOR in this example can be compared. This comparison is below in Table 3.

Table 3 -- Comparison of Manual and DSGNFREQ.FOR Transformations

Method		Manual, yrs	DSGNFREQ.FOR, yrs
LTEC	Discrete	28.5	32.9
	Continuous	15.3	17.1
	Weighted	21.1	23.9
Extended LTEC	Discrete	29.7	34.3
	Continuous	16.0	20.5
	Weighted	22.0	28.8

A.3.4 SENSITIVITY ANALYSIS

It is useful to the hydraulics engineer to know, in general, how the technology advanced by this research project compares to the intuitive practices currently used by agencies such as the WDT. This was attempted in two ways.

- Comparison of the mean LTEC design frequencies with the traditional design frequencies that would be selected using current WDT Operating Policy[2] 18-6

[2] This intuitive policy is similar to that used by many highway agencies.

- Sensitivity analysis to identify the change in the LTEC design frequencies for a range of variables

The sensitivity analysis in this section is based on an earlier version of DSGNFREQ.FOR. As such, these findings are subjective and not numerically reflective of the current version of DSGNFREQ.FOR. However, it is believed that the sensitivity related findings of this section would probably not change significantly. This should be verified with future research.

Comparison with Operating Policy 18-6 -- Typical drainage sites were evaluated to compare the traditional design frequencies selected using WDT Operating Policy 18-6 with those design frequencies estimated using the foregoing LTEC and Extended LTEC practices. The input values used in this comparison that were held constant are listed below.

NP = 0.04	DELL = 0.1
NC = 0.03	RREP = 57
PR = 12	TM = 10
GF = 1	ASVD = 20
WP = 2	AR = 300
BRIWD = 32	CC = 1.5
INDXS = 3	CM = 340
COVERDEP = 2.0	UEMB = 4.5
RATE = 0.097	UBRDG = 40
BLDGELE = 2.5	UPAVE = 50
INDEX1 = 1	UOC = 18
INDEXC = 1	UDAMG = 6300
IRANGE = 1	UCOST STEEL = $0.55
KFARM = 1 where NRES is 1, otherwise 0	UCOST CONC = $350

Table A.3.10 a-c indicates the input values that were varied to compare the traditionally used recurrence intervals from Operating Policy 18-6 with the resulting LTEC and Extended LTEC recurrence intervals. Table A.3.11 a-c reflects these traditional recurrence interval values along with the findings from this comparison. For User convenience the contents of Tables A.3.10 and A.3.11 are listed below.

Table	Locale and Condition
A.3.10a	Typical Site Data for Testing -- Rural Collector and Minor Arterial
A.3.10b	Typical Site Data for Testing -- Rural Multi-lane & Interstate
A.3.10c	Typical Site Data for Testing -- Urban Arterial & Principle Arterial
A.3.11a	Comparison of LTEC/Extended LTEC Design Frequencies -- Rural Collector and Minor Arterial
A.3.11b	Comparison of LTEC/Extended LTEC Design Frequencies -- Rural Multi-lane & Interstate
A.3.11c	Comparison of LTEC/Extended LTEC Design Frequencies -- Urban Arterial & Principle Arterial

Table A.3.10a Typical Site Data for Testing -- Rural Collector & Minor Arterial

Site Variable		Rural Collector (ADT 750)					Rural Minor Arterial (ADT 750)				
		CMP	CMP	RCB	RCB	Bridge	CMP	CMP	RCB	RCB	Bridge
A, Sq Mi		0.1	1.0	10	100	1000	0.1	1.0	10	100	1000
Channel Characteristics	T	1	4	27	27	51	1	4	27	27	51
	D	1	1.5	2	2.5	3	1	1.5	2	2.5	3
	S_l	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_r	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_c	.03	.02	.01	.006	.002	.03	.02	.01	.006	.002
Structure/ Road Characteristics	NL	2					2				
	HEMB	4	6	8	10	10	4	8	12	16	20
	THICKPV	4					6				
	RDWID	28					36				
	INDXP	21	21	--	--	--	21	21	--	--	--
Economic Life, yrs		15	15	30	30	50	25	25	45	45	60
Rural Property	NRES	0					1	0	1	0	0
	BLDGVAL	0					70	0	70	0	0
Traffic ADT		10					2000				
Intangibles	WT1	3					2	3	2	3	3
	WT2	2					2				
	WT3	1					3	1	3	1	1
	WT4	1					2				

Table A.3.10b Typical Site Data for Testing -- Rural Multi-lane & Interstate

Site Variable		Rural Minor Arterial (Multi-lane)					Rural Principle Arterial (Interstate)				
		CMP	CMP	RCB	RCB	Bridge	CMP	CMP	RCB	RCB	Bridge
A, Sq Mi		0.1	1.0	10	100	1000	0.1	1.0	10	100	1000
Channel Characteristics	T	1	4	27	27	51	1	4	27	27	51
	D	1	1.5	2	2.5	3	1	1.5	2	2.5	3
	S_l	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_r	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_c	.03	.02	.01	.006	.002	.03	.02	.01	.006	.002
Structure/ Road Characteristics	NL	4					4				
	HEMB	4	8	10	14	16	4	8	14	18	20
	THICKPV	9					9				
	RDWID	68					80				
	INDXP	21	21	--	--	--	21	21	--	--	--
Economic Life, yrs		30	30	30	50	70	30	30	50	45	70
Rural Property	NRES	0					1	0	1	0	0
	BLDGVAL	0					70	0	70	0	0
Traffic ADT		5000					10000				
Intangibles	WT1	3					2	3	2	3	3
	WT2	2					2				
	WT3	1					3	2	3	2	2
	WT4	2					2				

Table A.3.10c Typical Site Data for Testing -- Urban Arterial & Principal Arterial

Site Variable		Urban Arterial (ADT 750)					Urban Principle Arterial (Interstate)				
		CMP	CMP	RCB	RCB	Bridge	CMP	CMP	RCB	RCB	Bridge
A, Sq Mi		0.1	1.0	10	100	1000	0.1	1.0	10	100	1000
Channel Characteristics	T	1	4	27	27	51	1	4	27	27	51
	D	1	1.5	2	2.5	3	1	1.5	2	2.5	3
	S_l	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_r	0.5	0.4	0.3	0.2	0.1	0.5	0.4	0.3	0.2	0.1
	S_c	.03	.02	.01	.006	.002	.03	.02	.01	.006	.002
Structure/ Road Characteristics	NL	2					4				
	HEMB	4	8	10	14	16	4	8	14	18	20
	THICKPV	9					12				
	RDWID	44					80				
	INDXP	21	21	–	–	–	21	21	–	–	–
Economic Life, yrs		30	30	30	50	70	50	50	50	70	70
Urban Property	NRES	1	2	3	4	5	5	4	3	2	1
	BLDGVAL	70	70	100	100	500	70	100	200	340	300
Traffic ADT		10000					25000				
Intangibles	WT1	2					2				
	WT2	2					2				
	WT3	3					3				
	WT4	3					3				

Table A.3.11a Comparison of Operating Policy and LTEC/Extended LTEC Design Frequencies -- Plains Region

Road Class	General Description	ADT	Structure	Mean Design Frequency, yrs						
				Operating Policy 18-6	LTEC			Extended LTEC		
					Discrete	Cont**	Weighted	Discrete	Cont**	Weighted
Rural Collector (ADT<750)	Low class SC-CFM with no property considerations	10	CMP D.A. 64 Ac.	10 yr	42.7	57.1	49.4	43.4 72.5 47.8	58.0 96.8 63.9	50.1 83.7 55.2
			CMP D.A. = 1 Sq Mi	10 yr	12.1	15.5	13.7	12.2 20.4 13.5	15.7 26.3 17.4	13.9 23.2 15.3
			RCB D.A. = 10 Sq Mi	10 yr (Minor) 25 yr (Major)	1.1	1.3	1.2	1.2 500.0 3.9	1.4 500.0 4.7	1.3 500.0 4.2
			RCB D.A. = 100 Sq Mi	25 yr	1.1	1.1	1.1	1.1 500.0 3.7	1.2 500.0 3.9	1.1 500.0 3.8
			Bridge D.A. = 1000 Sq Mi	25 yr	1.6	1.7	1.6	2.0 3.1 2.8	2.2 3.3 2.9	2.1 3.2 2.9
Rural Minor Arterial (ADT>750)	High class SC-CFM or low class secondary with upstream ranch house and farm buildings at the 64 acre and 100 square mile site	2000	CMP D.A. 64 Ac.	25 yr highway 100 yr property	137.3	169.6	152.5	139.3 500.0 190.3	172.1 500.0 235.1	154.8 500.0 211.4
			CMP D.A. = 1 Sq Mi	25 yr	34.7	42.0	38.1	39.8 58.8 51.6	40.1 71.2 62.4	43.7 64.7 56.7
			RCB D.A. = 10 Sq Mi	25 yr highway 100 yr property	7.0	14.4	10.3	8.3 7.0 22.5	17.2 14.4 46.6	12.3 10.3 33.2
			RCB D.A. = 100 Sq Mi	25 yr	2.1	3.6	2.7	2.1 500.0 6.4	3.7 500.0 11.1	2.8 500.0 8.5
			Bridge D.A. = 1000 Sq Mi	25 yr	4.3	4.2	4.2	4.7 8.4 19.3	4.6 8.2 18.9	4.6 8.3 19.1

Table A.3.11b Comparison of Operating Policy and LTEC/Extended LTEC Design Frequencies -- Plains Region

Road Class	General Description	ADT	Structure	Mean Design Frequency, yrs						
				Operating Policy 18-6	LTEC			Extended LTEC		
					Discrete	Cont**	Weighted	Discrete	Cont**	Weighted
Rural Minor Arterial (Multi-lane)	Lower class multi-lane with no property consideration	5000	CMP D.A. 64 Ac.	25 yr	131.7	196.5	160.7	138.1 223.2 149.4	206.0 333.0 222.9	168.5 272.3 182.3
			CMP D.A. = 1 Sq Mi	25 yr	35.6	51.6	42.8	40.8 60.3 52.9	59.1 87.4 76.6	49.1 72.5 63.6
			RCB D.A. = 10 Sq Mi	25 yr	2.0	3.6	2.7	2.0 500.0 6.1	3.7 500.0 11.1	2.7 500.0 8.2
			RCB D.A. = 100 Sq Mi	25 yr	1.6	2.4	1.9	1.6 500.0 4.9	2.5 500.0 7.4	2.0 500.0 6.0
			Bridge D.A. = 1000 Sq Mi	25 yr	8.2	7.1	8.6	9.0 15.9 36.8	7.7 13.8 31.8	8.3 14.8 34.2
Rural Principle Arterial (Interstate)	High class multi-lane or Interstate	10000	CMP D.A. 64 Ac.	50 yr highway 100 yr property	151.0	230.3	186.3	158.6 500.0 386.4	241.9 500.0 500.0	195.7 500.0 476.7
			CMP D.A. = 1 Sq Mi	50 yr highway 100 yr property	38.1	56.7	46.4	57.2 256.1 112.8	85.1 381.4 168.0	69.7 312.1 137.5
			RCB D.A. = 10 Sq Mi	50 yr highway 100 yr property	8.2	17.6	12.4	497.8 8.2 500.0	500.0 17.6 500.0	500.0 12.4 500.0
			RCB D.A. = 100 Sq Mi	50 yr highway 100 yr property	2.2	4.0	3.0	25.9 3.6 500.0	47.1 6.5 500.0	35.1 4.8 500.0
			Bridge D.A. = 1000 Sq Mi	50 yr highway 100 yr property	9.3	7.9	8.5	9.5 14.6 41.5	8.1 12.4 35.3	8.8 13.4 38.3

Table A.3.11c Comparison of Operating Policy and LTEC/Extended LTEC Design Frequencies -- Plains Region

Road Class	General Description	ADT	Structure	Mean Design Frequency, yrs						
				Operating Policy 18-6	LTEC			Extended LTEC*		
					Discrete	Cont**	Weighted	Discrete	Cont**	Weighted
Urban Arterial (ADT 750)	Lower class two lane with property considerations at all sites	10000	CMP D.A. 64 Ac.		10.1	9.0	9.6	10.2 10.3 11.9	9.1 9.2 10.6	9.7 9.7 11.2
			CMP D.A. = 1 Sq Mi		6.1	5.3	5.7	6.1 6.3 6.6	5.3 5.5 5.8	5.7 5.9 6.2
			RCB D.A. = 10 Sq Mi		13.4	36.3	22.0	14.4 45.1 16.4	38.9 121.7 44.4	23.6 73.9 23.1
			RCB D.A. = 100 Sq Mi		16.9	48.6	28.5	17.3 27.7 19.2	50.0 80.0 55.4	29.4 47.0 32.6
			Bridge D.A. = 1000 Sq Mi		3.5	2.9	3.2	8.1 5.1 8.9	6.6 4.1 7.2	7.3 4.5 7.9
Urban Principle Arterial (Interstate)	High class multi-lane or Interstate with property considerations at all sites	25000	CMP D.A. 64 Ac.		10.0	10.2	10.1	10.0 13.8 10.7	10.7 14.0 10.9	10.1 13.9 10.8
			CMP D.A. = 1 Sq Mi		5.9	5.8	5.9	6.0 9.7 6.2	5.8 9.5 6.0	5.9 9.6 6.1
			RCB D.A. = 10 Sq Mi		23.6	68.5	40.1	25.3 79.1 28.8	73.4 229.7 83.7	43.1 134.7 49.1
			RCB D.A. = 100 Sq Mi		34.6	115.9	63.4	37.2 116.2 42.4	124.3 388.8 141.7	68.0 212.6 77.5
			Bridge D.A. = 1000 Sq Mi		4.0	3.0	3.4	9.2 5.7 7.2	6.8 4.3 5.4	7.8 4.9 6.1

* The three values in each column values are,top to bottom, for the Extended LTEC design frequency for Maintenance/Litigation/Public Service. The larger value normally applies.
** Cont = Continuous.

Sensitivity Analysis -- Comparisons were made for both rural and urban bridges and pipe culverts with different potential upstream flood hazards and six different classes of roads (reflected in the ADT values). In addition, the tested variable range include three different hydrologic regions. These tests also compared the three methods for interpolating the results: discrete, continuous, and weighted. The site factors held constant and varied are shown in Table A.3.12 through Table A.3.19. Comparisons were made by varying one variable over a range of typical values while holding the other variables constant as described below.

First, the initial variable values used in the sensitivity analysis are displayed in Column 2, Table A.3.12 through Table A.3.19 and are for the plains hydrologic region. For this analysis the variable in column 2 was used to compute the mean LTEC or Extended LTEC (ELTEC) design frequency of column 3. Next each initial variable value was *increased* individually as shown in column 4 and the hydrologic region changed to High Desert while keeping all the remaining initial variable values the same as in column 2. The resulting mean design frequency is shown in column 5. Next this same process was repeated but the variable in column 2 was *decreased* as shown in column 6 and the hydrologic region changed to Mountains. The resulting mean LTEC or ELTEC design frequency is shown in column 7. By comparing columns 2, 5, and 7 the sensitivity of each variable was *assessed* as shown in Table A.3.20. Caution, this is not a precise comparison as the hydrologic region was varied as shown in columns 2, 4 and 6. Again, for the user's convenience the contents of Table A.3.12 through Table A.3.19 are listed below.

Table	Locale/Structure/Interpolation/LTEC vs Extended LTEC
A.3.12a	Rural Bridge w/Discrete LTEC
A.3.12b	Rural Bridge w/Continuous LTEC
A.3.12c	Rural Bridge w/Weighted LTEC
A.3.13a	Rural Bridge w/Discrete Extended LTEC
A.3.13b	Rural Bridge w/Continuous Extended LTEC
A.3.13c	Rural Bridge w/Weighted Extended LTEC
A.3.14a	Urban Bridge w/Discrete LTEC
A.3.14b	Urban Bridge w/Continuous LTEC
A.3.14c	Urban Bridge w/Weighted LTEC
A.3.15a	Urban Bridge w/Discrete Extended LTEC
A.3.15b	Urban Bridge w/Continuous Extended LTEC
A.3.15c	Urban Bridge w/Weighted Extended LTEC
A.3.16a	Rural Pipe Culvert w/Discrete LTEC
A.3.16b	Rural Pipe Culvert w/Continuous LTEC

A.3.16c	Rural Pipe Culvert w/Weighted LTEC
A.3.17a	Rural Pipe Culvert w/Discrete Extended LTEC
A.3.17b	Rural Pipe Culvert w/Continuous Extended LTEC
A.3.17c	Rural Pipe Culvert w/Weighted Extended LTEC
A.3.18a	Urban Pipe Culvert w/Discrete LTEC
A.3.18b	Urban Pipe Culvert w/Continuous LTEC
A.3.18c	Urban Pipe Culvert w/Weighted LTEC
A.3.19a	Urban Pipe Culvert w/Discrete Extended LTEC
A.3.19b	Urban Pipe Culvert w/Continuous Extended LTEC
A.3.19c	Urban Pipe Culvert w/Weighted Extended LTEC
A.3.20	Apparent Variable Sensitivity

It will be noted that some variables reflect little or no sensitivity. The question could be raised as to why such variables were retained in the algorithms. The reason is that these variables intuitively are often considered as being important by some engineers. It was deemed advisable to include them in the selected algorithms so that their influence could be assessed as well as to forestall repeated questions as to why these site factors were not being considered!

Table A.3.12a Rural Bridge w/Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	35.9	--	--	--	--
REGION	High Plains	" "	Desert	335.7	Mtns	254.7
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	42.7	50	29.5
CHAN DPTH	4.5	" "	7.5	7.5	2.5	27
FLDPLN SLOPE	0.03	" "	0.1	46.1	0.005	14.1
CHAN SLOPE	0.002	" "	0.01	68.4	0.0005	14.3
FLDPLN n	0.04	" "	0.06	45.4	0.02	24.2
CHAN n	0.035	" "	0.05	48.8	0.02	22.3
Basin Characteristics						
DRNGE AREA	350	" "	600	27.8	100	65.5
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.5	0.7	102.4
Structure and Road Characteristics						
NO. LANES	2	" "	4	NC	1	NC
PIER WIDTH	3	" "	5	45.4	1	21.8
DECK WIDTH	40	" "	60	34.4	20	38.7
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	46.7	8	22.2
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	33.2	0.02	41.1
DSGN LIFE	50	" "	75	69.9	25	11.9

Table A.3.12a Rural Bridge w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	2	" "	5	39.8	0	33.6
BLDG VALUE	100	" "	200	48.1	50	31.1
BLDG ELEV	9	" "	15	35.5	5	36.2
IRRIGATED	No	" "	Yes	36.3	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	36.8	0	35.1
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	39.1	5	30
REPAIR RATE	60.2	" "	200	27.5	30	42
MOB TIME	15.2	" "	30	42.7	5	27.2
DETOUR SPEED	30	" "	60	32	15	40.3
ACCIDENT RATE	265	" "	400	83.8	100	5.5
ADT	1000	" "	10000	56.4	200	26.3
Cost Characteristics						
COST ADJ	1.32	" "	1.6	25.9	1	57.9
MOB COST	450	" "	2000	69.7	200	25.2
EMB COST	3	" "	6	26.6	1.5	48.7
UNIT BRDG COST	50	" "	100	24.7	25	52.5
UNIT PVMNT COST	40	" "	80	26.8	20	48.3
OCCUPANT COST	20	" "	40	49.4	10	26.2
DAMAGE COST	6250.6	" "	10000	39.9	3000	30.5

Table A.3.12a Rural Bridge w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change   N/A = Not Applicable

Table A.3.12b Rural Bridge w/Continuous LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	33.1	--	--	--	--
REGION	High Plains	" "	Desert	322.3	Mtns	333.5
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	39.2	50	27.2
CHAN DPTH	4.5	" "	7.5	42.2	2.5	25
FLDPLN SLOPE	0.03	" "	0.1	63.3	0.005	12.9
CHAN SLOPE	0.002	" "	0.01	106.2	0.0005	12.5
FLDPLN n	0.04	" "	0.06	42.4	0.02	21.7
CHAN n	0.035	" "	0.05	45.2	0.02	20.4
Basin Characteristics						
DRNGE AREA	350	" "	600	25.7	100	59.7
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.5	0.7	88.7
Structure and Road Characteristics						
NO. LANES	2	" "	4	31.1	1	35.1
PIER WIDTH	3	" "	5	40.9	1	21
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	40.3	8	22.9
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	31.1	0.02	36.8
DSGN LIFE	50	" "	75	68.4	25	10

Table A.3.12b Rural Bridge w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	2	" "	5	37.7	0	30.3
BLDG VALUE	100	" "	200	53.9	50	26
BLDG ELEV	9	" "	15	32.7	5	33.3
IRRIGATED	No	" "	Yes	33.4	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	33.9	0	32.3
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	35.6	5	28.2
REPAIR RATE	60.2	" "	200	25.9	30	38.1
MOB TIME	15.2	" "	30	38.5	5	25.8
DETOUR SPEED	30	" "	60	29.9	15	36.6
ACCIDENT RATE	265	" "	400	77.1	100	5.1
ADT	1000	" "	10000	49.1	200	25.1
Cost Characteristics						
COST ADJ	1.32	" "	1.6	23.3	1	55.3
MOB COST	450	" "	2000	69.6	200	22.2
EMB COST	3	" "	6	23.8	1.5	46.1
UNIT BRDG COST	50	" "	100	22.6	25	48.6
UNIT PVMNT COST	40	" "	80	24.6	20	44.5
OCCUPANT COST	20	" "	40	44.8	10	24.5
DAMAGE COST	6250.6	" "	10000	36.9	3000	27.9

Table A.3.12b Rural Bridge w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Cost Characteristics						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.12c Rural Bridge w/Weighted LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	34.5	–	–	–	–
REGION	High Plains	" "	Desert	328.2	Mtns	289.9
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	40.9	50	28.4
CHAN DPTH	4.5	" "	7.5	44.1	2.5	26
FLDPLN SLOPE	0.03	" "	0.1	65.8	0.005	13.5
CHAN SLOPE	0.002	" "	0.01	107	0.0005	13.4
FLDPLN n	0.04	" "	0.06	43.9	0.02	22.9
CHAN n	0.035	" "	0.05	47	0.02	21.3
Basin Characteristics						
DRNGE AREA	350	" "	600	26.8	100	62.6
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.5	0.7	95.4
Structure and Road Characteristics						
NO. LANES	2	" "	4	33.5	1	35.5
PIER WIDTH	3	" "	5	43.1	1	21.4
DECK WIDTH	40	" "	60	33.7	20	35.8
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	43.4	8	22.6
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	32.1	0.02	38.9
DSGN LIFE	50	" "	75	69.1	25	10.9

Table A.3.12c Rural Bridge w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	2	" "	5	38.7	0	31.9
BLDG VALUE	100	" "	200	50.9	50	28.4
BLDG ELEV	9	" "	15	34.1	5	34.7
IRRIGATED	No	" "	Yes	34.8	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	35.3	0	33.6
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	37.3	5	29.1
REPAIR RATE	60.2	" "	200	26.7	30	40
MOB TIME	15.2	" "	30	40.5	5	26.5
DETOUR SPEED	30	" "	60	31	15	38.4
ACCIDENT RATE	265	" "	400	80.4	100	5.3
ADT	1000	" "	10000	52.6	200	25.7
Cost Characteristics						
COST ADJ	1.32	" "	1.6	24.6	1	56.6
MOB COST	450	" "	2000	69.6	200	23.7
EMB COST	3	" "	6	25.2	1.5	47.4
UNIT BRDG COST	50	" "	100	23.6	25	50.5
UNIT PVMNT COST	40	" "	80	25.7	20	46.4
OCCUPANT COST	20	" "	40	47	10	25.3
DAMAGE COST	6250.6	" "	10000	38.4	3000	29.2

Table A.3.12c Rural Bridge w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.13a Rural Bridge w/Discrete Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	36.0/36.5/39.2	--	--	--	--
REGION	High Plains	" "	Desert	347.6/408.2/473.9	Mtns	255.2/255.5/289.3
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	42.8/43.3/46.6	50	29.6/29.9/32.2
CHAN DPTH	4.5	" "	7.5	46.3/46.8/50.4	2.5	27.1/27.4/29.5
FLDPLN SLOPE	0.03	" "	0.1	68.6/69.4/74.7	0.005	14.2/14.3/15.4
CHAN SLOPE	0.002	" "	0.01	108.2/109.5/117.8	0.0005	14.4/14.5/15.6
FLDPLN n	0.04	" "	0.06	45.5/46.1/49.6	0.02	24.3/24.5/26.4
CHAN n	0.035	" "	0.05	48.9/49.5/53.3	0.02	22.4/22.7/24.4
Basin Characteristics						
DRNGE AREA	350	" "	600	27.9/28.2/30.4	100	65.7/66.5/71.6
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.6/9.7/10.4	0.7	102.7/103.9/111.8
Structure and Road Characteristics						
NO. LANES	2	" "	4	NC	1	NC
PIER WIDTH	3	" "	5	45.5/46.1/49.6	1	21.9/22.2/23.9
DECK WIDTH	40	" "	60	34.5/34.9/37.6	20	38.8/39.3/42.3
EMB HGHT	16	" "	25	36.1/36.9/43.0	10	NC
PVMNT THCK	14.5	" "	20	46.9/47.4/51.0	8	22.3/22.6/24.3
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	33.3/33.7/36.3	0.02	41.2/41.7/44.9
DSGN LIFE	50	" "	75	70.1/70.9/76.3	25	12.0/12.1/13.0

Table A.3.13a Rural Bridge w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	2	**	5	39.9/40.4/43.5	0	33.7/34.1/36.7
BLDG VALUE	100	**	200	48.3/48.9/52.6	50	31.2/31.5/33.9
BLDG ELEV	9	**	15	35.6/36.0/38.8	5	36.3/36.7/39.5
IRRIGATED	No	**	Yes	36.3/36.6/36.8	N/A	N/A
CROP TYPE	1	**	1	NC	N/A	N/A
NO. FARM BLDGS	5	**	10	36.9/37.4/40.2	0	35.2/35.6/38.3
Traffic Characteristics						
DETOUR LNGTH	15	**	25	39.1/39.7/40.3	5	30.1/30.4/32.7
REPAIR RATE	60.2	**	200	27.6/27.9/30.0	30	42.1/42.6/45.9
MOB TIME	15.2	**	30	42.8/43.3/46.6	5	27.2/27.6/29.7
DETOUR SPEED	30	**	60	32.1/32.5/35.0	15	40.4/40.9/44.0
ACCIDENT RATE	265	**	400	84.0/85.0/91.5	100	5.5/5.6/6.0
ADT	1000	**	10000	56.4/57.2/61.5	200	26.5/26.7/28.7
Cost Characteristics						
COST ADJ	1.32	**	1.6	26.0/26.3/28.3	1	58.1/58.8/63.3
MOB COST	450	**	2000	69.9/70.7/76.1	200	25.3/25.6/27.5
EMB COST	3	**	6	26.6/27.0/29.0	1.5	48.9/49.4/53.2
UNIT BRDG COST	50	**	100	24.8/25.1/27.0	25	52.6/53.3/57.3
UNIT PVMNT COST	40	**	80	26.9/27.2/29.3	20	48.4/49.0/52.7
OCCUPANT COST	20	**	40	49.5/50.1/53.9	10	26.3/26.6/28.6
DAMAGE COST	6250.6	**	10000	40.0/40.5/43.6	3000	30.6/31.0/33.3

Table A.3.13a Rural Bridge w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	36.6/56.6/77.5	Less Important	35.9/36.0/36.2
MAINT. COST	Important	" "	Very Important	38.9/36.5/39.2	Less Important	36.4/36.5/39.2
LITIGATION COST	Important	" "	Very Important	36.0/37.6/39.2	Less Important	36.0/36.8/39.2
PUBLIC SERVICE	Important	" "	Very Important	36.0/36.5/38.3	Less Important	36.0/36.5/36.6

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.13b Rural Bridge w/Continuous Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	33.2/33.6/36.1	--	--	--	--
REGION	High Plains	" "	Desert	33.7/391.9/455.0	Mtns	334.5/334.6/378.8
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	39.3/39.7/42.8	50	27.3/27.6/29.7
CHAN DPTH	4.5	" "	7.5	42.3/42.8/46.1	2.5	25.1/25.4/27.3
FLDPLN SLOPE	0.03	" "	0.1	63.5/64.2/69.1	0.005	13.0/13.1/14.1
CHAN SLOPE	0.002	" "	0.01	106.5/107.8/116.0	0.0005	12.6/12.7/13.7
FLDPLN n	0.04	" "	0.06	42.5/43.0/46.3	0.02	21.8/22.0/23.7
CHAN n	0.035	" "	0.05	45.3/45.9/49.4	0.02	20.4/20.7/22.2
Basin Characteristics						
DRNGE AREA	350	" "	600	25.8/26.1/28.1	100	59.9/60.6/65.2
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.5/9.6/10.3	0.7	89.0/90.1/96.9
Structure and Road Characteristics						
NO. LANES	2	" "	4	31.5/31.6/34.0	1	35.2/35.6/38.4
PIER WIDTH	3	" "	5	41.1/41.5/44.7	1	21.0/21.3/22.9
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	33.2/34.0/39.6	10	NC
PVMNT THCK	14.5	" "	20	40.5/40.9/44.1	8	23.0/23.3/36.1
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	31.1/31.5/33.9	0.02	36.9/37.3/40.2
DSGN LIFE	50	" "	75	68.6/69.4/74.7	25	10.0/10.2/10.9

Table A.3.13b Rural Bridge w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	2	" "	5	37.8/38.3/41.2	0	30.4/30.8/33.1
BLDG VALUE	100	" "	200	54.0/54.7/58.8	50	26.0/26.4/28.4
BLDG ELEV	9	" "	15	32.8/33.2/35.7	5	33.4/33.8/36.3
IRRIGATED	No	" "	Yes	33.4/33.6/33.8	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	34.0/34.4/37.0	0	32.4/32.7/35.2
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	35.6/36.1/36.7	5	28.3/28.6/30.8
REPAIR RATE	60.2	" "	200	26.0/26.3/28.3	30	38.2/38.7/41.6
MOB TIME	15.2	" "	30	38.6/39.1/42.0	5	25.9/26.2/28.2
DETOUR SPEED	30	" "	60	30.0/30.3/32.6	15	36.7/37.1/39.9
ACCIDENT RATE	265	" "	400	77.3/78.3/84.2	100	5.2/5.2/5.6
ADT	1000	" "	10000	49.1/49.8/53.6	200	25.4/25.5/27.5
Cost Characteristics						
COST ADJ	1.32	" "	1.6	23.3/23.6/25.4	1	55.4/56.1/60.3
MOB COST	450	" "	2000	69.8/70.6/76.0	200	22.3/22.5/24.2
EMB COST	3	" "	6	23.9/24.2/26.0	1.5	46.2/46.8/50.3
UNIT BRDG COST	50	" "	100	22.7/22.9/24.7	25	48.7/49.3/53.1
UNIT PVMNT COST	40	" "	80	24.7/25.0/26.9	20	44.6/45.2/48.6
OCCUPANT COST	20	" "	40	44.9/45.5/48.9	10	24.5/24.8/26.7
DAMAGE COST	6250.6	" "	10000	37.0/37.4/40.3	3000	28.0/28.3/30.4

Table A.3.13b Rural Bridge w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	33.7/52.1/71.3	Less Important	33.1/33.1/33.3
MAINT. COST	Important	" "	Very Important	35.8/33.6/36.1	Less Important	33.5/33.6/36.1
LITIGATION COST	Important	" "	Very Important	33.2/34.6/36.1	Less Important	33.2/33.9/36.1
PUBLIC SERVICE	Important	" "	Very Important	33.2/33.6/35.3	Less Important	33.2/33.6/33.7
NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq						

Table A.3.13c Rural Bridge w/Weighted Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	34.6/35.0/37.6	--	--	--	--
REGION	High Plains	" "	Desert	339.3/399.1/463.4	Mtns	290.8/290.9/329.3
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	41.0/41.5/44.6	50	28.4/28.8/31.0
CHAN DPTH	4.5	" "	7.5	44.3/44.8/48.2	2.5	26.1/26.4/28.4
FLDPLN SLOPE	0.03	" "	0.1	66.0/66.8/71.9	0.005	13.5/13.7/14.8
CHAN SLOPE	0.002	" "	0.01	107.3/108.6/116.9	0.0005	13.4/13.6/14.6
FLDPLN n	0.04	" "	0.06	44.0/44.5/47.9	0.02	23.0/23.3/25.0
CHAN n	0.035	" "	0.05	47.1/47.7/51.3	0.02	21.4/21.7/23.3
Basin Characteristics						
DRNGE AREA	350	" "	600	26.8/27.2/29.2	100	62.8/63.5/68.3
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	9.5/9.6/10.4	0.7	95.6/96.8/104.1
Structure and Road Characteristics						
NO. LANES	2	" "	4	33.5/34.0/36.5	1	35.0/36.1/38.8
PIER WIDTH	3	" "	5	43.3/43.8/47.1	1	21.5/21.7/23.4
DECK WIDTH	40	" "	60	33.8/34.2/36.8	20	35.9/36.3/39.1
EMB HGHT	16	" "	25	34.6/35.4/41.3	10	NC
PVMNT THCK	14.5	" "	20	43.6/44.1/47.4	8	22.7/22.9/24.7
SOIL COHSV	Low	" "	High	NC	None	NC
Economic Characteristics						
DISCNT RATE	0.04	" "	0.06	32.2/32.6/35.1	0.02	39.0/39.5/42.5
DSGN LIFE	50	" "	75	69.3/70.2/75.5	25	11.0/11.1/11.9

Table A.3.13c Rural Bridge w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	2	" "	5	38.8/39.3/42.3	0	32.0/32.4/34.8
BLDG VALUE	100	" "	200	51.0/51.7/55.6	50	28.5/28.8/31.0
BLDG ELEV	9	" "	15	34.2/34.6/37.2	5	34.8/35.2/37.9
IRRIGATED	No	" "	Yes	34.8/35.1/35.3	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	35.4/35.8/38.6	0	33.7/34.1/36.7
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	37.3/37.9/38.5	5	29.2/29.5/31.8
REPAIR RATE	60.2	" "	200	26.8/27.1/29.2	30	40.1/40.6/43.7
MOB TIME	15.2	" "	30	40.7/41.1/44.3	5	26.6/26.9/28.9
DETOUR SPEED	30	" "	60	31.0/31.4/33.8	15	38.5/39.0/41.9
ACCIDENT RATE	265	" "	400	80.6/81.6/87.8	100	5.3/5.4/5.8
ADT	1000	" "	10000	52.7/53.4/57.5	200	26.0/26.1/28.1
Cost Characteristics						
COST ADJ	1.32	" "	1.6	24.6/24.9/26.8	1	56.8/57.4/61.8
MOB COST	450	" "	2000	69.9/70.7/76.1	200	23.7/24.0/25.8
EMB COST	3	" "	6	25.2/25.5/27.5	1.5	47.5/48.1/51.7
UNIT BRDG COST	50	" "	100	23.7/24.0/25.8	25	50.7/51.3/55.2
UNIT PVMNT COST	40	" "	80	25.8/26.1/28.1	20	46.5/47.0/50.6
OCCUPANT COST	20	" "	40	47.2/47.7/51.4	10	25.4/25.7/27.7
DAMAGE COST	6250.6	" "	10000	38.5/39.0/41.9	3000	29.3/29.6/31.9

Table A.3.13c Rural Bridge w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	35.1/54.3/74.3	Less Important	34.5/34.5/34.7
MAINT. COST	Important	" "	Very Important	37.4/35.0/37.6	Less Important	35.0/35.0/37.6
LITIGATION COST	Important	" "	Very Important	34.6/36.1/37.6	Less Important	34.6/35.3/37.6
PUBLIC SERVICE	Important	" "	Very Important	34.6/35.0/36.8	Less Important	34.6/35.0/35.1

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.14a Urban Bridge w/Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	43.1	–	–	–	–
REGION	High Plains	" "	High DES	89.3	Mtns	500
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	71.1	50	24.4
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	66.7	0.005	22.7
CHAN SLOPE	0.002	" "	0.01	90.7	0.0005	22.9
FLDPLN n	0.04	" "	0.06	47.8	0.02	36.2
CHAN n	0.035	" "	0.05	44.8	0.02	40.6
Basin Characteristics						
DRNGE AREA	350	" "	600	40.1	100	51
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	18.1	0.7	84.4
Structure and Road Characteristics						
NO. LANES	2	" "	4	44.3	1	42
PIER WIDTH	3	" "	5	48.3	1	33.8
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	59.9	8	23.6
SOIL COHSV	Low	" "	High	55.1	None	70.4
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	41	0.02	46.9
DSGN LIFE	50	" "	75	55.1	25	28.5

Table A.3.14a Urban Bridge w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	5	* *	15	65.3	1	36.5
BLDG VALUE	100	* *	200	47.5	50	41.1
BLDG ELEV	9	* *	15	42.2	5	43.7
Traffic Characteristics						
DETOUR LNGTH	15	* *	25	51.1	5	30
REPAIR RATE	60.2	* *	200	15.8	30	78.2
MOB TIME	15.2	* *	30	160.1	5	5.8
DETOUR SPEED	30	* *	60	35.2	15	52.8
ACCIDENT RATE	265	* *	400	53.2	100	26.4
ADT	1000	* *	10000	71.1	200	30.5
Cost Characteristics						
COST ADJ	1.32	* *	1.6	24.6	1	97.8
MOB COST	450	* *	2000	52.9	200	38.6
EMB COST	3	* *	6	29	1.5	64.4
UNIT BRDG COST	50	* *	100	36.6	25	50.7
UNIT PVMNT COST	40	* *	80	26.4	20	70.8
OCCUPANT COST	20	* *	40	61	10	30.6
DAMAGE COST	6250.6	* *	10000	57.3	3000	27.8

Table A.3.14a Urban Bridge w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change   N/A = Not Applicable

Table A.3.14b Urban Bridge w/Continuous LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	49.7	–	–	–	–
REGION	High Plains	" "	High DES	87	Mtns	500
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	83.5	50	27.6
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	79	0.005	25.1
CHAN SLOPE	0.002	" "	0.01	101.2	0.0005	27.2
FLDPLN n	0.04	" "	0.06	55.3	0.02	41.4
CHAN n	0.035	" "	0.05	51.5	0.02	47
Basin Characteristics						
DRNGE AREA	350	" "	600	46.3	100	58.6
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	20.2	0.7	99.4
Structure and Road Characteristics						
NO. LANES	2	" "	4	44.3	1	55.8
PIER WIDTH	3	" "	5	55.2	1	39.7
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	69.5	8	26.9
SOIL COHSV	Low	" "	High	62.3	None	78.1
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	47.6	0.02	53.6
DSGN LIFE	50	" "	75	63.9	25	32.5

Table A.3.14b Urban Bridge w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	5	" "	15	71	1	43.1
BLDG VALUE	100	" "	200	54.8	50	47.3
BLDG ELEV	9	" "	15	48.6	5	50.5
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	61.4	5	31.7
REPAIR RATE	60.2	" "	200	17.9	30	91
MOB TIME	15.2	" "	30	213.9	5	5.4
DETOUR SPEED	30	" "	60	41.8	15	59.1
ACCIDENT RATE	265	" "	400	60.5	100	31.3
ADT	1000	" "	10000	83.8	200	34.6
Cost Characteristics						
COST ADJ	1.32	" "	1.6	27.6	1	117.4
MOB COST	450	" "	2000	57.5	200	45.9
EMB COST	3	" "	6	35	1.5	70.8
UNIT BRDG COST	50	" "	100	42.8	25	57.7
UNIT PVMNT COST	40	" "	80	29.2	20	85.1
OCCUPANT COST	20	" "	40	71.1	10	34.8
DAMAGE COST	6250.6	" "	10000	65.3	3000	32.6

Table A.3.14b Urban Bridge w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change N/A = Not Applicable

Table A.3.14c Urban Bridge w/Weighted LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	46.6	--	--	--	--
REGION	High Plains	" "	High DES	88.2	Mtns	500
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	77.5	50	26.1
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	73.1	0.005	24
CHAN SLOPE	0.002	" "	0.01	63.2	0.0005	25.1
FLDPLN n	0.04	" "	0.06	51.7	0.02	38.9
CHAN n	0.035	" "	0.05	48.3	0.02	44
Basin Characteristics						
DRNGE AREA	350	" "	600	43.4	100	54.9
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	19.2	0.7	92.2
Structure and Road Characteristics						
NO. LANES	2	" "	4	44.3	1	48.9
PIER WIDTH	3	" "	5	51.9	1	36.8
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	NC	10	NC
PVMNT THCK	14.5	" "	20	64.9	8	25.4
SOIL COHSV	Low	" "	High	58.9	None	74.5
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	44.4	0.02	50.4
DSGN LIFE	50	" "	75	59.7	25	30.6

Table A.3.14c Urban Bridge w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Property Characteristics						
NO. BLDGS	5	" "	15	68.3	1	40
BLDG VALUE	100	" "	200	51.3	50	44.3
BLDG ELEV	9	" "	15	45.5	5	47.2
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	56.4	5	30.9
REPAIR RATE	60.2	" "	200	16.9	30	84.9
MOB TIME	15.2	" "	30	187.3	5	5.6
DETOUR SPEED	30	" "	60	38.6	15	56.1
ACCIDENT RATE	265	" "	400	57	100	28.9
ADT	1000	" "	10000	77.7	200	32.6
Cost Characteristics						
COST ADJ	1.32	" "	1.6	26.2	1	108
MOB COST	450	" "	2000	55.3	200	42.4
EMB COST	3	" "	6	32.1	1.5	67.8
UNIT BRDG COST	50	" "	100	39.9	25	54.4
UNIT PVMNT COST	40	" "	80	27.9	20	78.2
OCCUPANT COST	20	" "	40	66.3	10	32.8
DAMAGE COST	6250.6	" "	10000	61.5	3000	30.3

Table A.3.14c Urban Bridge w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change N/A = Not Applicable

Table A.3.15a Urban Bridge w/Extended Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	99.1/43.2/52.3	--	--	--	--
REGION	High Plains	" "	High DES	90.4/91.7/110.2	Mtns	500.0/500.0/500.0
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	163.5/71.2/86.3	50	56.2/24.5/29.7
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	153.5/66.8/81.0	0.005	52.2/22.7/27.6
CHAN SLOPE	0.002	" "	0.01	208.6/90.9/110.1	0.0005	52.8/23.0/27.9
FLDPLN n	0.04	" "	0.06	109.9/47.9/58.0	0.02	83.2/36.2/43.9
CHAN n	0.035	" "	0.05	103.0/44.9/54.4	0.02	93.4/40.7/49.3
Basin Characteristics						
DRNGE AREA	350	" "	600	92.3/40.2/48.7	100	117.2/51.0/61.9
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	41.5/18.1/21.9	0.7	194.0/84.5/102.4
Structure and Road Characteristics						
NO. LANES	2	" "	4	101.9/44.4/53.8	1	96.5/42.0/50.9
PIER WIDTH	3	" "	5	111.1/48.4/58.6	1	77.7/33.8/41.0
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	45.4/43.2/44.8	10	NC
PVMNT THCK	14.5	" "	20	137.8/60.0/72.7	8	54.3/23.7/28.7
SOIL COHSV	Low	" "	High	126.6/55.2/66.8	None	162.0/70.5/85.5
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	94.3/41.1/49.8	0.02	107.9/47.0/57.0
DSGN LIFE	50	" "	75	126.6/55.1/66.8	25	65.5/28.5/34.6

Table A.3.15a Urban Bridge w/Extended Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	5	" "	15	150.2/65.4/79.3	1	84.1/36.6/40.7
BLDG VALUE	100	" "	200	109.3/47.6/57.7	50	94.4/41.1/49.8
BLDG ELEV	9	" "	15	97.1/42.3/51.2	5	100.5/43.8/53.1
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	117.5/51.2/62.0	5	69.0/30.0/36.4
REPAIR RATE	60.2	" "	200	36.4/15.8/19.2	30	179.8/78.3/94.9
MOB TIME	15.2	" "	30	368.2/160.3/194.4	5	13.3/5.8/7.0
DETOUR SPEED	30	" "	60	81.0/35.3/42.7	15	121.5/52.9/64.1
ACCIDENT RATE	265	" "	400	122.3/53.2/64.5	100	60.6/26.4/32.0
ADT	1000	" "	10000	163.6/71.8/91.6	200	70.1/31.9/78.1
Cost Characteristics						
COST ADJ	1.32	" "	1.6	56.2/24.7/29.9	1	225.0/98.0/118.8
MOB COST	450	" "	2000	121.6/53.0/64.2	200	88.7/38.6/46.8
EMB COST	3	" "	6	66.7/29.0/35.2	1.5	148.0/64.5/78.1
UNIT BRDG COST	50	" "	100	84.3/36.7/44.5	25	116.7/50.8/61.6
UNIT PVMNT COST	40	" "	80	60.7/26.5/32.1	20	162.7/70.9/85.9
OCCUPANT COST	20	" "	40	140.2/61.1/74.0	10	70.3/30.6/37.1
DAMAGE COST	6250.6	" "	10000	131.7/57.4/69.5	3000	63.8/27.8/33.7

Table A.3.15a Urban Bridge w/Extended Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	58.1/43.2/49.5	Less Important	43.3/43.1/43.1
MAINT COST	Important	" "	Very Important	61.3/43.2/52.3	Less Important	66.8/43.2/52.3
LITIGATION COST	Important	" "	Very Important	99.1/46.3/52.3	Less Important	99.1/43.4/52.3
PUBLIC SERVICE	Important	" "	Very Important	99.1/43.2/91.6	Less Important	99.1/43.2/44.9

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.15b Urban Bridge w/Continuous Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	114.3/49.8/60.3	--	--	--	--
REGION	High Plains	" "	High DES	88.0/89.3/107.3	Mtns	500.0/500.0/500.0
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	192.0/83.6/101.3	50	63.4/27.6/33.5
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	181.8/79.2/96.0	0.005	57.8/25.2/30.5
CHAN SLOPE	0.002	" "	0.01	232.7/101.4/122.9	0.0005	62.5/27.2/33.0
FLDPLN n	0.04	" "	0.06	127.2/55.4/67.1	0.02	95.3/41.5/50.3
CHAN n	0.035	" "	0.05	118.4/51.5/62.5	0.02	108.2/47.1/52.1
Basin Characteristics						
DRNGE AREA	350	" "	600	106.5/46.4/56.2	100	134.7/58.7/71.1
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	46.5/20.2/24.5	0.7	228.6/99.6/120.7
Structure and Road Characteristics						
NO. LANES	2	" "	4	101.8/44.4/53.8	1	128.3/55.9/67.7
PIER WIDTH	3	" "	5	127.0/55.3/67.0	1	91.2/39.7/48.2
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	52.4/49.8/51.6	10	NC
PVMNT THCK	14.5	" "	20	159.7/69.6/84.3	8	62.0/27.0/32.7
SOIL COHSV	Low	" "	High	143.4/62.4/75.6	None	179.7/78.3/94.9
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	109.4/47.6/52.8	0.02	123.2/53.6/65.0
DSGN LIFE	50	" "	75	146.9/64.0/77.5	25	74.7/32.5/39.4

Table A.3.15b Urban Bridge w/Continuous Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	5	" "	15	163.3/71.1/86.2	1	99.2/43.2/48.0
BLDG VALUE	100	" "	200	126.1/54.9/66.5	50	108.8/47.4/57.4
BLDG ELEV	9	" "	15	111.7/48.6/59.0	5	116.1/50.5/61.3
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	141.1/61.4/74.5	5	72.9/31.7/38.5
REPAIR RATE	60.2	" "	200	41.2/17.9/21.7	30	209.2/91.1/110.4
MOB TIME	15.2	" "	30	492.0/214.3/259.7	5	12.3/5.4/6.5
DETOUR SPEED	30	" "	60	96.2/41.9/50.8	15	135.9/59.2/71.7
ACCIDENT RATE	265	" "	400	139.1/60.6/73.4	100	72.1/31.4/38.0
ADT	1000	" "	10000	192.7/84.6/107.9	200	79.6/36.2/88.7
Cost Characteristics						
COST ADJ	1.32	" "	1.6	63.5/27.7/33.5	1	270.1/117.6/142.6
MOB COST	450	" "	2000	132.3/57.6/69.8	200	105.6/46.0/55.7
EMB COST	3	" "	6	80.4/35.0/42.4	1.5	162.9/70.9/86.0
UNIT BRDG COST	50	" "	100	98.5/42.9/52.0	25	132.7/57.8/70.1
UNIT PVMNT COST	40	" "	80	67.1/29.2/35.4	20	195.7/85.2/103.3
OCCUPANT COST	20	" "	40	163.5/71.2/86.3	10	80.1/34.9/42.3
DAMAGE COST	6250.6	" "	10000	150.2/65.4/79.3	3000	74.9/32.6/39.5

Table A.3.15b Urban Bridge w/Continuous Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	67.0/49.8/57.1	Less Important	49.9/49.9/49.7
MAINT COST	Important	" "	Very Important	70.7/49.8/60.3	Less Important	77.0/49.8/60.3
LITIGATION COST	Important	" "	Very Important	114.3/53.4/60.3	Less Important	114.3/50.0/60.3
PUBLIC SERVICE	Important	" "	Very Important	114.3/49.8/105.6	Less Important	114.3/49.8/51.7

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.15c Urban Bridge w/Weighted Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	107.1/46.6/56.5	--	--	--	--
REGION	High Plains	" "	High DES	89.3/90.5/108.8	Mtns	500.0/500.0/500.0
STRUCTURE	Bridge	" "	Bridge	NC	Bridge	NC
Channel Characteristics						
CHAN WDTH	90	" "	150	178.3/77.7/94.1	50	60.0/26.1/31.7
CHAN DPTH	4.5	" "	7.5	NC	2.5	NC
FLDPLN SLOPE	0.03	" "	0.1	168.2/73.2/88.8	0.005	55.2/24.0/29.1
CHAN SLOPE	0.002	" "	0.01	221.3/94.4/116.8	0.0005	57.8/25.2/30.5
FLDPLN n	0.04	" "	0.06	118.9/51.8/62.8	0.02	89.5/39.0/47.2
CHAN n	0.035	" "	0.05	111.0/48.4/58.6	0.02	101.1/44.0/53.4
Basin Characteristics						
DRNGE AREA	350	" "	600	99.7/43.4/52.6	100	126.3/55.0/66.7
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	44.1/19.2/23.3	0.7	212.0/92.3/111.9
Structure and Road Characteristics						
NO. LANES	2	" "	4	101.9/49.4/53.8	1	112.5/49.0/59.4
PIER WIDTH	3	" "	5	119.4/52.0/63.0	1	84.7/36.9/44.7
DECK WIDTH	40	" "	60	NC	20	NC
EMB HGHT	16	" "	25	49.0/46.6/48.3	10	NC
PVMNT THCK	14.5	" "	20	149.3/65.0/78.8	8	58.3/25.4/30.8
SOIL COHSV	Low	" "	High	135.4/59.0/71.5	None	171.3/74.6/90.4
Economic Characteristics						
DISCNT RATE	0.042	" "	0.06	102.2/44.5/53.9	0.02	115.9/50.5/61.2
DSGN LIFE	50	" "	75	137.2/59.8/72.4	25	70.3/30.6/37.1

Table A.3.15c Urban Bridge w/Weighted Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Property Characteristics						
NO. BLDGS	5	" "	15	157.1/68.4/82.9	1	91.9/40.0/44.5
BLDG VALUE	100	" "	200	118.1/51.4/52.3	50	102.0/44.4/53.8
BLDG ELEV	9	" "	15	104.7/45.6/55.3	5	108.6/47.3/57.3
Traffic Characteristics						
DETOUR LNGTH	15	" "	25	129.7/56.5/68.5	5	71.1/30.9/37.5
REPAIR RATE	60.2	" "	200	38.9/16.9/20.5	30	195.2/85.0/103.0
MOB TIME	15.2	" "	30	430.7/187.6/227.3	5	12.8/5.6/6.7
DETOUR SPEED	30	" "	60	88.9/38.7/46.9	15	129.1/56.2/68.1
ACCIDENT RATE	265	" "	400	131.1/57.1/69.2	100	66.6/29.0/35.1
ADT	1000	" "	10000	178.7/78.4/100.0	200	75.1/34.1/83.6
Cost Characteristics						
COST ADJ	1.32	" "	1.6	60.3/26.2/31.8	1	284.4/108.2/131.1
MOB COST	450	" "	2000	127.3/55.4/67.2	200	97.5/42.4/51.5
EMB COST	3	" "	6	73.8/32.1/38.9	1.5	155.9/67.9/82.3
UNIT BRDG COST	50	" "	100	91.7/39.9/48.4	25	125.1/54.5/66.0
UNIT PVMNT COST	40	" "	80	64.1/27.9/33.8	20	179.8/78.3/94.9
OCCUPANT COST	20	" "	40	152.4/66.4/80.4	10	75.4/32.9/39.8
DAMAGE COST	6250.6	" "	10000	141.4/61.6/74.6	3000	69.6/30.3/36.7

Table A.3.15c Urban Bridge w/Weighted Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	62.7/46.6/53.3	Less Important	46.7/46.6/46.6
MAINT COST	Important	" "	Very Important	66.2/46.6/56.5	Less Important	72.1/46.6/56.5
LITIGATION COST	Important	" "	Very Important	107.1/50.0/56.5	Less Important	107.1/46.8/56.5
PUBLIC SERVICE	Important	" "	Very Important	107.1/46.6/98.9	Less Important	107.1/46.6/48.4

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.16a Rural Pipe Culvert w/Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	37.6	–	–	–	–
REGION	High Plains	" "	Desert	43.7	Mtns	244.4
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	23.9	50	64
CHAN DEPTH	4.5	" "	7.5	83.5	2.5	15.4
FLDPLN SLOPE	0.03	" "	0.1	15.3	0.005	149.1
CHAN SLOPE	0.002	" "	0.01	65.7	0.0005	23.4
FLDPLN n	0.04	" "	0.06	41.7	0.02	31.7
CHAN n	0.035	" "	0.05	40.3	0.02	33.8
Basin Characteristics						
DRAINAGE AREA	350	" "	600	31.9	100	55.4
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	4.5	0.7	216.9
Structure and Road Characteristics						
NO LANES	2	" "	4	33.8	1	41.9
COVER DEPTH	3	" "	5	NC	1	NC
CULVERT TYPE	3(CMP)	" "	2(RCP)	37.4	4(RCPA)	37.9
ROAD WIDTH	40	" "	60	34.6	20	43.4
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	NC	8	NC
SOIL COHSV	Low	" "	High	46.4	None	57.4

Table A.3.16a Rural Pipe Culvert w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	**	0.06	31.9	0.02	49.9
DESIGN LIFE	50	**	75	50.2	25	23.1
Property Characteristics						
NO. BLDGS	2	**	5	39	0	36.8
BLDG VALUE	100	**	200	40.7	50	36.2
BLDG ELEV	9	**	15	37.2	5	37.9
IRRIGATED	No	**	Yes	38.3	N/A	N/A
CROP TYPE	1	**	1	NC	N/A	N/A
NO. FARM BLDGS	5	**	10	37.7	0	NC
Traffic Characteristics						
DETOUR LENGTH	15	**	25	42.1	5	29.6
REPAIR RATE	60.2	**	200	33.1	30	40.5
MOB. TIME	15.2	**	30	41.3	5	32.4
DETOUR SPEED	30	**	60	24.2	15	58.9
ACCIDENT RATE	265	**	400	45.8	100	23.7
ADT	1000	**	10000	52.7	200	29.8
Cost Characteristics						
COST ADJ	1.32	**	1.6	29.4	1	53.8
MOB COST	450	**	2000	53.4	200	31.2
EMB COST	3	**	6	32.7	1.5	43.4
UNIT PVMNT COST	40	**	80	25.3	20	56.1
OCCUPANT COST	20	**	40	49.7	10	58.6
DAMAGE COST	6250.6	**	10000	44.3	3000	29.3

Table A.3.16a Rural Pipe Culvert w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.16b Rural Pipe Culvert w/Continuous LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	55.5	–	–	–	–
REGION	High Plains	" "	Desert	54.1	Mtns	285.8
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	35.2	50	94
CHAN DEPTH	4.5	" "	7.5	121.2	2.5	22.9
FLDPLN SLOPE	0.03	" "	0.1	19.7	0.005	269.1
CHAN SLOPE	0.002	" "	0.01	93.8	0.0005	35.4
FLDPLN n	0.04	" "	0.06	61.3	0.02	46.8
CHAN n	0.035	" "	0.05	57.4	0.02	52.5
Basin Characteristics						
DRAINAGE AREA	350	" "	600	46.3	100	84.4
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	8.7	0.7	239.8
Structure and Road Characteristics						
NO LANES	2	" "	4	NC	1	NC
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	NC	4(RCPA)	NC
ROAD WIDTH	40	" "	60	NC	20	NC
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	53.9	8	58.5
SOIL COHSV	Low	" "	High	69.4	None	86.9

Table A.3.16b Rural Pipe Culvert w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	47.7	0.02	71.9
DESIGN LIFE	50	" "	75	71.9	25	35.7
Property Characteristics						
NO. BLDGS	2	" "	5	57.6	0	54.1
BLDG VALUE	100	" "	200	59.4	50	53.6
BLDG ELEV	9	" "	15	54.7	5	56
IRRIGATED	No	" "	Yes	56.4	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	55.6	0	55.3
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	62.9	5	42.3
REPAIR RATE	60.2	" "	200	NC	30	NC
MOB. TIME	15.2	" "	30	62.1	5	46.1
DETOUR SPEED	30	" "	60	33	15	93.6
ACCIDENT RATE	265	" "	400	63.9	100	39.7
ADT	1000	" "	10000	76.2	200	44.5
Cost Characteristics						
COST ADJ	1.32	" "	1.6	43.7	1	78.5
MOB COST	450	" "	2000	76.6	200	46.6
EMB COST	3	" "	6	46.8	1.5	65.8
UNIT PVMNT COST	40	" "	80	38.5	20	80.2
OCCUPANT COST	20	" "	40	74.4	10	41.4
DAMAGE COST	6250.6	" "	10000	65.1	3000	43.2

Table A.3.16b Rural Pipe Culvert w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	* *	Very Important	NC	Less Important	NC
MAINT. COST	Important	* *	Very Important	NC	Less Important	NC
LITIGATION COST	Important	* *	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	* *	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.16c Rural Pipe Culvert w/Weighted LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Rural	45.6	--	--	--	--
REGION	High Plains	" "	Desert	48.9	Mtns	263.2
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	29	50	77.5
CHAN DEPTH	4.5	" "	7.5	100.5	2.5	18.7
FLDPLN SLOPE	0.03	" "	0.1	17.3	0.005	200
CHAN SLOPE	0.002	" "	0.01	78.4	0.0005	28.8
FLDPLN n	0.04	" "	0.06	50.5	0.02	38.4
CHAN n	0.035	" "	0.05	48.1	0.02	42
Basin Characteristics						
DRAINAGE AREA	350	" "	600	38.4	100	68.3
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	6.2	0.7	228
Structure and Road Characteristics						
NO LANES	2	" "	4	43.2	1	48.2
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	45.5	4(RCPA)	45.8
ROAD WIDTH	40	" "	60	43.8	20	49
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	45	8	46.8
SOIL COHSV	Low	" "	High	56.7	None	70.5

Table A.3.16c Rural Pipe Culvert w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	39	0.02	59.8
DESIGN LIFE	50	" "	75	60	25	28.7
Property Characteristics						
NO. BLDGS	2	" "	5	47.3	0	44.5
BLDG VALUE	100	" "	200	49.1	50	44
BLDG ELEV	9	" "	15	45	5	46
IRRIGATED	No	" "	Yes	46.4	N/A	N/A
CROP TYPE	1	" "	1	NA	N/A	N/A
NO. FARM BLDGS	5	" "	10	45.7	0	45.5
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	51.4	5	35.3
REPAIR RATE	60.2	" "	200	42.8	30	47.4
MOB. TIME	15.2	" "	30	50.6	5	38.6
DETOUR SPEED	30	" "	60	28.2	15	74.1
ACCIDENT RATE	265	" "	400	54.1	100	30.6
ADT	1000	" "	10000	63.3	200	36.3
Cost Characteristics						
COST ADJ	1.32	" "	1.6	35.8	1	64.9
MOB COST	450	" "	2000	63.9	200	38
EMB COST	3	" "	6	39.1	1.5	53.3
UNIT PVMNT COST	40	" "	80	31.2	20	67
OCCUPANT COST	20	" "	40	60.7	10	34.4
DAMAGE COST	6250.6	" "	10000	53.6	3000	35.5

Table A.3.16c Rural Pipe Culvert w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.17a Rural Pipe Culvert w/Discrete Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	38.3/67.2/52.3	–	–	–	–
REGION	High Plains	" "	Desert	48.6/44.1/52.6	Mtns	244.4/249.4/256.7
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	24.3/42.6/33.2	50	65.1/114.2/89.0
CHAN DEPTH	4.5	" "	7.5	84.9/149.1/116.1	2.5	15.7/27.5/21.4
FLDPLN SLOPE	0.03	" "	0.1	15.6/27.4/21.3	0.005	151.7/266.3/207.4
CHAN SLOPE	0.002	" "	0.01	66.8/117.3/91.4	0.0005	23.9/41.9/32.6
FLDPLN n	0.04	" "	0.06	42.4/74.4/57.9	0.02	32.2/56.5/44.0
CHAN n	0.035	" "	0.05	41.0/72.0/56.1	0.02	34.3/60.3/47.0
Basin Characteristics						
DRAINAGE AREA	350	" "	600	32.5/57.0/44.4	100	56.4/98.9/77.0
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	4.6/8.0/6.3	0.7	220.7/387.4/301.7
Structure and Road Characteristics						
NO LANES	2	" "	4	34.4/60.3/47.4	1	42.7/74.9/58.3
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	38.0/66.7/52.0	4(RCPA)	38.5/67.7/52.7
ROAD WIDTH	40	" "	60	32.5/61.9/48.2	20	44.1/77.5/60.3
EMB HEIGHT	16	" "	25	39.6/67.2/41.7	10	NC
PVMNT THICK	14.5	" "	20	NC	8	NC
SOIL COHSV	Low	" "	High	47.3/82.9/64.6	None	58.4/102.5/79.8

Table A.3.17a Rural Pipe Culvert w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	**	0.06	32.5/57.0/44.4	0.02	50.8/89.1/69.4
DESIGN LIFE	50	**	75	51.1/89.7/69.9	25	23.5/41.2/32.1
Property Characteristics						
NO. BLDGS	2	**	5	39.7/69.6/54.2	0	37.4/65.7/51.1
BLDG VALUE	100	**	200	41.4/72.7/56.6	50	36.8/64.6/50.3
BLDG ELEV	9	**	15	37.8/66.4/51.7	5	38.6/67.7/52.8
IRRIGATED	No	**	Yes	40.0/46.9/53.2	N/A	N/A
CROP TYPE	1	**	1	NC	N/A	N/A
NO. FARM BLDGS	5	**	10	38.4/67.3/52.4	0	38.2/67.1/52.2
Traffic Characteristics						
DETOUR LENGTH	15	**	25	42.4/58.3/46.7	5	30.1/52.8/41.1
REPAIR RATE	60.2	**	200	33.7/59.1/46.0	30	41.3/72.4/56.4
MOB. TIME	15.2	**	30	42.0/73.7/57.4	5	32.9/57.8/45.0
DETOUR SPEED	30	**	60	24.6/43.2/33.6	15	59.9/105.2/81.9
ACCIDENT RATE	265	**	400	46.6/81.8/63.7	100	24.1/42.1/33.0
ADT	1000	**	10000	55.9/94.2/136.0	200	29.0/53.2/32.7
Cost Characteristics						
COST ADJ	1.32	**	1.6	29.9/52.5/40.9	1	54.8/96.2/74.9
MOB COST	450	**	2000	54.3/95.4/74.3	200	31.7/55.6/43.3
EMB COST	3	**	6	33.2/58.3/45.4	1.5	44.1/77.5/60.3
UNIT PVMNT COST	40	**	80	25.8/45.2/35.2	20	57.1/100.3/78.1
OCCUPANT COST	20	**	40	50.5/88.7/69.1	10	29.1/51.0/39.7
DAMAGE COST	6250.6	**	10000	45.0/79.0/61.6	3000	29.8/52.2/40.7

Table A.3.17a Rural Pipe Culvert w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	39.8/142.6/42.8	Less Important	37.8/39.5/39.9
MAINT. COST	Important	" "	Very Important	40.7/67.2/52.3	Less Important	37.8/67.2/52.3
LITIGATION COST	Important	" "	Very Important	38.3/281.2/52.3	Less Important	38.3/41.2/52.3
PUBLIC SERVICE	Important	" "	Very Important	38.3/67.2/41.8	Less Important	38.3/67.2/90.0

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.17b Rural Pipe Culvert w/Continuous Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	56.4/99.1/77.2	–	–	–	–
REGION	High Plains	" "	Desert	60.3/54.7/65.3	Mtns	285.8/291.6/300.2
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	35.8/62.9/49.0	50	95.6/167.9/130.7
CHAN DEPTH	4.5	" "	7.5	123.3/216.5/168.6	2.5	23.3/40.9/31.9
FLDPLN SLOPE	0.03	" "	0.1	20.0/35.1/27.3	0.005	273.8/480.6/374.4
CHAN SLOPE	0.002	" "	0.01	95.4/167.5/130.5	0.0005	36.0/63.3/49.3
FLDPLN n	0.04	" "	0.06	62.4/109.5/85.3	0.02	47.6/83.5/65.0
CHAN n	0.035	" "	0.05	58.4/12.6/79.9	0.02	53.4/93.8/73.0
Basin Characteristics						
DRAINAGE AREA	350	" "	600	47.1/82.8/64.5	100	85.9/150.7/117.4
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	8.9/5.6/12.1	0.7	243.9/428.2/333.5
Structure and Road Characteristics						
NO LANES	2	" "	4	NC	1	NC
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	NC	4(RCPA)	NC
ROAD WIDTH	40	" "	60	NC	20	NC
EMB HEIGHT	16	" "	25	58.4/99.1/61.5	10	NC
PVMNT THICK	14.5	" "	20	54.8/96.3/75.0	8	59.5/104.4/81.3
SOIL COHSV	Low	" "	High	70.6/123.9/96.5	None	88.4/155.2/120.9

Table A.3.17b Rural Pipe Culvert w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	* *	0.06	48.5/85.2/66.3	0.02	73.1/128.4/100.0
DESIGN LIFE	50	* *	75	73.1/128.4/100.0	25	36.3/63.8/49.7
Property Characteristics						
NO. BLDGS	2	* *	5	58.6/102.9/80.2	0	55.0/96.6/75.2
BLDG VALUE	100	* *	200	60.4/106.1/82.6	50	54.5/95.7/74.5
BLDG ELEV	9	* *	15	55.6/97.6/76.0	5	57.0/100.0/77.9
IRRIGATED	No	* *	Yes	59.0/69.2/78.5	N/A	N/A
CROP TYPE	1	* *	1	NC	N/A	N/A
NO. FARM BLDGS	5	* *	10	56.6/99.3/77.3	0	56.3/98.8/77.0
Traffic Characteristics						
DETOUR LENGTH	15	* *	25	63.4/87.1/69.8	5	43.0/75.5/58.8
REPAIR RATE	60.2	* *	200	NC	30	NC
MOB. TIME	15.2	* *	30	63.2/111.0/86.4	5	46.9/82.3/64.1
DETOUR SPEED	30	* *	60	33.6/59.0/45.9	15	95.3/167.2/130.2
ACCIDENT RATE	265	* *	400	65.0/114.1/88.9	100	40.4/70.9/55.3
ADT	1000	* *	10000	80.7/136.1/196.5	200	44.7/79.4/48.8
Cost Characteristics						
COST ADJ	1.32	* *	1.6	44.4/78.0/60.7	1	79.9/140.2/109.2
MOB COST	450	* *	2000	78.0/136.8/16.6	200	47.4/183.2/64.8
EMB COST	3	* *	6	47.6/83.6/65.1	1.5	66.9/117.5/91.5
UNIT PVMNT COST	40	* *	80	39.1/68.7/53.5	20	81.6/143.2/111.5
OCCUPANT COST	20	* *	40	75.7/132.8/103.5	10	42.1/74.0/57.6
DAMAGE COST	6250.6	* *	10000	66.2/116.3/90.6	3000	44.0/77.2/60.1

Table A.3.17b Rural Pipe Culvert w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	58.7/210.2/63.0	Less Important	55.8/58.3/58.8
MAINT. COST	Important	" "	Very Important	60.0/99.1/77.2	Less Important	55.7/99.1/77.2
LITIGATION COST	Important	" "	Very Important	56.4/414.4/77.2	Less Important	56.4/60.8/77.2
PUBLIC SERVICE	Important	" "	Very Important	56.4/99.1/61.6	Less Important	56.4/99.1/132.6

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.17c Rural Pipe Culvert w/Weighted Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Rural	46.4/81.5/63.5	–	–	–	–
REGION	High Plains	" "	Desert	54.5/49.4/59.0	Mtns	263.2/268.7/276.6
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	29.5/51.7/40.3	50	78.8/138.3/107.7
CHAN DEPTH	4.5	" "	7.5	102.2/179.5/139.8	2.5	19.1/33.5/26.1
FLDPLN SLOPE	0.03	" "	0.1	17.6/31.0/24.1	0.005	203.5/357.2/278.2
CHAN SLOPE	0.002	" "	0.01	79.8/140.0/109.1	0.0005	29.3/51.4/40.0
FLDPLN n	0.04	" "	0.06	51.4/90.1/70.2	0.02	39.1/68.6/53.4
CHAN n	0.035	" "	0.05	48.9/85.9/66.9	0.02	42.8/75.1/58.5
Basin Characteristics						
DRAINAGE AREA	350	" "	600	39.1/68.6/53.4	100	69.5/121.9/95.0
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	6.3/11.1/8.6	0.7	232.0/407.2/317.2
Structure and Road Characteristics						
NO LANES	2	" "	4	44.0/77.2/60.1	1	49.0/86.1/67.0
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	46.3/81.2/63.3	4(RCPA)	46.6/81.8/63.7
ROAD WIDTH	40	" "	60	44.5/78.2/60.9	20	49.9/87.5/68.2
EMB HEIGHT	16	" "	25	48.0/81.5/50.6	10	NC
PVMNT THICK	14.5	" "	20	45.8/80.3/62.6	8	47.6/83.6/65.1
SOIL COHSV	Low	" "	High	57.7/10103/78.9	None	71.8/126.0/98.1

Table A.3.17c Rural Pipe Culvert w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	39.7/69.6/54.2	0.02	60.9/106.8/83.2
DESIGN LIFE	50	" "	75	61.1/107.2/83.5	25	29.2/51.2/39.9
Property Characteristics						
NO. BLDGS	2	" "	5	48.2/84.5/65.8	0	45.3/79.5/61.9
BLDG VALUE	100	" "	200	50.0/87.7/68.3	50	44.7/78.6/61.2
BLDG ELEV	9	" "	15	45.8/80.4/62.6	5	46.8/82.2/64.0
IRRIGATED	No	" "	Yes	48.5/56.9/64.5	N/A	N/A
CROP TYPE	1	" "	1	NC	N/A	N/A
NO. FARM BLDGS	5	" "	10	46.5/81.7/63.6	0	46.3/81.3/63.3
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	51.8/71.1/57.1	5	35.9/63.1/49.1
REPAIR RATE	60.2	" "	200	43.5/76.4/59.5	30	48.2/84.6/65.9
MOB. TIME	15.2	" "	30	51.5/90.3/70.4	5	39.2/68.9/53.6
DETOUR SPEED	30	" "	60	28.7/50.4/39.3	15	75.4/132.4/103.1
ACCIDENT RATE	265	" "	400	55.0/96.5/75.2	100	31.2/54.7/42.6
ADT	1000	" "	10000	67.1/113.1/163.3	200	36.5/64.9/39.9
Cost Characteristics						
COST ADJ	1.32	" "	1.6	36.4/63.9/49.8	1	66.1/116.0/90.3
MOB COST	450	" "	2000	65.0/114.1/88.9	200	38.7/67.9/52.9
EMB COST	3	" "	6	39.7/69.7/54.3	1.5	54.3/95.3/74.2
UNIT PVMNT COST	40	" "	80	31.7/55.7/43.3	20	68.2/119.7/93.2
OCCUPANT COST	20	" "	40	61.8/108.4/84.4	10	35.0/61.4/47.8
DAMAGE COST	6250.6	" "	10000	54.5/95.8/74.6	3000	36.1/63.4/49.4

Table A.3.17c Rural Pipe Culvert w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increase Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	48.3/172.9/51.8	Less Important	45.9/48.0/48.4
MAINT. COST	Important	" "	Very Important	49.4/81.5/63.5	Less Important	45.8/81.5/63.5
LITIGATION COST	Important	" "	Very Important	46.4/340.9/63.5	Less Important	46.4/50.0/63.5
PUBLIC SERVICE	Important	" "	Very Important	46.4/81.5/50.6	Less Important	46.4/81.5/109.1

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.18a Urban Pipe Culverts w/Discrete LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	145.1	–	–	–	–
REGION	High Plains	" "	Desert	21.3	Mtns	102.9
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	62.2	50	386.9
CHAN DEPTH	4.5	" "	7.5	500	2.5	34.5
FLDPLN SLOPE	0.03	" "	0.1	47.2	0.005	500
CHAN SLOPE	0.002	" "	0.01	60.4	0.0005	309.8
FLDPLN n	0.04	" "	0.06	148	0.02	140.1
CHAN n	0.035	" "	0.05	168	0.02	115.3
Basin Characteristics						
DRAINAGE AREA	350	" "	600	154.1	100	126.1
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	39.4	0.7	392.2
Structure and Road Characteristics						
NO LANES	2	" "	4	82.7	1	254.9
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	142.3	4(RCPA)	147.8
ROAD WIDTH	40	" "	60	127	20	182.1
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	NC	8	NC
SOIL COHSV	Low	" "	High	179.8	None	223

Table A.3.18a Urban Pipe Culverts w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
	Base Value		Increased Variable		Decreased Variable	
Variable	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	* *	0.06	132.8	0.02	168.8
DESIGN LIFE	50	* *	75	173.1	25	107.3
Property Characteristics						
NO BLDGS	5	* *	15	219.2	1	123
BLDG VALUE	100	* *	200	182.3	50	129.4
BLDG ELEV	9	* *	15	140	5	148.6
Traffic Characteristics						
DETOUR LENGTH	15	* *	25	167	5	107.2
REPAIR RATE	60.2	* *	200	26.9	30	390.9
MOB. TIME	15.2	* *	30	182.5	5	99.7
DETOUR SPEED	30	* *	60	56	15	378.5
ACCIDENT RATE	265	* *	400	170.1	100	99.5
ADT	1000	* *	10000	359.7	200	77.1
Cost Characteristics						
COST ADJ	1.32	* *	1.6	74.1	1	384.1
MOB COST	450	* *	2000	319.3	200	94.6
EMB COST	3	* *	6	97.2	1.5	216.7
UNIT PVMNT COST	40	* *	80	77.1	20	273.7
OCCUPANT COST	20	* *	40	186.3	10	113
DAMAGE COST	6250.6	* *	10000	177.7	3000	105.7

Table A.3.18a Urban Pipe Culverts w/Discrete LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC
NC = No Change N/A = Not Applicable						

Table A.3.18b Urban Pipe Culvert w/Continuous LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	136.8	–	–	–	–
REGION	High Plains	" "	Desert	25.7	Mtns	101
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	56.3	50	383
CHAN DEPTH	4.5	" "	7.5	500	2.5	30.9
FLDPLN SLOPE	0.03	" "	0.1	43.3	0.005	500
CHAN SLOPE	0.002	" "	0.01	57.9	0.0005	288.1
FLDPLN n	0.04	" "	0.06	140.7	0.02	130.4
CHAN n	0.035	" "	0.05	152.1	0.02	110.2
Basin Characteristics						
DRAINAGE AREA	350	" "	600	146.4	100	116.8
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	34.5	0.7	392.6
Structure and Road Characteristics						
NO LANES	2	" "	4	81	1	231.4
COVER DEPTH	3	" "	5	95.7	1	296
CULV TYPE	3(CMP)	" "	2(RCP)	134.3	4(RCPA)	139.3
ROAD WIDTH	40	" "	60	NC	20	NC
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	131.7	8	146.8
SOIL COHSV	Low	" "	High	173.2	None	219.4

Table A.3.18b Urban Pipe Culvert w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	127.2	0.02	154.8
DESIGN LIFE	50	" "	75	165.3	25	99
Property Characteristics						
NO BLDGS	5	" "	15	235.1	1	110.2
BLDG VALUE	100	" "	200	176.6	50	120.4
BLDG ELEV	9	" "	15	133	5	139.4
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	160.1	5	97.6
REPAIR RATE	60.2	" "	200	25.8	30	365.3
MOB. TIME	15.2	" "	30	174.5	5	92
DETOUR SPEED	30	" "	60	54.3	15	347.2
ACCIDENT RATE	265	" "	400	161.8	100	92.1
ADT	1000	" "	10000	250.1	200	89.9
Cost Characteristics						
COST ADJ	1.32	" "	1.6	73.5	1	336.7
MOB COST	450	" "	2000	331.3	200	84.8
EMB COST	3	" "	6	92.9	1.5	201.7
UNIT PVMNT COST	40	" "	80	67.8	20	277
OCCUPANT COST	20	" "	40	179.3	10	104.4
DAMAGE COST	6250.6	" "	10000	168.3	3000	99.1

Table A.3.18b Urban Pipe Culvert w/Continuous LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change N/A = Not Applicable

Table A.3.18c Urban Pipe Culverts w/Weighted LTEC

Column 1	2	3	4	5	6	7
	Base Value		Increased Variable		Decreased Variable	
Variable	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Location, Region, and Structure Characteristics						
LOCATION	Urban	141.1	–	–	–	–
REGION	High Plains	" "	Desert	23.1	Mtns	101.8
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	59.3	50	385.1
CHAN DEPTH	4.5	" "	7.5	500	2.5	32.8
FLDPLN SLOPE	0.03	" "	0.1	45.3	0.005	500
CHAN SLOPE	0.002	" "	0.01	59.3	0.0005	299.5
FLDPLN n	0.04	" "	0.06	144.5	0.02	135.5
CHAN n	0.035	" "	0.05	162.8	0.02	112.9
Basin Characteristics						
DRAINAGE AREA	350	" "	600	150.5	100	121.7
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	37	0.7	392.4
Structure and Road Characteristics						
NO LANES	2	" "	4	81.9	1	243.6
COVER DEPTH	3	" "	5	119.4	1	202.3
CULV TYPE	3(CMP)	" "	2(RCP)	138.5	4(RCPA)	143.8
ROAD WIDTH	40	" "	60	131.5	20	159.3
EMB HEIGHT	16	" "	25	NC	10	NC
PVMNT THICK	14.5	" "	20	138.6	8	145.9
SOIL COHSV	Low	" "	High	176.7	None	221.3

Table A.3.18c Urban Pipe Culverts w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	130.2	0.02	162.1
DESIGN LIFE	50	" "	75	169.4	25	103.3
Property Characteristics						
NO BLDGS	5	" "	15	226.5	1	116.8
BLDG VALUE	100	" "	200	179.6	50	125.1
BLDG ELEV	9	" "	15	136.7	5	144.2
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	163.7	5	102.6
REPAIR RATE	60.2	" "	200	26.4	30	378.7
MOB. TIME	15.2	" "	30	178.7	5	96
DETOUR SPEED	30	" "	60	55.2	15	363.5
ACCIDENT RATE	265	" "	400	166.2	100	96
ADT	1000	" "	10000	303.6	200	82.8
Cost Characteristics						
COST ADJ	1.32	" "	1.6	73.9	1	361.2
MOB COST	450	" "	2000	324.9	200	89.9
EMB COST	3	" "	6	95.2	1.5	209.5
UNIT PVMNT COST	40	" "	80	72.6	20	275.2
OCCUPANT COST	20	" "	40	183	10	108.9
DAMAGE COST	6250.6	" "	10000	173.2	3000	102.5

Table A.3.18c Urban Pipe Culverts w/Weighted LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs	Variable Increase	Frequency, yrs	Variable Decrease	Frequency, yrs
Intangibles						
PROJECT COST	Important	" "	Very Important	NC	Less Important	NC
MAINT. COST	Important	" "	Very Important	NC	Less Important	NC
LITIGATION COST	Important	" "	Very Important	NC	Less Important	NC
PUBLIC SERVICE	Important	" "	Very Important	NC	Less Important	NC

NC = No Change N/A = Not Applicable

Table A.3.19a Urban Pipe Culvert w/Discrete Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	145.1/158.0/169.9	–	–	–	–
REGION	High Plains	" "	Desert	26.8/22.3/21.3	Mtns	217.8/111.5/148.7
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	62.2/67.7/72.8	50	387.1/421.3/453.2
CHAN DEPTH	4.5	" "	7.5	500.0/500.0/500.0	2.5	34.5/37.6/40.4
FLDPLN SLOPE	0.03	" "	0.1	47.2/51.4/55.2	0.005	500.0/500.0/500.0
CHAN SLOPE	0.002	" "	0.01	60.5/65.8/70.8	0.0005	309.9/337.4/362.9
FLDPLN n	0.04	" "	0.06	148.1/161.2/173.4	0.02	140.2/152.6/164.2
CHAN n	0.035	" "	0.05	1688.1/182.9/196.8	0.02	115.3/125.5/135.0
Basin Characteristics						
DRAINAGE AREA	350	" "	600	154.2/167.8/180.5	100	126.2/137.3/147.7
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	39.4/42.9/46.2	0.7	392.4/427.1/459.4
Structure and Road Characteristics						
NO LANES	2	" "	4	82.8/90.1/96.9	1	255.0/277.5/298.5
COVER DEPTH	3	" "	5	NC	1	NC
CULV TYPE	3(CMP)	" "	2(RCP)	142.4/155.0/166.7	4(RCPA)	147.9/161.0/173.2
ROAD WIDTH	40	" "	60	172.1/138.3/148.8	20	182.2/198.3/213.3
EMB HEIGHT	16	" "	25	145.1/145.7/197.5	10	NC
PVMNT THICK	14.5	" "	20	145.1/145.7/197.5	8	145.1/145.7/19735
SOIL COHSV	Low	" "	High	179.9/195.8/210.6	None	223.1/242.8/261.2

Table A.3.19a Urban Pipe Culvert w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	" "	0.06	132.8/144.6/155.5	0.02	168.9/183.8/197.7
DESIGN LIFE	50	" "	75	173.2/188.5/202.7	25	107.4/116.9/125.7
Property Characteristics						
NO BLDGS	5	" "	15	219.4/238.7/256.8	1	123.1/123.5/175.5
BLDG VALUE	100	" "	200	182.4/198.5/213.6	50	129.5/140.9/151.6
BLDG ELEV	9	" "	15	140.0/152.4/164.0	5	148.6/161.8/174.0
Traffic Characteristics						
DETOUR LENGTH	15	" "	25	167.0/181.9/251.0	5	107.3/116.7/125.6
REPAIR RATE	60.2	" "	200	26.9/29.3/31.5	30	391.1/425.6/457.9
MOB. TIME	15.2	" "	30	182.6/198.8/213.8	5	99.8/108.6/116.8
DETOUR SPEED	30	" "	60	56.0/60.9/65.6	15	378.1/412.2/443.4
ACCIDENT RATE	265	" "	400	170.2/185.3/199.3	100	99.6/108.4/116.6
ADT	1000	" "	10000	360.1/413.3/393.2	200	77.2/81.2/101.5
Cost Characteristics						
COST ADJ	1.32	" "	1.6	74.2/80.7/86.9	1	384.3/418.3/449.9
MOB COST	450	" "	2000	319.5/347.8/374.1	200	94.7/103.0/110.8
EMB COST	3	" "	6	97.3/105.9/113.9	1.5	216.8/235.9/253.8
UNIT PVMNT COST	40	" "	80	77.1/84.0/90.3	20	273.9/298.1/320.6
OCCUPANT COST	20	" "	40	186.4/202.8/218.2	10	113.1/123.1/132.4
DAMAGE COST	6250.6	" "	10000	177.8/193.5/208.2	3000	105.7/115.1/123.8

Table A.3.19a Urban Pipe Culvert w/Discrete Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	145.1/145.5/190.8	Less Important	145.1/149.0/158.6
MAINT. COST	Important	" "	Very Important	161.0/158.0/169.9	Less Important	NC
LITIGATION COST	Important	" "	Very Important	145.1/199.9/169.9	Less Important	145.1/160.6/169.9
PUBLIC SERVICE	Important	" "	Very Important	145.1/158.0/172.9	Less Important	145.5/158.0/377.0

NC = No Change   N/A = Not Applicable   *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.19b Urban Pipe Culvert w/Continuous Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	136.9/149.0/160.2	–	–	–	–
REGION	High Plains	" "	Desert	32.3/26.9/25.7	Mtns	213.9/109.5/146.0
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	56.3/61.3/65.9	50	383.2/417.1/448.7
CHAN DEPTH	4.5	" "	7.5	500.0/500.0/500.0	2.5	31.0/33.7/36.2
FLDPLN SLOPE	0.03	" "	0.1	43.3/47.2/50.7	0.005	500.0/500.0/500.0
CHAN SLOPE	0.002	" "	0.01	58.0/63.1/67.9	0.0005	288.2/313.7/337.5
FLDPLN n	0.04	" "	0.06	140.8/153.2/164.8	0.02	130.4/142.0/152.7
CHAN n	0.035	" "	0.05	157.1/171.0/184.0	0.02	110.2/120.0/129.0
Basin Characteristics						
DRAINAGE AREA	350	" "	600	146.5/159.5/171.5	100	116.9/127.2/136.8
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	34.5/37.5/40.4	0.7	392.8/427.6/459.9
Structure and Road Characteristics						
NO LANES	2	" "	4	81.1/88.2/94.9	1	231.5/252.0/271.1
COVER DEPTH	3	" "	5	95.7/104.2/112.1	1	296.1/322.3/346.7
CULV TYPE	3(CMP)	" "	2(RCP)	134.4/146.3/157.4	4(RCPA)	139.4/151.7/163.2
ROAD WIDTH	40	" "	60	136.9/149.0/160.2	20	NC
EMB HEIGHT	16	" "	25	136.8/137.4/186.3	10	NC
PVMNT THICK	14.5	" "	20	131.7/132.2/179.3	8	146.9/147.5/199.9
SOIL COHSV	Low	" "	High	173.3/188.6/202.9	None	219.5/238.9/257.0

Table A.3.19b Urban Pipe Culvert w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	* *	0.06	127.3/138.6/149.0	0.02	154.9/168.8/181.4
DESIGN LIFE	50	* *	75	165.4/180.1/193.7	25	99.0/107.8/116.0
Property Characteristics						
NO BLDGS	5	* *	15	235.2/256.1/275.5	1	110.3/110.7/157.3
BLDG VALUE	100	* *	200	176.7/192.3/206.9	50	120.5/131.1/141.0
BLDG ELEV	9	* *	15	133.1/144.9/155.8	5	139.4/151.8/163.3
Traffic Characteristics						
DETOUR LENGTH	15	* *	25	160.1/174.3/240.6	5	97.7/106.3/114.4
REPAIR RATE	60.2	* *	200	25.8/28.1/30.2	30	365.5/397.8/427.9
MOB. TIME	15.2	* *	30	174.5/190.0/204.41	5	92.0/100.2/107.8
DETOUR SPEED	30	* *	60	54.3/59.1/63.6	15	347.3/378.0/406.7
ACCIDENT RATE	265	* *	400	161.9/176.2/189.5	100	92.1/100.3/107.8
ADT	1000	* *	10000	250.4/287.4/273.4	200	89.9/94.6/118.2
Cost Characteristics						
COST ADJ	1.32	* *	1.6	73.6/80.1/86.1	1	336.9/366.7/394.4
MOB COST	450	* *	2000	331.5/360.8/388.1	200	84.8/92.3/99.3
EMB COST	3	* *	6	92.9/101.2/108.8	1.5	201.8/219.6/236.2
UNIT PVMNT COST	40	* *	80	67.8/73.8/79.4	20	277.2/301.7/324.5
OCCUPANT COST	20	* *	40	179.4/195.3/210.1	10	104.5/113.7/122.3
DAMAGE COST	6250.6	* *	10000	168.3/183.2/197.1	3000	99.1/107.9/116.0

Table A.3.19b Urban Pipe Culvert w/Continuous Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	136.8/137.2/180.0	Less Important	136.8/140.5/149.5
MAINT. COST	Important	" "	Very Important	151.8/149.0/160.2	Less Important	136.8/149.0/160.2
LITIGATION COST	Important	" "	Very Important	136.9/188.5/160.5	Less Important	136.9/151.5/160.2
PUBLIC SERVICE	Important	" "	Very Important	136.9/149.0/163.1	Less Important	136.9/149.0/355.5

NC = No Change N/A = Not Applicable *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.19c Urban Pipe Culvert w/Weighted Extended LTEC

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Location, Region, and Structure Characteristics						
LOCATION	Urban	141.2/153.7/165.3	--	--	--	--
REGION	High Plains	" "	Desert	29.1/24.2/23.1	Mtns	215.5/110.4/142.2
STRUCTURE	Culvert	" "	Culvert	NC	Culvert	NC
Channel Characteristics						
CHAN WIDTH	90	" "	150	59.4/64.6/69.5	50	385.3/419.3/154.1
CHAN DEPTH	4.5	" "	7.5	500.0/500.0/500.0	2.5	32.8/35.7/38.4
FLDPLN SLOPE	0.03	" "	0.1	45.3/49.3/53.1	0.005	500.0/500.0/500.0
CHAN SLOPE	0.002	" "	0.01	59.3/64.5/69.4	0.0005	299.3/326.1/350.8
FLDPLN n	0.04	" "	0.06	144.6/157.4/190.9	0.02	135.6/147.5/158.7
CHAN n	0.035	" "	0.05	162.9/177.3/190.7	0.02	112.9/122.9/132.2
Basin Characteristics						
DRAINAGE AREA	350	" "	600	150.5/163.8/176.2	100	121.7/132.5/142.5
PRECIP	12	" "	20	NC	6	NC
GEO FACTOR	1.1	" "	2	37.0/40.3/43.4	0.7	392.6/427.3/459.7
Structure and Road Characteristics						
NO LANES	2	" "	4	82.0/89.2/96.0	1	243.8/265.3/285.4
COVER DEPTH	3	" "	5	119.5/130.0/139.9	1	202.4/220.3/237.0
CULV TYPE	3(CMP)	" "	2(RCP)	138.6/150.9/162.3	4(RCPA)	143.9/156.6/168.4
ROAD WIDTH	40	" "	60	131.6/143.2/154.0	20	159.4/173.5/186.6
EMB HEIGHT	16	" "	25	141.2/141.8/192.2	10	NC
PVMNT THICK	14.5	" "	20	138.7/139.2/188.8	8	145.9/146.5/198.6
SOIL COHSV	Low	" "	High	176.8/192.4/207.0	None	221.4/241.0/259.2

Table A.3.19c Urban Pipe Culvert w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Economic Characteristics						
DISCOUNT RATE	0.04	**	0.06	130.2/1417/152.5	0.02	162.2/176.6/189.9
DESIGN LIFE	50	**	75	169.5/184.5/198.5	25	103.4/112.5/121.1
Property Characteristics						
NO BLDGS	5	**	15	226.6/246.7/265.4	1	117.0/117.3/166.8
BLDG VALUE	100	**	200	179.7/195.6/210.4	50	125.2/136.3/146.6
BLDG ELEV	9	**	15	136.7/148.8/160.1	5	144.3/157.0/168.9
Traffic Characteristics						
DETOUR LENGTH	15	**	25	163.8/178.3/246.1	5	102.7/111.7/120.2
REPAIR RATE	60.2	**	200	26.4/28.7/30.9	30	378.9/412.4/443.6
MOB. TIME	15.2	**	30	1785.8/194.6/209.3	5	96.1/104.6/112.5
DETOUR SPEED	30	**	60	55.2/60.1/64.6	15	363.7/395.9/425.9
ACCIDENT RATE	265	**	400	166.3/181.0/194.7	100	96.0/104.5/112.4
ADT	1000	**	10000	303.9/548.8/331.8	200	82.9/87.2/109.0
Cost Characteristics						
COST ADJ	1.32	**	1.6	73.9/80.4/86.5	1	361.4/393.3/423.1
MOB COST	450	**	2000	325.0/353.8/380.6	200	89.9/97.9/105.3
EMB COST	3	**	6	95.2/103.6/111.5	1.5	209.6/228.2/245.4
UNIT PVMNT COST	40	**	80	72.6/79.1/85.1	20	275.4/299.7/322.4
OCCUPANT COST	20	**	40	183.1/199.3/214.4	10	109.0/118.6/127.6
DAMAGE COST	6250.6	**	10000	176.3188.7202.9	3000	102.6/111.7/120.1

Table A.3.19c Urban Pipe Culvert w/Weighted Extended LTEC (Continued)

Column 1	2	3	4	5	6	7
Variable	Base Value		Increased Variable		Decreased Variable	
	Value	Frequency, yrs*	Variable Increase	Frequency, yrs*	Variable Decrease	Frequency, yrs*
Intangibles						
PROJECT COST	Important	" "	Very Important	141.1/141.6/185.7	Less Important	141.1/144.9/154.3
MAINT. COST	Important	" "	Very Important	156.6/153.7/165.3	Less Important	NC
LITIGATION COST	Important	" "	Very Important	141.2/194.5/165.3	Less Important	141.2/156.3/165.3
PUBLIC SERVICE	Important	" "	Very Important	141.2/153.7/168.3	Less Important	141.2/153.7/366.8

NC = No Change   N/A = Not Applicable   *Maint Freq/Litigation Freq/Public Service Freq

Table A.3.20 shows the relative sensitivity of the variables influencing the LTEC and Extended LTEC design flood frequency.

Table A.3.20 Apparent Variable Sensitivity

Locale	Rural Bridge						Urban Bridge						Rural Pipe						Urban Pipe					
LTEC or Extended LTEC	LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC		
Table A.3.N Key: ● Variance > 15 ○ Variance 10-15 — Variance < 10	12a	12b	12c	13a	13b	13c	14a	14b	14c	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c	19a	19b	19c
Variable																								
Region	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Chan Width	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Chan Depth	●	●	●	●	●	●	—	—	—	—	—	—	●	●	●	●	●	●	●	●	●	●	●	●
Floodplain Slope	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Chan Slope	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Floodplain n	●	●	●	●	●	●	○	○	○	●	●	●	○	○	○	○	●	●	—	○	—	—	○	●
Chan n	●	●	●	●	●	●	—	—	—	—	○	—	—	—	—	—	—	○	●	●	●	●	●	●
Drainage Area	●	●	●	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Precip	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Geo Factor	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
No Lanes	—	—	—	—	—	—	—	○	—	—	●	○	—	—	—	○	—	○	●	●	●	●	●	●
Pier Width	●	●	●	●	●	●	○	●	●	●	●	●												
Deck Width	—	—	—	—	—	—	—	—	—	—	—	—												
Emb Height	—	—	—	—	—	—	—	—	—	●	●	●	—	—	—	—	—	—	—	—	—	●	●	●
Pvmnt Thck	●	●	●	●	●	●	●	●	●	●	●	●	—	—	—	—	—	—	—	●	—	●	●	●
Soil Cohesive	—	—	—	—	—	—	●	●	●	●	●	●	○	●	○	●	●	●	●	●	●	●	●	●
Cover Depth													—	—	—	—	—	—	—	●	●	—	●	●
Culvert Type													—	—	—	—	—	—	—	—	—	—	—	—
Road Width													—	—	—	●	—	—	●	—	●	●	●	●
Discnt Rate	—	—	—	—	—	—	—	—	—	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●

Table A.3.20 Apparent Variable Sensitivity (Continued)

Locale	Rural Bridge						Urban Bridge						Rural Pipe						Urban Pipe					
LTEC or Extended LTEC	LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC		
Table A.3.N Key: ● Variance > 15 ○ Variance 10-15 — Variance < 10	12a	12b	12c	13a	13b	13c	14a	14b	14c	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c	19a	19b	19c
Dsgn Life	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
No Bldgs	—	—	—	—	—	—	●	●	●	●	●	●	—	—	—	—	—	—	●	●	●	●	●	●
Bldg Value	●	●	●	●	●	●	—	—	—	○	●	●	—	—	—	—	○	—	●	●	●	●	●	●
Bldg Elev	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	—	—
Irrigated	—	—	—	—	—	—							—	—	—	○	●	●						
Crop Type																								
No. Farm Bldgs	—	—	—	—	—	—							—	—	—	—	—	—						
Detour Length	—	—	—	—	—	—	●	●	●	●	●	●	○	●	●	○	●	●	●	●	●	●	●	●
Repair Rate	○	○	○	●	○	○	●	○	○	●	●	●	—	—	—	○	—	—	●	●	●	●	●	●
Mob Time	●	○	○	●	○	●	●	●	●	●	●	●	—	●	○	●	●	●	●	●	●	●	●	●
Detour Speed	—	—	—	—	—	—	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Accident Rate	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ADT	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Cost Adj	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Mob Cost	●	●	●	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
EMB Cost	●	●	●	●	●	●	●	●	●	●	●	●	○	●	○	●	●	●	●	●	●	●	●	●
Unit Brdg Cost	●	●	●	●	●	●	○	○	○	●	●	●												
Unit Pymnt Cost	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Occupant Cost	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Damage Cost	—	—	—	○	—	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table A.3.20 Apparent Variable Sensitivity (Continued)

Locale	Rural Bridge						Urban Bridge						Rural Pipe						Urban Pipe					
LTEC or Extended LTEC	LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC			LTEC			ELTEC		
Table A.3.N Key: ● Variance > 15 ○ Variance 10-15 — Variance < 10	12a	12b	12c	13a	13b	13c	14a	14b	14c	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c	19a	19b	19c
Project Cost				●	●	●				●	●	●				●	●	●				●	●	●
Maint Cost				—	—	—				●	●	●				—	—	—				—	—	—
Litigat Cost				—	—	—				—	—	—				●	●	●				●	●	●
Public Service				—	—	—				—	—	—				●	●	●				●	●	●

A.3.5 APPLICATION OF RESEARCH FINDINGS AND POLICY EXAMPLE

The user may elect to implement this research in several ways.

- Estimate an LTEC or Extended LTEC design frequency using a site specific alternative
- Use DSGNFREQ.FOR to generate data from which policy criteria can be formulated for routine application
- Employ a combination of these two methods

The site specific approach was illustrated with the foregoing five examples. A combined method would use a policy devised from evaluating numerous combinations of site variables such as was illustrated in Table A.3.10 through Table A.3.20 for routine sites coupled with a site specific analysis at very sensitive sites. Using the findings in these tables along with the results of the foregoing sensitivity analysis, a procedure for converting these research findings into a policy forth routine application was explored. These findings are set forth below for one particular hydrologic region (plains); as noted in the previous section, the findings in this section are also based on an earlier version of DGNFREQ.FOR and thus only illustrate what might be done to devise a policy based on this research. For this reason, the design flood frequency values found in the sample policy of Tables A.3.21a - *l* are only for illustration purposes. Using the current version of DSGNFREQ.FOR would probably result in very different but more reliable values.

This procedure attempts to devise a defensible policy for use in routinely selecting a design flood frequency so as to avoid or minimize the subjectivity currently present in most transportation department policies. This procedure is one possible approach for coupling the findings from DSGNFREQ.FOR and the foregoing sensitivity analysis so as to provide some defensible support for the design flood frequencies placed in a policy.

Table A.3.21a-*l* illustrates one example of how the sensitivity findings from DSGNFREQ.FOR were used to devise a sample policy for routine use in a particular hydrologic region (plains region in this instance). This was done for six types of highways.

- Rural Collectors
- Rural Minor Arterial
- Rural Minor Arterial -- Multilane

- Rural Principle Arterial -- Interstate
- Urban Arterial
- Urban Principle Arterial -- Interstate

For comparison purposes the traditional, LTEC, Extended LTEC (ELTEC), and Example Policy (EXP) flood frequencies for the plains hydrologic region are provided in Table A.3.21a-*l*; i.e., in a policy the traditional, LTEC, and ELTEC frequencies would be omitted and only the EXP frequencies provided. Table A.3.21a-*l* attempts to present a consensus of the findings in Table A.3.11a-c while still recognizing traditional values in a conservative manner. Several arbitrary guidelines were used in formulating Table A.3.21a-*l* which suggests how they might be used.

- For LTEC and ELTEC frequencies *greater* than 100 years the traditional 100-year regulatory flood frequency was selected

- For LTEC and ELTEC frequencies *less* than the traditional values the traditional value was selected

- For sites having an unusual traffic related hazard due to flood related accidents and with no significant property related flood hazard, the Example (EXP) values from the first table (Tables A.3.21a, c, e, etc) might be more appropriate for a particular road class

- For sites having significant property related flood hazard, the EXP values from the second table (Tables A.3.21b, d, f, etc) might be more appropriate for a particular road class

- The Minimum [LTEC] EXP value from the first table applies where there are no unusual flood related traffic hazards

- Where there is judged to be an unusual flood related traffic hazard, the applicable EXP value is obtained from the "Other Considerations (Litigation)" values by using (1) the smaller value for low ADTs (perhaps 50 or less) and the corresponding larger value for high ADTs (perhaps 750 or more) to reflect the increased potential for flood related traffic accidents, and (2) straight line interpolating for ADT values between these limits rounded to say the next highest 5 or 10 years

- After determining which table applies for a particular road class, the "Minimum [LTEC]" EXP value would apply unless there was a real concern regarding maintenance, litigation as discussed above, or public service in which case the larger of the "Minimum [LTEC]" EXP or "Other Considerations [ELTEC]" EXP values would apply

- Weighted values were used rather than the continuous or discrete values

The following tables are for comparison purposes only and show the values for the traditional design flood frequencies as well as the LTEC and ELTEC frequencies. Again, these would not appear in a policy statement as only the four columns of EXP values need be shown.

RURAL COLLECTORS

Table A.3.21a -- No Potentially Significant Property Flood Hazards Due To the Road

Drainage Struct	Design Flood Frequency Standard, RI in Yrs									
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)						
		LTEC	EXP	Maintenance		Litigation		Public Service		
				ELTEC	EXP	ELTEC	EXP*	ELTEC	EXP
Small Culvert	10	49.4	50	50.1	50	83.7	50-85	50.1	55
Moderate Culvert	10	13.7	15	13.9	15	23.2	15-25	13.9	15
Large Culvert	10	1.2	10	1.3	10	500	10-100	1.3	5
V. Large Culvert	25	1.1	10	1.1	10	500	10-100	1.1	5
Bridge	25	1.6	10	2.1	10	3.2	10-100	2.1	5

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21b -- Potentially Significant Property Flood Hazards Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	LTEC		Extended LTEC					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP	LTEC	EXP
Small Culvert	10 Highway 100 Prop	49.4	50	50.1	50	83.7	100	55.2	55
Moderate Culvert	10 Highway 100 Prop	13.7	15	13.9	15	23.2	100	15.3	15
Large Culvert	10 Highway 100 Prop	1.2	10	1.3	5	500	100	4.2	5
V. Large Culvert	25 Highway 100 Prop	1.1	10	1.1	5	500	100	3.8	5
Bridge	25 Highway 100 Prop	1.6	10	2.1	5	3.2	100	2.9	5

Table A.3.21c -- No Potentially Significant Property Flood Hazards Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	LTEC		Extended LTEC					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	10	153	100	155	100	500	100	211	200
Moderate Culvert	10	38.1	40	43.7	45	64.7	40-65	56.7	55
Large Culvert	10	10.3	10	12.3	10	10.3	10	33.2	35
V. Large Culvert	25	2.7	10	2.8	5	500	10-100	8.5	10
Bridge	25	4.2	10	4.6	5	8.3	10	19.1	20

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21d -- Potentially Significant Property Flood Hazards Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	LTEC		Extended LTEC					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP	LTEC	EXP
Small Culvert	10 Highway 100 Prop	153	100	155	100	500	100	211	200
Moderate Culvert	10 Highway 100 Prop	38.1	40	43.7	45	64.7	100	56.7	55
Large Culvert	10 Highway 100 Prop	10.3	10	12.3	10	10.3	100	33.2	35
V. Large Culvert	25 Highway 100 Prop	2.7	5	2.8	5	500	100	8.5	10
Bridge	25 Highway 100 Prop	4.2	5	4.6	5	8.3	100	19.1	20

RURAL MINOR ARTERIAL -- MULTI-LANE

Table A.3.21e -- No Potentially Significant Property Flood Hazards Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs									
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)						
		LTEC	EXP	Maintenance		Litigation		Public Service		
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	25	161	100	169	100	272	100	182	100
Moderate Culvert	25	42.8	45	49.1	50	72.5	45-75	63.6	65
Large Culvert	25	2.7	25	2.7	5	500	25-100	8.2	10
V. Large Culvert	25	1.6	25	2.0	5	500	25-100	6.0	10
Bridge	25	8.6	25	8.3	10	14.8	15-25	34.2	35

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21f -- Potentially Significant Property Flood Hazard Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	25 Highway 100 Prop	161	100	169	100	500	100	182	100
Moderate Culvert	25 Highway 100 Prop	42.8	45	49.1	50	312	100	63.6	65
Large Culvert	25 Highway 100 Prop	2.7	25	2.7	5	12.4	100	8.2	10
V. Large Culvert	25 Highway 100 Prop	1.6	25	2.0	5	4.8	100	6.0	10
Bridge	25 Highway 100 Prop	8.6	25	8.3	10	13.4	100	34.2	35

Table A.3.21g -- No Potentially Significant Property Flood Hazard Due To The Road

Drainage Struct	Design Flood Frequency Standard, RI in Yrs									
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)						
		LTEC	EXP	Maintenance		Litigation		Public Service		
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	50	186	100	195.7	100	500	100	477	100
Moderate Culvert	50	46.4	50	69.7	70	312	50-100	138	100
Large Culvert	50	12.4	50	500	100	12.4	15-50	500	100
V. Large Culvert	50	3.0	50	35.1	35	4.8	5-50	500	100
Bridge	50	8.5	50	8.8	10	13.4	15-50	38.3	40

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21h -- Potentially Significant Property Flood Hazard Due To The Road

Drainage Struct	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP	LTEC	EXP
Small Culvert	50 Highway 100 Prop	186	100	195.7	100	500	100	477	100
Moderate Culvert	50 Highway 100 Prop	46.4	50	69.7	70	312	100	138	100
Large Culvert	50 Highway 100 Prop	12.4	50	500	100	100	100	500	100
V. Large Culvert	50 Highway 100 Prop	3.0	50	35.1	35	4.8	100	500	100
Bridge	50 highway 100 Prop	8.5	50	8.8	10	13.4	100	38.3	40

Table A.3.21i -- No Potentially Significant Property Flood Hazard Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	50	9.6	50	9.7	10	9.7	10-50	11.2	15
Moderate Culvert	50	5.7	50	5.7	5	5.9	5-50	6.2	5
Large Culvert	50	22.0	50	23.6	25	73.9	50-75	23.1	25
V. Large Culvert	50	28.5	50	29.4	30	47.0	50	32.6	35
Bridge	50	3.2	50	7.3	10	4.5	5-50	7.9	10

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21j -- Potentially Significant Property Flood Hazard Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP	LTEC	EXP
Small Culvert	50 Highway 100 Prop	9.6	50	9.7	10	9.7	100	11.2	15
Moderate Culvert	50 Highway 100 Prop	5.7	50	5.7	5	5.9	100	6.2	5
Large Culvert	50 Highway 100 Prop	22.0	50	23.6	25	73.9	100	23.1	25
V. Large Culvert	50 Highway 100 Prop	28.5	50	29.4	30	47.0	100	32.6	35
Bridge	50 Highway 100 Prop	3.2	50	7.3	10	4.5	100	7.9	10

Table A.3.21k -- No Potentially Significant Property Flood Hazard Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	50	10.1	50	10.1	10	13.9	15-50	10.8	10
Moderate Culvert	50	5.9	50	5.9	5	9.6	10-50	6.1	5
Large Culvert	50	40.1	50	43.1	45	134	50-100	49.1	50
V. Large Culvert	50	63.4	50	68.0	70	213	50-100	77.5	80
Bridge	50	3.4	50	7.8	10	4.9	5-50	6.1	5

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Table A.3.21*l* -- Potentially Significant Property Flood Hazard Due To The Road

Drainage Structure	Design Flood Frequency Standard, RI in Yrs								
	Traditional	Minimum (LTEC)		Other Considerations (Extended LTEC)					
		LTEC	EXP	Maintenance		Litigation		Public Service	
				ELTEC	EXP	ELTEC	EXP*	LTEC	EXP
Small Culvert	50 Highway 100 Prop	10.1	50	10.1	10	13.9	100	10.8	10
Moderate Culvert	50 Highway 100 Prop	5.9	50	5.9	5	9.6	100	6.1	5
Large Culvert	50 Highway 100 Prop	40.1	50	43.1	45	134	100	49.1	50
V. Large Culvert	50 Highway 100 Prop	63.4	50	68.0	70	213	100	77.5	80
Bridge	50 Highway 100 Prop	3.4	50	7.8	10	4.9	100	6.1	5

* Design Flood Frequency rounded to next highest 5 years for ADT's ranging from 0-750 VPD. Use maximum for ADT's of 750 or larger.

Any design values selected from the Tables A.3.21a-*l* are based on very general averages of only a few of the significant variables identified in Table A.3.20. Indirectly Tables A.3.21a-*l* makes some provision for changes in certain variables such as hydrologic region, drainage area, geographic factor, number of lanes, road width, and ADT. However, there are other variables not included in Tables A.3.21a-*l*, directly or indirectly, that may influence a selected design value. General guidance such as might be provided by Table A.3.20 and Table A.3.22 below could be used to decide whether a variable should be increased or decreased some arbitrary amount where a site specific variable is judged as being above the norm. If a variable in Table A.3.22 is judged as being below the norm, the adjustment would, of course, be reversed from that shown in Table A.3.22. Note, in some instances a particular variable might have to either increase or decrease the norm. In these instances the variable was omitted from Table A.3.22.

Table A.3.22 -- Design Frequency Adjustment for Variables Exceeding the Norm[1]

Variable	Locale				Adjust[1]	
	Rural		Urban			
	BRDG/RCB	Pipe Culv	BRDG/RCB	Pipe Culv	+	—
PIER WIDTH	•		•		•	
DISCNT RATE		•		•		•
DSGN LIFE	•	•	•	•	•	
NO BLDGS (OR RES)			•	•	•	
BLDG VALUE	•		•	•	•	
DETOUR LENGTH		•	•	•	•	
REPAIR RATE	•		•	•		•
MOB TIME	•	•	•	•	•	
DETOUR SPEED		•	•	•		•
ACCIDENT RATE	•	•	•	•	•	
COST ADJ	•	•	•	•		•
MOB COST	•	•	•	•	•	
EMB COST	•	•	•	•		•
UNIT BRDG COST	•		•			•
OCCUPANT COST	•	•	•	•	•	
DAMAGE COST		•	•	•	•	

[1] Increase (+) or decrease (-) if a site specific variable is above the norm; reverse these adjustments if below the norm.

Table A.3.20 reflects the findings from a sensitivity analysis for a range of site conditions in only one of three hydrologic regions (plains) found in Wyoming. In comparing these findings to the more traditional recurrence interval (RI) found in WTD Operating Policy 18-6 it was possible to assess whether these traditional RI values were too low (L), too high (H), or reasonable (R). This assessment for the plains hydrologic region is shown in Table A.2.23 for five general drainage structure sizes, four site specific considerations, six road classes, and two predominate types of flood related hazards.

Table A.3.23 -- Trend of Traditional Recurrence Interval (RI) -- Plains Region

Drainage Structure	Consideration	Traffic Hazard Concerns*						Property Hazard Concerns*					
		Rural Collector	Rural Minor Arterial	Rural Minor Arterial (Multi-lane)	Rural Principle Arterial (Interstate)	Urban Arterial	Urban Principle Arterial (Interstate)	Rural Collector	Rural Minor Arterial	Rural Minor Arterial (Multi-lane)	Rural Principle Arterial (Interstate)	Urban Arterial	Urban Principle Arterial (Interstate)
Smaller Culverts	Minimum	L	L	L	L	H	H	L	L	L	L	H	H
	Maint	L	L	L	L	H	H	L	L	L	L	H	H
	Litigation	L	L	L	L	H	H	L	L	L	L	H	H
	Public Svc	L	L	L	L	H	H	L	L	L	L	H	H
Moderate Culverts	Minimum	R	L	L	L	H	H	R	L	L	L	H	H
	Maint	R	L	L	L	H	H	R	L	L	L	H	H
	Litigation	L	L	L	L	H	H	H	H	L	L	H	H
	Public Svc	R	L	L	L	H	H	L	L	L	L	H	H
Large Culverts	Minimum	H	R	H	H	H	H	H	R	H	H	H	H
	Maint	H	R	H	L	H	H	H	R	L	L	H	H
	Litigation	L	R	L	H	L	L	L	H	H	R	H	L
	Public Svc	H	L	H	L	H	R	H	L	H	L	H	R
V. Large Culverts	Minimum	H	H	H	H	H	L	H	H	H	H	H	L
	Maint	H	H	H	H	H	L	H	H	H	H	H	L
	Litigation	L	L	L	H	R	L	L	L	H	H	H	L
	Public Svc	H	H	H	L	H	L	H	R	H	L	H	L

Table A.3.23 -- Trend of Traditional Recurrence Interval (RI) -- Plains Region (Continued)

Drainage Structure	Consideration	Traffic Hazard Concerns*						Property Hazard Concerns*					
		Rural Collector	Rural Minor Arterial	Rural Minor Arterial (Multi-lane)	Rural Principle Arterial (Interstate)	Urban Arterial	Urban Principle Arterial (Interstate)	Rural Collector	Rural Minor Arterial	Rural Minor Arterial (Multi-lane)	Rural Principle Arterial (Interstate)	Urban Arterial	Urban Principle Arterial (Interstate)
Bridges	Minimum	H	H	H	H	H	H	H	H	H	H	H	H
	Maint	H	H	H	H	H	H	H	H	H	H	H	H
	Litigation	H	H	H	H	H	H	H	H	H	H	H	H
	Public Svc	H	H	L	H	H	H	H	H	L	H	H	H

* Key L = Traditional RI is too low
R = Traditional RI is reasonable
H = Traditional RI is too high