ing treatments for erosion control, have been developed as operational tools for Forest Service preconstruction engineers. Good progress has been made on estimating runoff and sediment yield for selected road surface treatments for the granitic materials of the Idaho Batholith. Measurements are for roadway surfaces only; contributions from cut slopes, fills, and ditches (with one exception--plot 4) are not included.

The research studies outlined in this paper represent a reasonable approach to developing a method for estimating surface erosion from forest roads and for predicting the cost of erosion-control treatments. Infiltrometer tests supplemented with data from continuously monitored road sections should provide sufficient information to achieve research objectives.

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Opinion Survey for Selection of Low-Water Crossing Structures

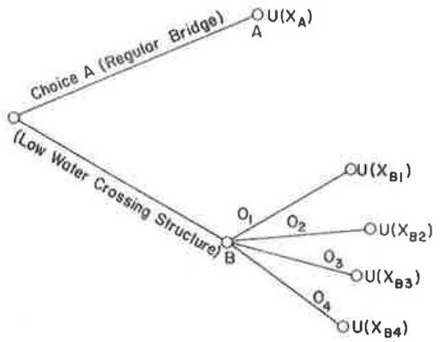
HSIEH WEN SHEN

The low-water crossing structure (LWCS) frequently represents a significant financial saving, although these structures may be overtopped and damaged by floods. Thus, decisionmakers are hesitant to build them. Currently, there is no guide on the selection of the LWCS. Consequently, a public opinion survey was conducted and the results are presented to serve as a useful guide for the selection of the type of structure to build. About 60 responses (36 detailed, 24 brief) from the United States and 3 responses from Canada were received and analyzed. The most important tangible factors (in order of importance) are possible damage to human life, average daily traffic (ADT), frequency of possible flooding, legal considerations, and location as part of an emergency route. Availability of an alternate route, duration of traffic interruptions, and possible property damage form the second most important group of factors. There is no difference of opinion among different regions of the country. For a 28 percent saving of total tangible costs, decisionmakers would consider the LWCS. The desirable conditions are less than 5 ADT, average annual flooding frequency less than 2, good hydrologic analysis, average duration of traffic interruption less than 24 h, not more than 60 min of travel by alternate route, chance of having a human life involved less than 1 in 1 billion, and an excellent warning system. A set of absolute constraints below which no LWCS would be considered was also obtained. It must be emphasized that each decisionmaker must use his or her judgment to decide on which type of structure to build for each location, and there can never be any rigid rule to be followed. Ultimately, the decisionmaker must evaluate all the tangible and intangible factors involved for a given case to make the selection of the structure to build. The method must be chosen, the analysis conducted, and the decision made. Defense of the decision may also be required.

The first purpose of this study is to collect, summarize, and analyze information from different regions of the United States and Canada regarding the use of the low-water crossing structure (LWCS). The second purpose is to develop a simple decision model to assist highway engineers in the selection of either an LWCS or a regular bridge.

The LWCS is a structure designed to carry traffic across a stream. It is different from the regular bridge, which is designed to span above anticipated floods with rather long return periods and thus is

Figure 1. Decision model.



not expected to be interrupted by floods. Traffic over the LWCS may be interrupted by relatively frequent flooding. A major purpose of this study is to determine the allowable annual flood interruption. Examples of the LWCS include fords, vented fords, and low-water bridges. Fords (or dips) are roadways that carry traffic across ephemeral streams during dry seasons. Usually the highest point of a ford is lower than the approach road to allow the passage of occasional stream flows over the ford. Vented fords are fords with culverts so that low stream flows can be carried through the fords by the culverts. Occasionally, stream flows can pass over the fords, which causes traffic to be interrupted. Low-water bridges are small bridges that carry traffic when stream flows are low or nonexistent. Occasionally, stream flows can reach the low-water bridge decks and can interrupt traffic.

A general discussion of the LWCS is provided first. The next section describes the method of approach. Then a simple analysis of the questionnaire and the resultant simple decision model are presented, followed by a summary of this study.

GENERAL DISCUSSION

The LWCS has been used extensively at locations of low traffic volume and infrequent flooding. They are usually built for the financial saving over regular high bridges. The selection of LWCS involves a great many calculated risks. The tangible cost factors such as capital costs, maintenance, flooding damage, removal of debris and sediment, increase of travel time, and others are possible to estimate. However, the intangible factors such as social, legal, political, and other factors are difficult to assess. There is no doubt that a regular high bridge would be selected in each case if the total tangible costs of an LWCS are close to the total tangible costs of a regular high bridge.

Each decisionmaker must use his or her judgment to decide which type of structure to build for each individual location, and there can never be any rigid rule to be followed. Ultimately, the decisionmaker must evaluate all the tangible and intangible factors involved to make the selection of the structure to build. The method must be chosen, the analysis conducted, and the decision made. Defense of the decision may also be required.

The purpose of this study is to investigate under what conditions one would consider selecting an LWCS rather than a regular high bridge. After discussions with the staffs from various state and federal agencies and after a search of the existing literature, there does not appear to be any available guide for the selection of an LWCS. Thus, an attempt was made to search for a guide through an opinion survey of staffs from county, state, and federal agencies.

METHOD OF APPROACH

There is only a limited number of approaches one can explore for the evaluation of intangible factors. One may (a) identify the opinions of a large number of experts through the Delphi method, (b) determine one or more subjective rating systems through discussion by a panel of specialists, (c) employ a surrogate-worth trade-off method (1), (d) evaluate both the relative and absolute values of the ratio between tangible (monetary) and intangible (nonmonetary) benefits (2), and (e) determine the relative ranking of each intangible factor through comparison (3, p. 16).

Since the selection of the LWCS is a subject that has never been analyzed, it would be extremely useful to secure the opinions of decisionmakers. Knowledge of their opinions may form a basis for further analysis. Thus, a relatively extensive public opinion survey was conducted to search for the opinions of decisionmakers from various county, state, and federal agencies. More than 200 questionnaires were sent and more than 50 replies were obtained.

The method of approach adopted contains three steps: (a) to seek the opinions of decisionmakers through a questionnaire; (b) to discuss preliminary results of the questionnaire with a group of specialists through a presentation at Fort Collins, Colorado, on August 6, 1981, to the Technical Committee on Hydrology, Hydraulics, and Water Quality of the Transportation Research Board; and (c) to analyze and summarize the results.

ANALYSIS OF QUESTIONNAIRE

Decision Model

In order to develop a simple and effective model, it is proposed to use the costs of various types of LWCS and of the regular bridge as inputs to this model. How to evaluate the different types of costs is not included in this study. Computations of economic losses due to loss of pavement and embankment; interruption of normal traffic flow; damage to surrounding property due to backwater; and structural damage, including scouring of foundations, are described by Tseng, Knepp, and Schmalz (4); Schneider and Wilson (5); and Corry, Jones, and Thompson (6).

Highway engineers often have two choices of structure to carry traffic over a stream: a regular bridge or an LWCS. This is illustrated in Figure 1. Of course, even a regular high bridge may be subject to flooding, either because of a wrong estimation of flood magnitude or because of floods with greater magnitude than the design value. The tangible factors that cause these damages should be included in the value of $U(X_A)$. The intangible factors can be analyzed the same way as they are for the LWCS.

The engineers may choose A for a regular bridge to reach point A. Let us assume that this regular bridge will not fail and that the total tangible cost (including construction, maintenance, etc.) of the bridge is $U(X_A)$. In this case, there is no uncertainty. Let O_i be the probability for the occurrence of certain floods with magnitudes falling within a certain range and let $U(X_{Bi})$ be the total tangible cost (including construction, maintenance, traffic delay, damage to surroundings, repairs, etc.) to this particular selected LWCS when floods within a certain range of magnitude occur (corresponding to the probability of O_i). All of these tangible costs can be calculated as the total tangible cost within a selected time period, say 50 years, and amortized to the first year for easy comparison.

Now, the expected total tangible cost for the selection of A (a regular bridge) is $U(X_A)$ and the expected total tangible cost for the selection of B (an LWCS) is

$$\sum_i O_i U(X_{Bi}) \quad (1)$$

Let us define a variable q to be the ratio between the two expected tangible costs as follows:

$$q = \sum_i O_i U(X_{Bi})/U(X_A) \quad (2)$$

Technically, if all costs are properly calculated in the function of U, one should choose B (an LWCS) if q is less than 1. Calculation of tangible costs can easily be done through accepted procedures; however, the intangible costs are difficult to determine, since there are no set procedures to follow. Let us assume that the cost function U includes only tangible costs and we shall use an opinion survey from decisionmakers to estimate the intangible costs.

The following is an example of selection of q, the preference index. If decisionmaker A typically does not want to use an LWCS, it will be selected if and only if the tangible cost of an LWCS is less than 10 percent of the tangible cost of a regular bridge. In this case,

$$q_1 = \sum_i O_i U(X_{Bi})/U(X_A) = 0.1 \quad (3)$$

If decisionmaker B typically does want to use an LWCS more than decisionmaker A, an LWCS will be selected if the tangible cost of an LWCS is less than 50 percent of the tangible cost of a regular bridge. In this second case,

$$q_2 = \sum_i O_i U(X_{Bi})/U(X_A) = 0.5 \quad (4)$$

From the above two cases, it is clear that the greater the value of q, the higher the preference for the LWCS. Furthermore, if a decisionmaker assigns 0 as the value of q, it would indicate that the LWCS would not be chosen regardless of the amount of cost savings. On the other hand, a q-value of 1 would indicate that all the intangible costs of an LWCS have been ignored. Thus, the value of q should vary between 0 and 1. The value of q can be treated as a preference index.

Relative Importance of Intangible Factors

We all realize that intangible factors are difficult to evaluate, and many of them are highly interrelated. However, an attempt was made to rate their relative importance based on subjective opinions. A rating scale was set between 0 and 10; 10 was the most important factor. One may assign a value of 10 to more than one of the factors. Decisionmakers were asked to rate, not to rank, these factors. All those who returned the questionnaire answered this section. The results are given below:

Factor	Avg Rating
Possible damage to human life	9.5
Amount of traffic per day	9.2
Frequency of possible flooding	8.6
Legal considerations	8.3
Use as emergency route	8.1
Availability of alternate route	7.8
Duration of traffic interruption	7.6
Possible property damage	7.3
Availability of funding	6.0
Social considerations	6.0
Availability of future funding	5.3
Availability of reliable warning system	5.3
Political considerations	5.2
Characteristics of structure (dimension)	5.1
Characteristics of flooding over structure	4.3
Uncertainty in estimating flooding	3.5

According to these results, the most important factors include damage to human life, amount of daily traffic, frequency of possible flooding, legal considerations, and use as an emergency route. Availability of an alternate route, duration of traffic interruption, and possible property damage form the second most important group. All the other factors are of less importance than those above. Although uncertainty in estimating flooding was rated the least important factor in this section, its significance cannot be ignored, as will be discussed in a later section of this paper.

Absolute Constraints for Not Building LWCS

The absolute constraints for not building an LWCS are used under the condition that funding is available for a regular bridge. Otherwise, if an LWCS is the only alternative, these constraints would not apply.

It is generally agreed that the LWCS should not be used under the following conditions: possible damage to human life, heavy traffic over the structure, location subject to frequent flooding, alternate route unavailable, and legal and other constraints.

The purposes of this section are to quantify these constraints and to investigate the flexibility of decisionmakers to change these constraints according to opinions expressed by others.

It was found that about two-thirds of the respondents chose not to answer this section. Among those who answered, there was a great diversity of opinion. As discussed by the Committee on Hydrology, Hydraulics, and Water Quality of the Transportation Research Board, respondents are hesitant to define a set of absolute constraints.

The following are the results for this section on possible absolute constraints for not using an LWCS (from a rather limited number of responses):

1. Possible damage to human life: The vote was 18 to 2 in favor of the following statement: "From my best estimate, there is no chance of loss of human life. However, there always exists the unforeseen possibility that I may be wrong. In this case, I would still consider the possibility of using an LWCS."
2. Amount of traffic (only five responses to this question): (a) Average daily traffic (ADT) less than 10, (b) average weekly traffic less than 38, and (c) maximum daily traffic less than 25.
3. Frequency of possible flooding (14 responses): (a) Average of three times per year and (b) average of six times per five years.
4. Duration of traffic interruption (13 responses): (a) Average duration should not exceed 20 h, (b) maximum duration should not exceed 38 h, and (c) total duration should not exceed 18 days/year.
5. Availability of alternate route: If there is no alternate route, 17 respondents would still consider the use of an LWCS and 12 would not.
6. Defense and emergency evacuation route: Nineteen respondents would use this as an absolute constraint and 5 respondents would not.
7. Other factors (limited responses): (a) Sixteen out of 29 respondents had the experience of choosing an LWCS (less than five times per year) be-

cause no funding was available for a regular high bridge. (b) Eleven out of 26 respondents had the experience of needing to consider the availability of future funding for maintenance purposes. (c) Maximum flow velocity over the LWCS should not exceed about 6 ft/s. (d) Flood flow depths should not exceed 2 ft over the roadway of the LWCS. (e) Nearly half the respondents indicated that the lack of a warning system does not constitute an absolute constraint.

8. Flexibility of the decisionmaker in reconsidering own absolute contraints: By a vote of 21 to 3, the decisionmaker is willing to reconsider his or her own constraints if 75-90 percent of the others have a different degree of constraint. The votes for reconsidering were 15 to 7 if the majority of others have a different degree of constraint.

Table 1. Comparison of absolute constraints with q = 0.2.

Factor	q = 0.2[a]	Absolute Constraint[b]
Traffic per day	100-200	10
Avg annual frequency of possible flooding	5-10 times	3 times
Duration of avg traffic interruption	48-72 h	20 h
Chance of damage to human life	1/100 000	Nil
Extra travel time involved for alternate route	>2 h	No criterion
Property damage	$1 000 000	No criterion
Frequency of use as emergency route	About once/month	No criterion
Availability of future funding	Very slim	No criterion
Adequacy of warning system	Poor	No criterion
Quality of hydrologic analysis	Weak	-

[a]With more responses. [b]With fewer responses.

Table 2. Values of q for most desirable conditions.

Factor	Condition	q-Value
Avg traffic	0-5/day	0.80
Avg annual frequency of flooding	0-2 times	0.75
Quality of hydrologic analysis	Very good	0.75
Avg duration of traffic interruption	<24 h	0.70
Extra time for alternate route	<60 min	0.70
Chance of damage to human life	<1 in 1 billion	0.64
Warning system	Excellent	0.72

Table 3. Variation of preference index q with different factors.

Factor	q-Value	Factor	q-Value
Traffic per day		Possible damage to human life	
0-5	0.8	1/10 000	0.2
30-50	0.5	1/1 billion	0.65
200-500	0.1	Total property damage	
>500	0.1	>$100 000	0.4
Average annual frequency of possible flooding		>$1 million	0.2
0-2	0.75	>$5 million	0.1
5-10	0.3	Availability of future repair funding	
>10	0.2	Very slight	0.2
Quality of hydrologic analysis		Very good	0.7
Very good	0.75	Adequacy of warning system	
Average	0.5	Excellent	0.7
Weak	0.2	Poor	0.25
Duration of traffic interruption		Frequency of use as emergency route	
<24 h	0.7	>once/month	0.1
24-48 h	0.4	Once/month to once/year	0.2
>72 h	0.15	<once/year	0.45
Length of alternate route			
30-60 min	0.7		
>2 h	0.25		

There was more willingness to raise constraints than to lower them.

Many more responses were received for the next section of the selection of q-values. Theoretically, for an absolute constraint, one should assign a q-value of 0. Since no one assigned a zero value, one may try to use a q-value of 0.2 for the purpose of comparison with the absolute constraints as defined by this section. The results are listed in Table 1.

Table 1 indicates that perhaps the criteria related to q = 0.2 would give a set of reasonably absolute criteria. In other words, in considering the building of the LWCS, the following modified absolute constraints may be adopted:

Factor	Absolute Constraint
Traffic per day	<200
Average annual flooding frequency	5-10 times
Duration of average traffic interruption	<48-72 h
Damage to human life	No chance
Extra time for alternate route	<2 h
Property damage	<$1 000 000
Frequency of use as emergency route	About once/month

No absolute constraints due to legal, political, and social considerations are present.

General Preference for Selection of LWCS

As stated above, the value of q can be used as an indication of the preference for selection of an LWCS. The q-value should vary between 0 and 1. The greater the q-value, the higher the preference is for the selection of an LWCS.

For the most desirable conditions, the values of q are given in Table 2. According to Table 2 and the weighted average for q (the relative importance of weighted values was given above),

$$(9.5 \times 0.64 + 9.2 \times 0.80 + 8.6 \times 0.75 + 7.8 \times 0.70 + 5.3 \times 0.72 + 7.6 \times 0.70 + 3.5 \times 0.75)/(9.5 + 9.2 + 8.6 + 7.8 + 5.3 + 7.6 + 3.5) = 0.72.$$

In other words, for a saving of about 30 percent, the use of an LWCS would be considered under the most desirable conditions, as given in Table 2.

In general, vented fords or low-water bridges are favored over unvented fords 2 to 1.

Variation of Preference Index q with Different Factors

The respective variations of the preference index q with the amount of daily traffic, average annual frequency of flooding, quality of hydrologic analysis, duration of traffic interruption, length of alternate route, possible damage to human life, property damage, funding, warning system, and use as emergency route are given in Table 3. The slopes of all these curves seem to be rather smooth, which indicates no critical limits beyond which the preference index q would drop sharply.

Although the quality of hydrologic data was rated last among all the important factors for the selection of an LWCS, the q-value dropped significantly from 0.75 for very good hydrologic data to 0.2 for weak hydrologic data.

Warning Systems

Usually, the LWCS is constructed in a relatively remote area, and it is difficult to install an effective warning system. Nevertheless, the effectiveness of each system is rated below (5, most effective; 1, practically useless):

System	Rating
Blockage by patrol cars	4.4
Crossbars to block traffic	4.3
Warning by patrol cars	3.3
Lighted warning signs	2.9
Radio broadcasting	2.7
TV broadcasting	2.3

It is interesting to note that lighted warning signs are rated to be nearly as effective as warning by patrol cars. Radio broadcasting is judged to be less effective than warning signs. TV broadcasting is viewed to be the least effective method. There was one suggestion that helicopters be used, which was not rated.

Responses to several related questions are given below:

1. An overwhelming 27 to 3 are in favor of having some device to stop the traffic directly if human life may be endangered.
2. A vote of 16 to 6 is in favor of having public education to increase the effectiveness of using warning by patrol cars.
3. A vote of 19 to 7 indicates that respondents believe that a warning system is either extremely important or very important to the selection of an LWCS.
4. The vote was evenly divided on "Stopping of traffic is not critical to the selection of LWCS."
5. Bell County, Texas, found that the following warning sign is rather useful:

WARNING
This Road may be Flooded
During Heavy Rains
Do Not Drive into Water

County Engineer

Response to Other Questions

Responses to other questions were as follows:

1. In general, we have some regional hydrological data: yes, 33; no, 15.
2. In general, we have little or no hydrological data on the particular stream of concern: yes, 15; no, 15.
3. LWCS should be avoided whenever possible: yes, 15; no, 19.
4. I would use more LWCSs if I knew more from others: yes, 15; no, 10.
5. I would use more LWCSs if proper criteria could be defined: yes, 21; no, 6.
6. I would be willing to reconsider my constraints if the majority of others' constraints were different: yes, 15; no, 7.
7. I would be willing to reconsider my constraints if 75-90 percent of others' constraints were different: yes, 19; no, 3.
8. This questionnaire is: useless, 2; of some benefit, 23; very useful, 9.
9. Twenty-two respondents have designed 0 to 5 LWCSs/year; one respondent has designed more than 5 LWCSs/year.

Variation of Preference Index q over Different Regions

The United States was divided roughly into four zones: eastern, midwestern, mountain, and western. The limited number of samples from each zone makes drawing reliable conclusions difficult. However, the respondents from the eastern zone generally assigned a 10 percent higher value of q to nearly all factors, and the respondents from the midwestern zone generally assigned a slightly lower value of q to many factors.

SUMMARY AND CONCLUSIONS

The LWCS is used to carry traffic across a stream. It is different from a regular bridge, which is designed to span anticipated floods with certain return periods and thus should not be interrupted by floods of less than designed values. On the contrary, traffic over the LWCS may be interrupted by relatively frequent flooding. Examples of the LWCS include fords, vented fords, and low-water bridges.

The LWCS frequently represents a significant amount of financial saving, although these structures may be overtopped and damaged by floods. Thus, decisionmakers are hesitant to build them. Currently, there is no guide on the selection of the LWCS. Consequently, a public opinion survey was conducted to search for various points of view. It is hoped that the results from this study can serve as a useful guide to assist the decisionmaker in choosing which type of structure to build, an LWCS or a regular high bridge.

We must emphasize that each decisionmaker must use his or her judgment to decide on which type of structure to build for each location, and there can never be any rigid rule to be followed. Ultimately, the decisionmaker must evaluate all the tangible and intangible factors involved for a given case to select the structure to build.

We were fortunate to receive about 60 responses (36 detailed, 24 brief) from various ones of the United States and 3 responses from Canada. The significant findings are stated below:

1. As a rule, many state departments of transportation (including those of Idaho, Connecticut, Florida, Hawaii, Illinois, Missouri, New Hampshire, Rhode Island, South Carolina, Washington, and Wisconsin) do not use the LWCS for their state highways.
2. Although opinions varied greatly on several issues, there is no doubt concerning the establishment of a reliable average trend, particularly for more important issues such as the rating of various important intangible factors, the assignment of the preference index q, etc.
3. A preference index q is defined as the dividing index to separate the selection of the LWCS from the selection of a regular bridge. The q-value is a ratio between the total tangible cost of the LWCS and the total tangible cost of a regular bridge. The value of q should vary between 0 and 1. For example, if decisionmaker A does not like the LWCS, it will be selected only when $q < 0.10$, or the tangible cost of an LWCS is less than 10 percent of the tangible cost of a regular bridge. A second decisionmaker, B, who likes the LWCS more than decisionmaker A, will select an LWCS when $q < 0.9$, or the tangible cost of an LWCS is less than 90 percent of the tangible cost of a regular bridge.
4. The most important intangible factors for the selection of the LWCS are (in order of importance): possible damage to human life, amount of daily traffic, frequency of possible flooding, legal considerations, and use as part of an emergency route. Availability of an alternate route, duration of traffic interruption, and possible property damage form the second most important group. There is no difference of opinion among the different regions of the country on this issue.

Table 4. k-Factors used to obtain actual preference index q.

Factor	Less-Favorable Condition	k-Factor
Traffic count >10 ADT	50 ADT	$k_1 = 0.9$
	90 ADT	$k_1 = 0.81$
	130 ADT	$k_1 = 0.73$
	170 ADT	$k_1 = 0.66$
	210 ADT	$k_1 = 0.59$
	Every +40 ADT	$k_1 = -10$ percent
Avg annual flooding frequency >2	4	$k_2 = 0.90$
	6	$k_2 = 0.81$
	Every +2	$k_2 = -10$ percent
Hydrologic analysis less than very good	Avg analysis	$k_3 = 0.8$
	Poor analysis	$k_3 = 0.4$
Avg duration of traffic interruption >24 h	>48 h	$k_4 = 0.8$
	>72 h	$k_4 = 0.6$
Alternate route >60 min	>2 h	$k_5 = 0.7$
	>3 h	$k_5 = 0.6$
Chance of damage to human life >1/1 billion	>1/1 million	$k_6 = 0.6$
	>1/10 000	$k_6 = 0.2$

5. The total weighted average (weighted according to relative importance) for all responses is 0.72 for the following conditions. (In other words, for a 28 percent saving of total tangible cost, decisionmakers would consider an LWCS.) The desirable conditions for the selection of an LWCS are less than 5 ADT, average annual flooding frequency less than 2, good hydrologic analysis, average duration of traffic interruption less than 24 h, not more than 60 min of travel through alternate route, chance of having human life involved less than 1 in 1 billion, and an excellent warning system.

6. The United States is divided roughly into four zones: eastern, midwestern, mountain, and western. The limited number of samples from each zone makes drawing reliable conclusions difficult. However, the respondents from the eastern zone generally assigned a 10 percent higher value of q to nearly all factors, and the respondents from the midwestern zone generally assigned a slightly lower value of q to many factors.

7. Decisionmakers are usually reluctant to establish a set of absolute constraints below which no LWCS would be considered. After responses from several sections of the country had been examined, however, a set of absolute constraints was formed (provided no legal, political, and/or social constraints were violated).

8. The variations of q with change of different individual factors such as traffic count, possible annual frequency of flooding, average duration of traffic interruption, etc., were also determined.

9. Blockage of traffic by patrol cars and use of crossbars are rated as the most effective methods to warn traffic. However, according to numerous responses, since the LWCS is usually used in remote areas, it may not be practical to employ these methods. A warning sign (with or without lighting) is perhaps a reasonably effective method. An overwhelming number of respondents are in favor of having some device to stop the traffic directly if human life may be endangered.

10. More than 75 percent of the respondents indicated that more LWCSs would be used if proper criteria could be defined.

11. The majority of respondents expressed the opinion that, whenever possible, the LWCS should not be avoided.

12. Respondents overwhelmingly (more than 85 percent) indicated that they would be willing to change their constraints for the selection of the LWCS if a majority (more than 75 percent) of others' constraints were different from their own.

13. About two-thirds of those who gave detailed responses have designed between zero and five LWCSs/year.

14. Twenty-three respondents indicated that some benefit may be derived from this questionnaire. Nine respondents believed that this questionnaire could be very useful. Two respondents felt that this questionnaire was useless.

15. Results from this study can serve as a useful guide for decisionmakers in the selection of an LWCS. The suggested decision model, based on the results from the questionnaire, is as follows:

Step 1: estimate all the tangible costs of a regular high bridge;

Step 2: estimate all the tangible costs of an LCWS;

Step 3: calculate the actual q:

q = all tangible costs of LWCS/all tangible costs of regular bridge;

Step 4: multiply 0.72 by the k-factors (see Table 4) to obtain the actual preference index q (one may wish to interpret the in-between values); k is a set of multipliers to modify the value of q for each variation of conditions that is different from the favorable condition. (One may wish to include the warning system in this assessment.) Perform the following calculation:

$$q^* = k_1 \times k_2 \times k_3 \times k_4 \times k_5 \times k_6 \times 0.72,$$

where 0.72 is the value of q for the most desirable conditions.

Step 5: compare q* and q.

Step 6: use own judgment in the selection of the LWCS; if one agrees with all the major results of this study, one will select an LWCS if $q \leq q^*$; one will select regular high bridges if $q \geq q^*$. Remember that this suggested model can serve only as a guide. The decisionmaker must use his or her judgment to make a decision in each case.

Example: ADT = 100,
Average annual flooding = 4,
Quality of hydrologic analysis is average,
Average traffic interruption is about 48 h,
Extra time for alternate route is 1 h,
Chance of possible damage to human life is 1/1 million:

$$kq = 0.79 \times 0.90 \times 0.8 \times 0.8 \times 1 \times 0.6 \times 0.72 = 0.20.$$

SUGGESTIONS FOR FUTURE RESEARCH

As stated previously, results from this study can serve as a useful guide to the decisionmaker for the selection of an LWCS. However, these results should be discussed and examined in detail by a group of 10-20 experienced decisionmakers. Perhaps a two- to three-day workshop should be scheduled to achieve this purpose.

A study should be conducted to coordinate results from the studies suggested above with tangible factors such as those in the reports by Tseng, Knepp, and Schmalz (4); Schneider and Wilson (5); and Corry, Jones, and Thompson (6). At the same time, work should be done to improve the actual design of the LWCS through laboratory modeling as well as mathematical analysis.

A manual should be written that discusses the selection of the LWCS, different factors affecting the design of the LWCS, what types of LWCS are best suited to different cases, and how best to design different types of LWCSs for various conditions.

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Cost-Effective Low-Volume-Road Stream Crossings

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Because of their high relative cost and degree of importance in any transportation system, stream-crossing structures warrant careful site selection, structure type selection, and design. All too often a stream is spanned with a conventional structure merely because that is the way it has always been done, or a replacement structure is designed to the same standard as the previous structure without consideration of other options. The features to look for in selecting a stream-crossing site for low-volume roads are discussed and ideas are provided on improving communication among the road locators and designers, the bridge designers, and other necessary specialists. Some of many possible alternatives to conventional bridge-type crossings are offered, and ways are suggested to make a design and contracting system more cost effective through the use of standard drawings and contractor design options. Several examples are included of how low-water crossings can be used. These examples show some of the many possible variations that can be included in the design of low-water crossings. Costs are used to compare the low-water crossings and the design alternatives. Costs of the low-water crossings are based on actual bid prices, whereas costs of the design alternatives are based on the engineer's estimate.

Bridge construction and maintenance costs can be a substantial percentage of total road construction and maintenance costs. Careful site location, innovative structure type selection, and efficient design can significantly lower these costs without reducing the service, safety, load-carrying capacity, durability, or design lives of these structures. These structures can be designed and installed without damaging fisheries, wildlife, or aesthetics.

The Northern Region of the Forest Service of the U.S. Department of Agriculture (USDA) includes 15 national forests in northern Idaho and Montana. The region has jurisdiction over approximately 30 000 miles of road, which include more than 1300 existing bridges. The region annually constructs or reconstructs approximately 1600 miles of road and 30-50 stream-crossing structures. Approximately one-half of these structures replace existing structures and one-half are new construction. These crossing structures are usually on road systems that have low traffic volumes, low design speeds, and difficult alignments as well as fisheries constraints, limited access, and often difficult design parameters. These conditions offer many opportunities for imaginative design to produce the most cost-effective alternatives possible.

Ideas on crossing-site selection, structure type selection, types of design, and several examples of how low-water crossings can be cost-effectively used are discussed.

SITE SELECTION

Careful site selection provides the greatest potential for cost savings. Poor site selection can result in a longer, wider, or higher structure than is really needed or may result in a very costly curved bridge or complex and costly foundations. A poor location can cause difficult, dangerous alignments and a shortened structure life.

Determining the optimum crossing site requires balancing many variables; some affect design of the road and some affect design of the bridge. An ideal stream crossing from the perspective of the bridge designer may be described as follows:

1. It would cross the stream at an area with well-defined banks. The stream is generally narrower at these locations and the stable banks indicate a stable stream channel.
2. It would cross the stream away from curves in the stream. These areas are often unstable because the stream tends to move toward the outside of the curve. Also a stream usually is wider in a curve than in a tangent reach. A curve may require channel straightening if a pipe-type structure is installed or cause roadway fill retention problems if a bridge is installed.
3. It would cross the stream at an area with a uniform stream gradient. An increasing gradient increases erosion and scour potential. A decreasing gradient can cause streambed load and debris deposition.