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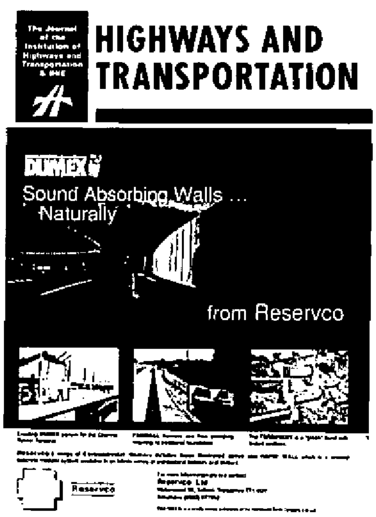

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Journal note

Members are advised that with immediate effect, the publishing of the mid-month Appointments Supplement is on hold until the economic position on recruitment advertising makes it a viable proposition. An August issue of the Journal will be published.

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Estimation of design flows for culvert design

by S McCurdy

The cost of culvert construction generally comprises a significant percentage of the overall construction costs of new highway projects and as such represents a not unsubstantial investment. It is therefore important that these structures are designed for an appropriate discharge. Over-provision can result in an uneconomic structure whereas a cross-section of insufficient size can result in frequent flooding upstream of the culvert. The design flow to be used for culvert design should be predicted by assessing a suitable return period and estimating the catchment runoff and stream discharge for this assumed frequency of flooding.

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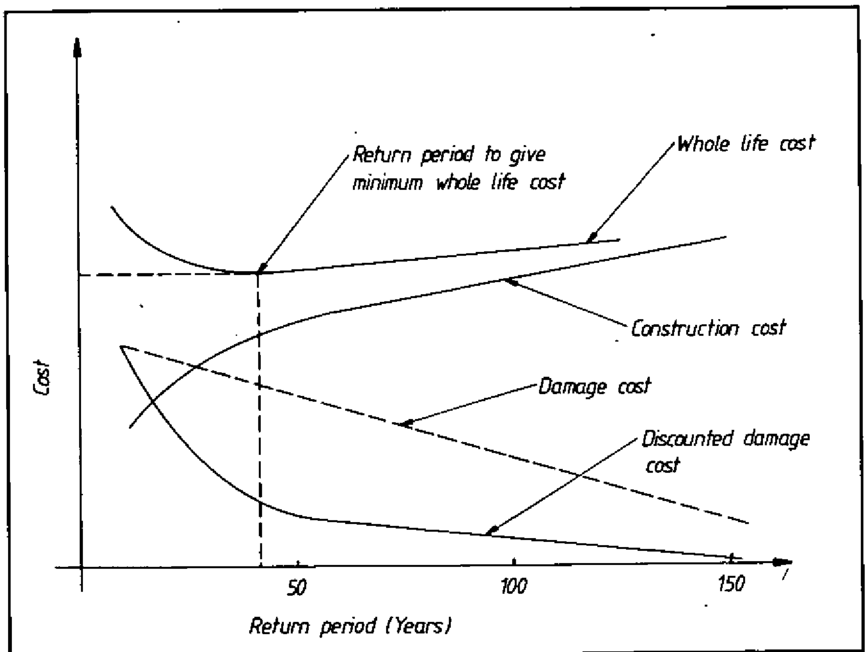

Fig. 1. Schematic diagram showing relationship between whole life cost and return period

Flood return period

The flood return period or recurrence interval is the average period between floods greater than or equal to a certain value. It is usually specified as the number of years between the recurrence of a particular flood level although it can also be specified as the probability of a flood of a certain size. For example a 1 in 10 year flood has a 0.095 probability of occurring in any one year.

In Britain the return period is usually based on engineering experience or the requirements of the client or statutory bodies such as the appropriate River Authority. A uniform period is usually specified irrespective of the culvert characteristics or the cost and consequences of flooding. This can lead to the over-design of some culverts and the under-design of others resulting in frequent flooding of the area upstream from the culvert.

In order to optimise culvert provision every location should be studied and an assessment made of the risk and economics associated with the expected frequency and severity of flooding for any given return period.

An economic assessment of these factors is possible using a cost benefit analysis which considers the whole life costs of construction and maintenance together with the risk and cost of flooding. A schematic diagram illustrating the relationship between whole life cost and return period is shown in Fig 1.

1 in 10 years Peak Discharge (m^3/s)	Design Return Period (Years)		
	Motorways	Trunk Roads	Minor Roads
5	10	10	5
5-15	20	10	5
15-50	50	20	10
more than 50	100	50	20

Note : This chart was derived from the table given in the Paper on Practical Culvert Hydraulics – A South African Perspective by Rooseboom (Ref 1)

Table 1. Standard return periods

It is probable that construction costs savings and improvements to the quality of designs could be achieved using cost benefit analysis, particularly for larger culverts. Such an appraisal would require detailed analysis and considerable development would be necessary to provide a credible method which would be quick and easy to apply.

A qualitative approach to the choice of return period

An alternative to a cost benefit analysis is a qualitative approach where a range of factors are considered when choosing the culvert return period. Two of the most significant of these factors are the design flow and the class of highway. Using these parameters the author has developed standard return periods for a range of 1 in 10 year flood flows and highway classes ranging from motorways to minor roads. Details of the standard return periods are given in Table 1 and range from 1 in 5 years for a minor road crossing a small watercourse to 1 in 100 years for a motorway crossing a river with a 1 in 10 year peak discharge of more than 50m³/sec.

The standard return periods act only as a general guide and should be adjusted to take into account local conditions and the risk of flood damage at the culvert site. These factors can be appraised using the standard return period review chart shown in Table 2. The chart lists a range of traffic, hydraulic and flood damage factors which are used to determine an overall weighted rating for the culvert. If the culvert falls into the low risk category the standard return period may be reduced whereas if the culvert falls into the high risk category the standard return period should be increased.

Catchment runoff

The magnitude of runoff from an area depends on the amount of rainfall, the characteristics of the catchment and the nature of the stream. Various methods have been developed which attempt to model these variables to estimate the volume of runoff from a catchment for a given return period. These procedures include the analysis of stream flow data, Flood studies report formula, rational formula and hydrograph methods. Each of these approaches is discussed in more detail in the following paragraphs.

Analysis of stream flow data

The most accurate method of predicting runoff is the analysis of stream flow record data. Historical stream flow data is generally available from River Authorities for the larger catchments throughout Britain. Providing the records have been taken for a significant length of time and no large scale alterations to the nature of the catchment have occurred or are planned then this stream flow data can be used to estimate the magnitude of the design flood.

The distribution of stream flow records has a skewed probability which cannot be modelled using the normal distribution. Other distributions are therefore used to model runoff which include the Gumbel and Log Pearson Distributions. These procedures are discussed by E M Wilson in his book on Engineering Hydrology (Ref: 3) and in the paper on Flood Frequency Analysis by Dalrymple (Ref: 4).

Flood studies report formula

In general only the large catchments have adequate records to allow a rigorous

Factor/Category	1	2	3
1. HYDRAULIC CONSIDERATIONS			
1.1 Type of catchment	Flat	Hilly	Steep
1.2 Obstructions upstream from culvert	Several	One	None
1.3 Depth and velocity of floodwaters	Low	Medium	High
1.4 Number of known floods with a 1 in 10 year return period	None	One	Several
1.5 Roadway overflow section	Yes	Nominal	No
1.6 Risk of debris blocking culvert	Low	Medium	High
2. FLOOD DAMAGE			
2.1 Non-highway flooding risk and damage costs	Low	Medium	High
2.2 Highway flooding risk and damage costs	Low	Medium	High
2.3 Potential loss of life	Low	Medium	High
2.4 Time needed to make route serviceable after flood	Short	Medium	Long
3. TRAFFIC CONSIDERATIONS			
3.1 Average daily traffic (veh/day)	<100	100 to 750	>750
3.2 Detours available	Yes	Poor	None
3.3 Economic importance	Low	Medium	High
3.4 Period of flooding	Short	Medium	Long

Overall Weighted Rating	Flood Damage Risk
1	Low
2	Average
3	High

Notes

1. Additional factors may be added to the list for consideration.
2. All factors are not of equal weight under all circumstances and therefore the weighted rating is subjective and only serves as a guide in selecting the design frequency.
3. Chart was derived from the flood frequency selection chart given in the AASHTO Drainage Guidelines (Ref: 2).

Table 2. Return period review chart.

analysis of flow data. In order to improve the prediction of runoff from smaller catchments which are generally ungauged, the Flood Studies Report (FSR) (Ref: 5) analysed more than 600 catchments in Britain and Ireland to establish a causal formula based on catchment and stream characteristics.

A six term formula was developed using regression analysis techniques which relate runoff to the area, stream frequency, soil type, rainfall, slope and the fraction of the catchment draining through a lake or reservoir. This formula estimates the mean annual flood $\bar{Q}$ and has the following form:

$$\bar{Q} = C[AREA^{0.94}\ STMFRQ^{0.27}\ SOIL^{1.23}\ RSMD^{1.03}\ S1085^{0.16}\ (1 + LAKE^{-0.85})]$$

C — Regional coefficient
AREA — Area in square kilometres
STMFRQ — Stream frequency in junctions/km^2
SOIL — Soil index – Calculate from soil survey maps
RSMD — Net one day rainfall of five year return period – Available from maps published in the FSR
S1085 — Stream slope between 10% to 85% of main stream length
LAKE — The fraction of catchment draining through a lake or reservoir

The application of the generalised FSR formula can be time consuming to apply especially for smaller catchments. Various authors including Poots and Cochrane (Ref: 6) and The Institute of Hydrology (Ref: 7) have proposed simplified formulae for these cases and although they do offer minor saving in design time they do not give any better prediction of runoff than the generalised FSR formula.

Rational Formula

The first generally accepted formula for the calculation of runoff was the rational formula which due to its simplicity remains in widespread use. The basic formula has the following form:

$$Q = 2.78CIA$$

Q — Peak discharge in litres/sec.
I — Average rainfall intensity in millimetres/hour. Charts are available from the Meteorological Office which will give the rainfall intensity for various parts of Britain for a range of return periods.
A — Catchment area in hectares
C — The catchment coefficient.

The main drawbacks with the rational formula approach are that rainfall is assumed to be of an equal intensity throughout the catchment and no allowance can be made for storage or routing effects. This results in the estimate of excessive flows for larger catchments and it is generally recommended that the rational formula should not be used for catchments with an area greater than 100 hectares.

The other main problem with the application of the rational method is determining the catchment co-efficient C which expresses the ratio of the rate of runoff to the rate of rainfall. The Wallingford Modified Rational Procedure (Ref: 8) recommends that the C coefficient should be taken as the product of C_V and C_R where C_V is the proportion of rain falling on to the catchment and C_R is a factor which takes into account routing effects. A modified version of the rational formula is available as part of the "WASSP" suite of programs.

Hydrograph methods

Experiences with the rational formula showed that it gave unreliable predictions of runoff for large and urban catchments. Hydrograph methods were therefore developed to model these situations and are now widely used for the production of storm runoff profiles.

The Road Research Laboratory developed its hydrograph model in 1963. This procedure is known as the TRRL Hydrograph Method and details of the procedure are given in Road Note No 35 (Ref: 9). This procedure is used extensively throughout Britain, especially in urban areas where catchment storage is a significant factor controlling the amount of runoff.

The number of calculations required by a hydrograph analysis method is such that a computer program is generally required. Computerised versions of the TRRL Hydrograph Method and a further development of this approach called the Wallingford Hydrograph Method are available in the WASSP software package.

Conclusions

The return period to be adopted for culvert design should be based on standard return periods shown in Table 1 for a range of highway classes and discharge flows. These standard periods should be adjusted if the culvert falls into either a low or high flood risk category using the return period review chart shown in Table 2.

Runoff estimation should be based wherever possible on stream flow records. When this information is not available the Flood Studies Report formula can be used to estimate runoff from rural catchments and the TRRL Hydrograph method in urban areas. For both rural and urban catchments with an area less than 100 hectares the Rational Formula can be used to predict runoff.

References

1. Rooseboom A: Practical Culvert Hydraulics: A South African Perspective, Paper presented at the 2nd International Conference on the Hydraulics of Floods and Flood Control, Cranfield, 1985.
2. AASHTO: Highway Drainage Guidelines, Task Force on Hydrology and Hydraulics, AASHTO Highway Sub-Committee on Design, Washington, 1979.
3. Wilson E M: Engineering Hydrology, The MacMillan Press Ltd, 3rd Edition, London, 1984.
4. Dalrymple T: Flood Frequency Analysis, US Geological Survey Water Supply, Paper 1543-A, Washington, 1960.
5. Natural Environment Research Council: Flood Studies Report, Vols 1-5, NERC, London, 1975.
6. Poots A D and Cochrane S R: Design Flood Estimation for Bridges, Culverts and Channel Improvement Works on Small Rural Catchments, Proc Instn Civ Engineers, Volume 66, Pages 663-666, November, London, 1979.
7. Flood Studies Supplementary Report No 6: Flood Return for Small Catchments, FSR Supplementary Report No 6, Institute of Hydrology, Wallingford, UK, 1976.
8. National Water Council, DoE: Design and Analysis of Urban Sorom Drainage, The Modified Rational Method, Wallingford Procedure, Volumes 1-4, Standing Technical Committee Report 31, October 1981.
9. Transport and Road Research Laboratory: A Guide for Engineers on the Design of Storm Sewer Systems, Road Note 35 Second Edition, HMSO, London 1976.