The 25-Year Storm and Culvert Size

A CRITICAL APPRAISAL

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ABSTRACT

Application of the 25-year stormflow guideline, as a basis for selecting culvert size for logging-road stream crossings, is severely restricted in British Columbia by lack of small-stream flow data. The problems associated with realistic indirect evaluation of 25-year peak flows are discussed, including an outline of the concept of return period and risk and the processes of peak flow generation. Several techniques for estimating peak flow values are described: namely, precipitation-runoff relationships, transposition of streamflow data, the Manning equation, and surveys of existing culvert installations. Precipitation-runoff relationships are the principal means of determining the frequency of occurrence of computed peak flows. Choice of culvert size also requires application of a safety factor to account for culvert plugging by debris and ice and for potential logging-induced changes in runoff. To improve 25-year peak flow estimates, increased joint measurement and analysis of precipitation and small-stream peak flow data are required. Forest industry personnel could play a valuable role in assisting government agencies with data collection.

Résumé

Dans la Colombie-Britannique, la norme pour dimensionner les ponceaux de voirie forestière aux intersections de ruisseaux est le débit de pointe ayant une intervalle de récurrence de 25 ans. La réalisation de cette norme se trouve fortement limitée par la pénurie de données hydrométriques des petits cours d'eau. Ce rapport discute les problèmes associés à l'évaluation réaliste des débits de pointes à intervalle de récurrence de 25 ans, y compris une discussion des concepts de l'intervalle de récurrence et du risque et des processus génératifs des débits de pointe. Plusieurs techniques pour évaluer les débits de pointe sont décrites: les rapports précipitation-débit, la transposition de données hydrométriques, l'équation de Manning et les inventaires des ponceaux déjà installés. Les rapports précipitation-débit servent de principal moyen de déterminer les fréquences d'occurrence des débits de pointe calculés. Le dimensionnement optimum des ponceaux exige l'application d'un facteur de sécurité pour tenir compte des possibilités de blocage par les débris et la glace et d'augmentation de ruissellement occasionnée par le déboisement. Afin d'obtenir les estimations améliorées des débits de pointe à l'intervalle de récurrence de 25 ans, il faut augmenter les mesures et l'analyse des données de précipitation et de débit des petits cours d'eau. Le personnel de l'industrie forestière pourrait jouer un rôle important dans l'obtention de ces données hydrologiques.

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INTRODUCTION

The B.C. Forest Service Coastal Logging Guidelines, recognizing that adequately sized culverts at stream crossings are essential for stream protection and maintenance of good road conditions, specify that culverts be designed to handle the 25-year storm (Truck Logger, 1972). Because of insufficient precipitation and small-stream flow data, realistic evaluation of 25-year storm flows is severely restricted in most parts of the province. Hence, adherence to this guideline is problematical at the present time. In the context of the guideline, the word "storm" is intended to mean peak streamflow. Since the latter expression is more appropriate, further reference in relation to streamflow will be mainly to peak flow rather than storm.

The main purpose of this report is to outline the problems and severe limitations associated with evaluating 25-year frequency peak flows by indirect methods. The concepts of return period and risk are reviewed to clarify what is meant by the phrase "25-year peak flow." Regional differences in peak flow generation processes are then outlined to indicate the need for different types of data and analytical procedures. A number of techniques for evaluating peak flows are described in detail to illustrate the extent and significance of data limitations, to provide some insight into the techniques themselves, and to point out relevant reference material.

A second objective is to place the role of computed 25-year peak flow values in perspective. Once a design peak flow has been determined, an appropriate culvert size must be selected. Risk of culvert plugging and changes in runoff following logging are additional factors to be considered. Suggestions for selecting safety factors are offered and recommendations are made concerning collection and analysis of required precipitation and streamflow data.

INTERPRETATION OF 25-YEAR CONCEPT

The expression 25-year peak flow (or storm) can be defined as the maximum stream discharge which has an expected return period of 25-years. As outlined in a later section, 25-year peak flows can be produced in more than one way and there are regional differences in frequency of runoff producing processes. The concept of return period, described below, is used to establish a standard criterion for all streams, irrespective of size or location. Because the objective is to select a culvert size large enough to handle maximum flows, only maximum annual events are considered, regardless of season of occurrence.

Return period and risk

The selection of a given return period for culvert design purposes is an arbitrary decision which is ideally based on the expected life of the road and the risk of damage if the design flow is exceeded. A brief discussion of the true meaning of return period and risk will help place their role and significance in proper perspective. The return period T is defined by

$$T = \frac{1}{p} , \qquad (1)$$

where p is the probability that an event will equal or exceed a given magnitude. Such an event is referred to as a T-Year event (i.e. the 25-year storm). It is expected to occur once every T years on the average, rather than at regular intervals. In fact, the probability that a T-year event will occur within the next T years is quite high. Table 1 presents some representative probabilities P_n

of a T-year event occurring at least once in a period of n years as derived from the equation

$$P_n = 1 - (1 - \frac{1}{T})^n . \qquad (2)$$

Thus, as shown in Table 1, there is a probability of 0.64 that a 25-year peak flow will be equalled or exceeded at least once during a 25-year period. The probabilities defined by equation (2) may be considered as risk factors because they represent the risk of damage if the design flow is exceeded.

Table 1

Probability P_n that an event with return period T years will occur at least once within a period of -

T	10 years	25 years	50 years
10	0.65	0.93	0.99
25	0.34	0.64	0.87
50	0.18	0.40	0.64
100	0.10	0.22	0.40

For greater assurance that the capacity of a culvert will not be exceeded during a specified period, a longer return period must be selected for design purposes. The probability P_r or risk that an event will not occur within a period of r years is given by

$$P_r = 1 - P_n . \qquad (3)$$

Figure 1, based on equation (3), illustrates the relationship between design return period T and desired lifetime Td (where Td=n) for various values of P_r. Thus, for a 90% probability (P_r=.90) that culvert capacity will not be exceeded during a 25-year period, the culvert must be designed to accommodate a peak flow with return period of approximately 235 years. This value is obtained from Figure 1 by

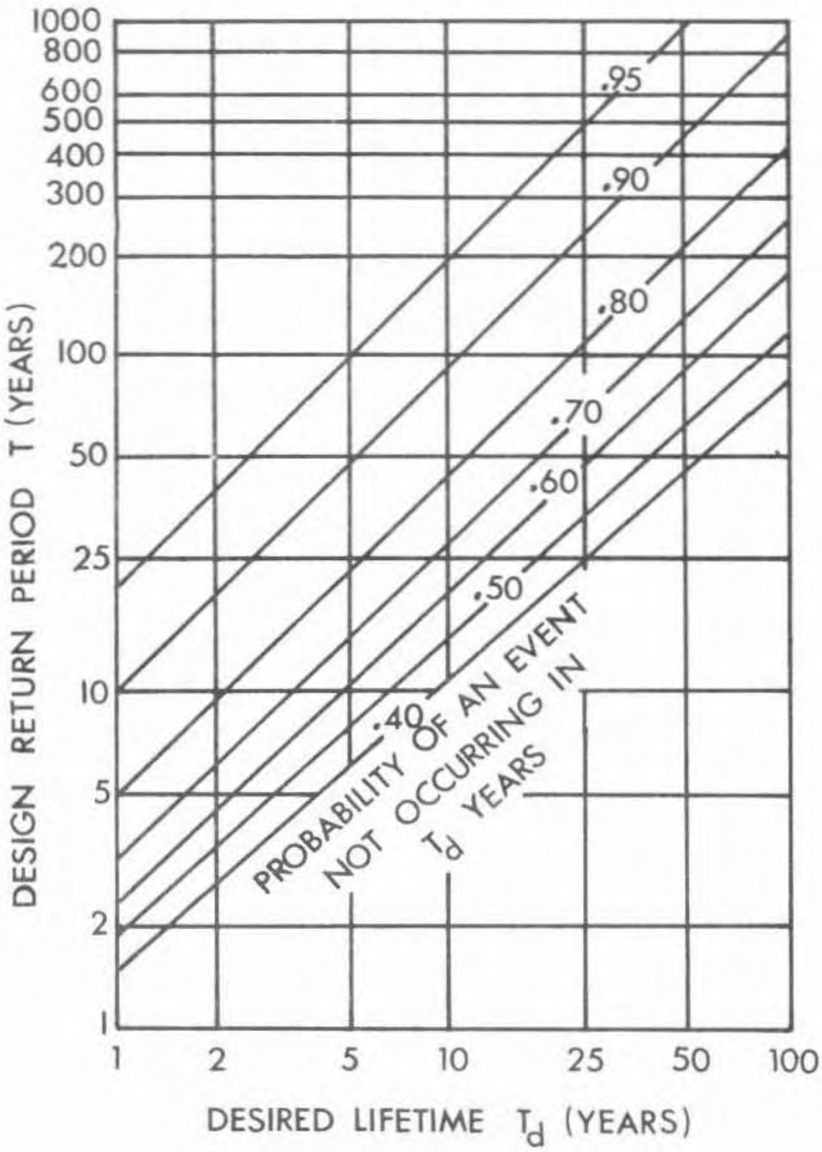

Figure 1. Risk diagram (based on format composed by Bolter Parish Trimble Ltd., Edmonton, Alberta).

selecting Td=25 on the horizontal axis, moving upward to the intersection with the line representing P_r=.90, and then across to the vertical axis to read T=235. For further information on return period and risk, the reader is referred to Kendall (1959).

Return periods for peak streamflows or maximum rainfall intensities are usually determined by plotting observed data on probability graph paper. In general, return period values obtained by extrapolating the resulting curve much beyond the period of record of the observed data are not reliable. Based on data published by the Water Survey of Canada (1972), the following approximate relationships between peak flow return periods could be used as guidelines for watersheds less than about 50 square miles in area:

1. 25-year peak flows appear to be about 20-30% higher than 10-year values.
2. 100-year peak flows appear to be on the order of 40-50% higher than 25-year estimates.

This information is based on data from a very small sample of streams and is intended only as a rough guide to place the relative return period values in prespective.

Genesis of peak flows

To evaluate peak flows, it is necessary to have an understanding of the meteorological and physical processes which produce them. In fact, there are several ways in which a 25-year peak flow could be generated. Because of major differences in climate between coastal and interior B.C., there are also regional differences in the likelihood of occurrence of processes producing peak flows.

Thunderstorms, for example, occur much more frequently in the Interior than on the Coast. The regionally important peak runoff - generating conditions are listed separately for the Coast and the Interior.

Coastal regions

1. Major rain storms with durations of 12 to 36 hours or greater are a major cause of high peak runoff events on the Coast. Maximum annual peak flows from this source normally occur during late fall to winter when watershed soil and vegetation moisture levels are high. Hypothetically, the 25-year peak flow for coastal B.C. could be defined as that flow produced by the 25-year rain storm falling on an already saturated watershed.
2. High runoff events also occur as a result of rain falling on snow. In this case, rainfall of a lower return period, say 10 years, in combination with a wet snow pack and warm temperatures could produce a 25-year streamflow peak. On the Coast, this situation could occur at any time during winter or spring when there is sufficient snow on the ground, provided that the snowpack is not excessively deep.
3. A peak discharge equivalent to the 25-year value could also be generated when flow of lower return period is temporarily blocked by a debris jam. Storm runoff water could be backed up behind the debris dam and then released as a powerful surge when the dam collapsed. It would be extremely difficult to relate this type of occurrence to a return period.

Interior regions

1. A probable cause of the 25-year peak flow in the Interior is rapid springtime melting of an above-average winter snow pack, brought on by an extended period of warm, clear weather.

2. In very small watersheds of a few hundred acres or less, the 25-year peak flow could be produced by high intensity convective rainfall (thundershower) of duration less than 2-3 hours. This "flash-flood" situation would normally occur during the summer months.
3. High peak flows in the Interior could also be generated when major storm rains occur while a significant snow pack still exists. This situation would most likely happen in late spring.
4. As on the Coast, debris jams could result in 25-year peak flow surges during otherwise lower return period precipitation and runoff conditions.

EVALUATION OF PEAK FLOWS

One of the main problems in evaluating 25-year peak flows is the lack of direct measurements of streamflow from small watersheds in British Columbia. For streams on which culverts are likely to be installed, a small drainage area can be defined as being less than about 5 square miles. In lieu of direct measurement, the magnitude of the 25-year peak flow from small watersheds must be estimated. An essential feature of the estimating procedure is that it relate computed flows to the desired return period. Relationships between precipitation and streamflow data provide a basis for indirect evaluation of stream discharge which conforms to this criterion. The use and limitations of such relationships are discussed below.

Other approaches to peak flow evaluation can also be taken, as outlined in a later section. However, a problem with some of the other methods in relation to the B.C. Forest Service guideline is the difficulty in linking derived flow values to their return period.

Precipitation-runoff relationships

Runoff can be related to precipitation in a variety of ways, including differences of approach for rain or snowmelt events. In this report, the simplest, most practical approaches are described and the reader is referred to indicated references for information on more elaborate techniques.

To properly derive peak flow values for a particular region, the conditions most likely to produce the higher flows in the region should be selected. Another constraint is the availability of data or information on which to base assumptions. On the Coast, large-scale rain storms are the major producers of extreme runoff events. Thus, a logical approach to defining 25-year peak flow values in coastal regions is to use 25-year storm rainfall data in conjunction with a rainfall-runoff model (see item 1 top of page 6). For interior watersheds, 25-year peak flows are more likely to be generated by high intensity showers or spring snowmelt and could be defined in two ways; namely, using a convective rainfall-runoff model or a snowmelt-runoff model. Examples of the above-mentioned models are described following a discussion of the problems and limitations of evaluating the precipitation input to the models. As noted in the previous section, rain-on-snow events are an important cause of major peak flows, particularly in coastal regions. This situation is not considered as a basis for derivation of 25-year flow values because of extreme uncertainties and variability in timing of associated snowmelt.

Precipitation estimation

The use of precipitation-runoff models is based on the following assumptions: precipitation data are more readily available than appropriate streamflow data, easier to collect and more amenable to extrapolation.

However, although meteorological stations are more numerous than small watershed stream-gauge installations, they are still widely scattered and mostly located at low elevations. Determination of precipitation amounts or intensities for a given area involves extrapolation, horizontally as well as vertically, from observations taken at single points. In mountainous terrain, where precipitation patterns are complex and measurements few, direct observations may be far removed from the area of concern. Hence, the reliability of areal precipitation estimations may be highly uncertain. There are also differences in the reliability of evaluations of rainfall versus snow pack distribution, as noted below.

Rainfall

Rainfall-runoff models require data on mean rainfall intensities for specified durations and return periods. For peak flow calculations, the duration selected should correspond to the concentration time of the watershed (time required for a particle of water to move from the most remote part of the watershed to the outlet or point of culvert installation). For major rain storms, the time of concentration will range from about 6 to 12 hours or greater for watersheds from 1 to 5 square miles in area. For smaller drainage areas subjected to major rains or high intensity convective showers, the time required to develop peak flows will be on the order of 1 to 3 hours in steep mountainous terrain and possibly greater on flatter ground.

The problem of evaluating precipitation over an area, or at a point far away from single station measurements, has received considerable attention in the literature over the years. Unfortunately, little effort has been directed toward the study of short duration, high-intensity storm rainfall in mountainous terrain, particularly its extrapolation. Some limited information for coastal B.C. is presented by Sporns (1964) for the Vancouver area and this topic forms part of a current Ph.D. thesis study by Hetherington. The following general observations may help place the problems of extrapolation of rainfall data in better perspective:

1. Major storm rainfall frequency data for low elevation valley stations within mountainous terrain should be applicable to nearby higher elevations. Since rainfall from major storms is generally widespread, both high and low elevation sites are subjected simultaneously to the same storms, although the relative magnitudes may differ.
2. In contrast to major storm rainfall, the nature of convective or shower-type rain is such that plateau, valley bottom or mountain slope locations are all potentially subject to the same range of rainfall intensities. Consequently, maximum rainfall intensities measured at lower elevations can be extrapolated directly to higher elevations. However, regional variations in storm frequencies must be taken into account, particularly between plateau and mountainous regions.
3. Major storms in British Columbia tend to follow similar pathways. Since terrain is fixed, relative storm rainfall patterns in the mountains should be fairly consistent. Once general distribution patterns are defined on a local or regional basis for specific terrain configurations, extrapolation will be greatly facilitated.
4. Significant elevational differences in rainfall intensity

during major storms result in areas where mountain slopes are exposed directly to rain-bearing winds. This effect occurs, for example, along the western slopes of Vancouver Island, the Queen Charlotte Islands, the Coast mountains and the Interior mountain belts.

Snow

The basic precipitation parameter required for snowmelt-runoff models is maximum snow pack accumulation expressed in terms of water equivalent, which is the depth of melt water which would be obtained from melting the snow pack. The areal depth distribution of the accumulated snow cover may be highly variable and thus difficult to measure or even estimate with any degree of accuracy. In mountainous terrain, information on snow cover depth and water equivalent is normally collected on a monthly basis during the snow season from selected sites around the province. Although high elevation areas are perhaps better sampled for snow than for rain, the network of snow survey sites is still sparse. Hence, extensive extrapolation of snow survey data is necessary and even more tenuous than for rainfall data. At best, the data can be assumed to be only indices of the snow pack characteristics over the large area represented by each snow course. The use of snow survey data is further discussed in the section on snowmelt-runoff models.

Data Sources

The addresses of agencies from which precipitation and streamflow information pertinent to British Columbia may be obtained are listed at the end of this report.

The sparse and restricted nature of the existing rain-gauge network in the province has already been noted. The number of these gauges which automatically record short duration rainfall intensities is limited, as most stations collect rainfall in standard, non-recording gauges. These gauges are read once or twice a day but the data are usually reported on a daily basis. Many of the existing precipitation stations, particularly those with recording gauges, have a very short period of record which greatly restricts the reliability of frequency or return period calculations.

Some information on short-duration rainfall frequencies is available. Murray (1964) has prepared maps of the mean 6- and 24-hour annual maximum rainfall amounts for return periods of 2, 5, 10 and 25 years for B.C. In Murray's report, the following relation was used for deriving the 6-hour rainfall (R_6) from the 24-hour values (R_{24}):

$$R_6 = 0.176 + 0.469\ R_{24}\ \text{(inches)} \qquad (4)$$

More recent information on rainfall intensities for various durations and frequencies for selected individual stations, including estimates for durations of less than 6 hours, can be obtained from the Scientific Support Unit of the Atmospheric Environment Service (see Appendix). The amount of short-duration rainfall data will hopefully increase substantially in the future as the need for this type of data becomes recognized by both provincial and federal government agencies and industry.

Daily rainfall totals are published on a monthly basis by the Atmospheric Environment Service, in the Monthly Record of Meteorological Observations in Canada. However, no analyses or long-term summaries are included in this publication.

Snow survey data are published by the provincial Water Resources Service in a monthly Snow Survey Bulletin. As well as current data, minimum and maximum snow pack depth and water equivalent are given for the period of record at each site.

Rainfall-runoff models

The simplest and most practical models for estimating peak flows from rainfall are empirical formulae relating peak flow to rainfall intensity of desired return period and duration, and physiographic parameters of the watershed such as drainage area or basin slope. Gray (1970) presents a number of such formulae that have been used in various countries. The common problem with these formulae is that each contains an empirical constant C, usually called the runoff coefficient. This coefficient can vary widely for differing conditions of topography, soil, vegetation and climate. Moreover, a given formula is really only reliable in the area for which it has been developed. No models of this type appear to have been developed or adequately tested in British Columbia.

In the absence of locally derived information, foresters have turned to relationships developed elsewhere, as illustrated by the following two examples. One relationship that has been used in British Columbia is the Burkli-Ziegler formula described by the Forest Club (1971):

$$Q = C\ I\ M\ (S/M)^{.25}, \qquad (5)$$

where Q is the peak flow in cubic feet per second, C a constant, I the rainfall intensity in inches per hour, M the drainage area in acres and S the average slope in watershed area in feet per 1000 feet. This formula was developed in Europe, using one-hour precipitation intensities, but has not been formally tested in British Columbia. It is strictly applicable to very small watersheds with short concentration times. However, the formula has been applied to larger watersheds of much longer concentration times in areas where peak flows are produced by major storm events rather than convective rains. This application is questionable, and any relation between computed flow values and actual 25-year peaks must be considered purely coincidental.

Another relationship used for forest roads is the Talbot formula discussed by Rothwell (1971):

$$A = C\ (M)^{.75}, \qquad (6)$$

where A is the area of the culvert opening in square feet, C a constant and M is the drainage area in acres. This formula was developed from very high intensity convective rain storm data in the Eastern United States, and assumes a given rainfall intensity of 4 inches per hour. Rothwell presents graphs showing adjusted culvert size versus drainage area for several lower rainfall intensities. The Talbot formula is a convective rainfall-runoff model which might be applicable for very small watersheds in the Interior. However, the problem of determining representative values for the runoff coefficient C must still be overcome.

Snowmelt-runoff models

Procedures for estimation of peak streamflows generated by snowmelt are more complex than for rainfall events. The basic techniques are described in detail in Gray (1970) and are also outlined by Bruce and Clark (1966). Essentially, the volume and rate of snowmelt must first be computed, losses deducted, and the excess melt converted to runoff. The information required to develop snowmelt-runoff relationships includes maximum snow pack depth and water equivalent, critical sequences of daily temperature and streamflow records. Ideally, soil moisture content preceding the melt period and extent of snow cover should also be known. However, for determining maximum flows, it is reasonable to make simplifying assumptions concerning these two parameters. In general, snow survey data are used as an index of areal snow cover characteristics and relationships are developed using point or single snow course data. Maximum snowmelt peak flows tend to occur when heavy winter snow is followed by an extended period of clear weather and high temperatures.

The amount of snowmelt can be computed either from a single temperature index or an energy balance method such as the generalized snowmelt equations developed by the U.S. Corps of Engineers (Gray, 1970). For practical purposes, the temperature index or degree-day approach is adequate and has been found to provide snowmelt estimates comparable in accuracy to the more elaborate methods (Gray, 1970). The basic degree-day equation is

$$Sm = k\ (T_a - T_b)\ \text{inches/day}, \qquad (7)$$

where Sm is snowmelt in inches per day, k is a coefficient, T_a is mean daily or maximum daily air temperature in ^{o}F, and T_b is base temperature in ^{o}F which is usually chosen close to $32^{o}F$.

To account for losses of melt water, some estimates must be made of evaporation and storage, both in the snowpack itself and in or on the ground. Estimation of storage, in particular, is highly subjective and liable to considerable error. An alternative procedure that takes losses into account indirectly is to compute snowmelt runoff volume directly from the degree-day method (Bruce and Clark, 1966). The basic equation then becomes

$$Sro = k''\ (Ta - T_b)\ \text{inches/day}, \qquad (8)$$

where Sro is the daily runoff volume from snowmelt in inches depth on the watershed.

Winter snow-pack accumulation, rate of spring snowmelt and subsequent runoff are phenomena that tend to be relatively similar over large areas, at least on a regional basis. As a result, streamflow and appropriate meteorological data for larger gauged watersheds might provide an estimate of snow-pack and weather conditions that produce 25-year runoff events on smaller drainage areas, provided elevational differences are taken into account.

The conversion of snowmelt to stream discharge is really the most critical and difficult aspect of developing snowmelt-peak flow relationships. For small watersheds, the simplest method is to convert the excess melt or daily runoff volume into a streamflow hydrograph by application of unit hydrograph theory. Once the stream hydrograph is developed, the peak flow is automatically provided.

The unit hydrograph concept was originally developed for rainfall and is described by Gray (1970) and Bruce and Clark (1966). A unit hydrograph can be defined as the hydrograph of a unit volume of direct runoff that is produced by an excess rainfall of uniform intensity and unit duration. Excess rainfall is the total rainfall reaching the ground less infiltration, and the unit duration depends on the size of the drainage area. The unit hydrograph represents the integrated effects of all the physical factors of a watershed. The hydrograph for a given storm is derived by multiplying the ordinates of the unit hydrograph by the ratio of excess rainfall for the storm over the unit excess rainfall amount. Procedures for deriving unit hydrographs for ungauged watersheds have been developed, based on hydrograph characteristics and basin physical parameters. The derived hydrographs have been termed synthetic unit hydrographs (Gray, 1970).

As noted above, the unit hydrograph concept has been applied to snowmelt situations. For a given stream, a unit snowmelt hydrograph would be selected and the corresponding runoff volume determined and related to snowmelt computations. Since runoff timing from snowmelt can be particularly sensitive to watershed characteristics, extrapolation is a definite problem. The appropriate relationships for deriving synthetic unit snowmelt hydrographs, if they exist, have not been reported in the literature. However, such relationships should, in any case, be developed on a local or regional basis.

Alternative procedures

From the constraints outlined thus far, it is evident that there are significant problems in determining reliable estimates of the magnitude of 25-year peak flows from indirect relationships. Limitations in both precipitation data and existing precipitation-runoff models inject uncertainties into calculations. Estimates derived from precipitation-runoff models could therefore differ markedly from actual values. Because of these uncertainties in deriving 25-year peak flow volumes, it is desirable to have more than one estimate of potential peak flows in order to arrive at an acceptable value for practical culvert design. Some alternative approaches are outlined below, keeping in mind that precipitation-runoff models provide peak flow estimates for specified return periods.

Transposition of streamflow data

Peak flow data from larger streams could be transposed to small streams on a simple discharge per unit area basis. A comprehensive summary of peak flow measurements, including data plotted on probability or return period graphs, has been published for British Columbia streams by the Water Survey of Canada (1972). However, because of differences in timing of runoff between large and small watersheds, this approach is likely to underevaluate small-stream peak flows. This procedure should be confined to watersheds with similar physiographic and climatic characteristics and limited to drainage areas of about 50 square miles or less. If streamflow records are sufficiently long, say over 10 years, an estimate of return period is also provided.

Slope-area method

A commonly applied approach, which involves actual field measurements of stream channel characteristics, is the slope-area method outlined by the American Iron and steel Institute (1971), Church and Kellerhals (1970), Gray (1970) and the Forest Club (1971). This method uses the Manning equation

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}, \qquad (9)$$

where n is the roughness coefficient, A the cross-sectional area of flow in square feet, and S the water surface slope in feet per feet. R is the hydraulic radius in feet defined as

$$R = \frac{A}{WP},$$

where WP is the wetter perimeter or length, in feet, of wetted contact between the stream and its containing channel measured at right angles to the direction of flow. Both A and R are derived from field observations of high-water marks, usually the highest discernible evidence of peak water levels at the time of field inspection. The roughness coefficient must be estimated from observations of channel bottom characteristics. This approach gives no direct indication of the return period represented by observable high-water marks.

Culvert Survey

A wealth of information on peak flows is stored in existing culvert installations. In particular, when culverts are known to have survived very high runoff events, observation of their sizes can give some indication of peak flow volumes to be expected. If the length of time for which a culvert has performed satisfactorily is known, maximum rain storm or snowmelt conditions for that period can be determined or estimated from climatic records. Where precipitation records are of sufficient length to assign return periods, it becomes possible to draw inferences as to adequacy of culvert size in relation to frequency of occurrence of peak runoff volumes.

Flow volumes estimated in this manner should be adjusted to take into account differences in physical characteristics of the watersheds, including the nature of the vegetation cover. In the case of peak flows from rainfall, for example, the adjustment could be done by applying ratios of area, slope and runoff coefficient to the same powers as used in a rainfall-runoff equation such as the Burkli-Ziegler formula. In addition, the possible effects of logging on runoff patterns should also be considered, as outlined in the next section.

SELECTION OF CULVERT SIZE

In practical terms, the computed 25-year flow is really just a guide to help establish a reasonable value for determining the minimum desirable culvert size. The calculation of peak flow values by several different approaches helps place precipitation-runoff model estimates of 25-year return period flows in better perspective. From the viewpoint of stream and road protection, the largest of the computed peak flow values should probably be selected for culvert design purposes. However, the largest computed value could be unrealistic and some combination or average of derived values might provide a closer approximation to the desired 25-year flow. If more than oneadditional value coincides with the 25-year estimate, confidence is increased that this estimate is a reasonable one. In the final analysis, the experience and extent of local knowledge of the responsible individual will be important factors in ensuring the selection of acceptable and reasonable peak flow design values.

Once a design peak flow has been chosen, the size of culvert to handle the flow can be determined from standard tables and may vary depending on the type of installation. However, the selected size may be insufficient to pass the 25-year runoff under all field conditions. The possible influences of culvert plugging and logging-induced flow changes necessitate application of safety factors, as outlined below.

Culvert Plugging

Plugging of culverts is considered by many to be one of the major problems associated with culverts. Forest debris or gravel may partially fill or block the culvert, or ice may form in the culvert where temperatures remain below freezing for extended periods. The ice problem can be particularly critical in the Interior. In selecting culvert size, consideration should be given to the possibility of these occurrences, to enable design flows to pass through the culvert, and for ease of clearing them out where necessary. Where freezing occurs, the type of culvert installation can also be of critical importance. In addition, where debris is a potential problem, debris barriers should be considered an integral part of the overall culvert design procedure.

Logging-induced flow changes

In addition to culvert plugging, the possibility of increased peak streamflow volumes following logging should be taken into account. Both clearcutting and road construction cause changes in natural drainage and runoff patterns which promote higher streamflow peaks. Removal of the forest cover results in more rapid melting of exposed snow and increased soil moisture content. Roads cause water to flow overland and thus accelerate water delivery to streams. The significance of logging impacts on peak flows differs for snowmelt and rainfall regimes, as noted below. Moreover, the magnitude of potential logging effects will depend on the percentage of watershed area cut over and will tend to decrease with time as the forest cover regenerates.

For coastal regions, Rothacher (1973) cites evidence that clearcutting and road construction increase peak streamflow values for average or low return period rainfall events. One very small drainage area which was completely clear-cut showed increases in peak flows up to one-third of pre-logging values. These increases occur under relatively dry conditions when soil moisture contents are below saturation values. However, high return period or major peak flows generally occur when watershed soils and vegetation are completely saturated. Under these conditions, it appears that little difference in peak flows between logged and unlogged areas can be expected. In fact, Rothacher (1973) concludes for major storms that "the design of structures to handle the water in small streams does not need an additional safety factor for increased peak runoff from logged areas to avoid water damage." At the same time, he does note the need to design structures to accommodate debris as well as peak water flow. His conclusions are based on data from western Oregon and Washington. While these effects of logging have not been verified in British Columbia, similar results can be expected.

For interior watersheds, clear-cutting can lead to increased peak flows from small watersheds. Although measurements are lacking for B.C. conditions, studies reported in the literature (Gray, 1970; Johnson, 1967) indicate increases in peak flows from snowmelt ranging from 10% to over 50% following harvesting. Unfortunately, reported peak flow events are not related to any specific return period. However, the effect of an increase in peak flows would be to increase the magnitude of flow value for a given return period. The removal of forest cover can also be expected to result in increased peak flows in very small watersheds from high intensity summer rain storms. In summary, the possibility of increased peak flows following logging further emphasizes the desirability of selecting a culvert size greater than that needed to pass the estimated 25-year flow.

Safety factor

In practice, a common rule of thumb for selecting culvert size is to choose a culvert pipe one or two sizes larger than that necessary to handle the design flow. If the culvert remains unobstructed and free from debris, it will be approximately two-thirds or one-half full, respectively, for the design flow. The corresponding safety factors are thus 1.5 and 2. In view of the uncertainty of flow calculations, and the possibility of culvert obstruction or logging-induced flow changes, the application of additional safety factors of this magnitude is more than warranted. The calculations of culvert capacities are based on data for metal culverts with inlet water surface the same elevation as the top of the pipe and outlet unsubmerged (The Forest Club, 1971). However the indicated safety factors would apply to any type of culvert installation.

SUMMARY AND RECOMMENDATIONS

The 25-year peak flow establishes a baseline for determining adequate culvert size for stream crossings. However, this criterion should be viewed in the perspective of the true meaning of return period, the limitations of available data, and the possible effects of culvert obstruction and logging-induced flow changes. Applying a safety factor to estimated 25-year flow values is a logical and desirable means of realistically attaining the central goal of the guideline, which is protection of streams and roads from unnecessary damage. Alternatively, a flow of higher return period could be established as the guideline value. A disadvantage of this approach is the low reliability that could be placed on longer return period estimates because of the insufficient length of most streamflow and precipitation records.

To improve the reliability of 25-year peak flow estimates, increased information on precipitation and peak flows from small watersheds are required. For rainfall-generated peak flows, steps should be taken to determine and check regional runoff coefficients for existing rainfall-runoff equations and to develop new relationships. In the case of snowmelt peaks, even more work is required to develop appropriate snowmelt-runoff relationships.

To facilitate development of precipitation-runoff relationships, joint measurements on small watersheds of peak flows and rainfall intensities or snow accumulation and melt are required on a regional basis. Collection and interpretation of data should be undertaken and co-ordinated by the appropriate government agencies. Forest industry personnel could provide valuable assistance in data collection, particularly for storm-related runoff events. For example, they could take readings on a storm basis from simple crest-stage gauges designed to measure peak water levels. Industry could also undertake culvert surveys and otherwise provide information on culvert sizes and periods of operation for application of the approach suggested in the section on alternative procedures for peak flow evaluation. Actual stream discharge measurements would normally, but not necessarily, be the responsibility of government agencies.

In addition to expanding data collection programs, synthesis of existing information should be undertaken. Both streamflow and precipitation data undoubtedly are in the files of a number of agencies other than those officially responsible for data collection. Some possible examples are the University of B.C., B.C. Department of Highways, B.C. Hydro, municipalities and consulting firms. Systematic assemblage and analysis of all existing data in the province would provide a much better basis for estimating 25-year peak flows than presently exists.

In summary, current information is generally insufficient for proper evaluation of 25-year peak flow values for small streams in British Columbia. Considerable effort will be required to overcome this information gap. At the same time, equal attention should be given to coping with the problems of culvert obstruction by debris and ice formation. Determining the effects of logging on runoff is essentially a research problem. Two research watershed studies, in progress on coastal British Columbia, will provide some local information on this subject in the next few years. Otherwise, potential changes in runoff following logging or other forms of land disturbance will have to be estimated from data collected outside of the province.

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GLOSSARY

Concentration time - time required for a particle of water to move from the most remote part of a watershed to the point of reference on the stream.

Hydrograph - graph of rate of flow or water level of a stream as a function of time.

Small stream or small watershed - have been defined in this report as having a drainage area less than about 5 square miles.

Snow pack water equivalent - depth of water that would be obtained from melting the snow pack.

Stream discharge - rate of flow of water in a stream, usually expressed in terms of cubic feet per second.

25-year peak flow - maximum stream discharge which is expected to occur on the average once every 25 years.

APPENDIX

Addresses of Data Source Agencies

1. Scientific Support Unit,
   Atmospheric Environment Service,
   739 West Hastings Street,
   Vancouver, B.C.

   - precipitation intensity and frequency data.

2. Climatologist,
   Atmospheric Environment Service,
   416 Cowley Crescent,
   Vancouver International Airport South,
   Richmond, B.C.

   - general climatological information, including precipitation.

3. Officer-in-charge,
   Regional Climate Data Centre,
   Atmospheric Environment Service,
   302 Denison Road,
   Victoria, B.C.

   - monthly precipitation records for recording and non-recording gauges.

4. Hydrology Division,
   Water Resources Service,
   Water Investigations Branch,
   Parliament Buildings,
   Victoria, B.C.

   - snow survey data.

5. District Engineer,
   Water Survey of Canada,
   1001 West Pender Street,
   Vancouver, B.C.

   - daily stream discharge data, including information on frequency of peak flows.

   - annual publication of Surface Water Data.