APPENDIX E

ESTIMATING RUNOFF FROM SMALL WATERSHEDS

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E.1 Introduction

Drainage areas along rural highways are typically small (less than 20 ha) and can have long flow lengths. Rural highway catchments have relatively low imperviousness levels that generate lower runoff rates than similarly sized urban catchments. Runoff does, however, become concentrated along ditches and near outlet points, thus increasing erosion potential. Estimating peak runoff flow rate from small watersheds on a highway construction site is a key activity in the design of suitable erosion and sedimentation control measures. Using estimates of peak runoff flows, channels and control structures can be adequately sized to prevent overtopping and washout.

This chapter focuses on runoff calculation methods for highway construction sites in rural conditions. The estimation of runoff for urban highway construction sites is complicated by the effects of urbanization and development. As such, urban runoff flow rate estimation methods are not presented in this document. Reference should be made to Design Bulletin #16 for information relating to drainage for Provincial Highways in urban areas (www.transportation.alberta.ca/649.htm).

The objective of utilizing flow estimates is to provide a stable and economical erosion protection design. It is of paramount importance that the erosion and sedimentation control strategy withstand the design runoff flow rates during its lifespan. Generally, it is usually most cost-effective to utilize the existing drainage pattern as much as possible. In terms of design frequency, different road types have specific purposes and require different design standards. Table E.1 summarizes the general design levels for runoff capacity for several road service levels.

Table E.1: Return Frequencies for Roadway Drainage Design

Road Classification (RTAC 1976)	Return Period or Other Criteria for Storm Drainage System		
	Minor System	Major System	Stream Channels
Freeway urban arterial	10 year	100 Year	10 year
Rural arterial collector	2 to 5 year	100 Year	2 to 5 year
Local	2 year	100 Year	2 year
Depressed roadways	10 to 25 year		

Notes:

1. The flood frequencies for storm drainage systems may be modified to reflect local municipal requirements and adjacent land uses.
2. The minor system comprises the road gutters, inlets, storm sewers, and minor ditches. The major system is the route followed by runoff waters when the capacity of the minor system is exceeded and generally includes the roadway surface itself and major channels.

The amount of time involved in carrying out an economic analysis often cannot be justified when implementing small temporary or permanent erosion and sedimentation control measures. Guidelines are thus established by various jurisdictions for the choice of an appropriate event to be used in design based on experience. Erosion control work of a permanent nature should thus be designed for a runoff event that corresponds to a return period of at least once in 10 years (a 1:10 year event). Furthermore, provision should be made for safe overflow or bypass in more extreme events. Temporary erosion control work may be designed for a runoff event that corresponds to a return period of at least twice in 5 years (a 2:5 year event).

Permanent vegetative or bio-engineered measures that will replace any temporary measures should be capable of withstanding at least a 1:10 year runoff event.

Economic analyses are appropriate for large temporary or permanent structures. Costs associated with various structure sizes are estimated and are compared with the benefits to be derived, including the benefit of having a reduced probability of failure and reduced maintenance effort. The frequency of the event chosen for design is then based on an optimization of investment expenditure. However, major roadways required for emergency purposes will always be designed to withstand runoff events of 1:100 years. Therefore, erosion protection measures for these roadways should have a similar standard.

Designs should be based on professional judgement and should be performed by a qualified professional.

E.2 Approaches to Runoff Estimation

There are several different approaches to estimating peak runoff flow. The main categories for estimating peak runoff flow are listed as follows:

- Rational Method;
- Flood frequency analysis;
- Hydrologic modeling; and
- Empirical formulae.

Of these methods, only the Rational Method will be discussed in this document. The Rational Method provides reasonable peak runoff flow estimates for small watersheds. The use of this procedure assumes that precipitation events of a given frequency produce runoff events of similar frequency.

The individual or firm responsible for designing erosion and sedimentation control measures must use their judgement and experience in determining the most appropriate means for estimating runoff flow rates.

E.2.1 Rational Method

The Rational Method is widely practiced in determining peak runoff flows for small to moderately sized catchments and can be applied to rural basins up to 25 km^2 (MTO 1984). However, it is considered to be most applicable to basin sizes under 100 ha where storage and channel routing effects are small. It is understood that there is no specific design manual for use of the Rational Method in Alberta, but there are complete reference documents in several other Provinces and from the United States. Caution should be exercised where lake storage and attenuation effects are significant within a basin. This does not generally apply to roadway areas where grading is continuous. The procedure is simple and relies on a minimal amount of local data. The formulation for the Rational Method is presented as follows:

$$Q = 0.00278\ C \times I \times A \qquad \text{(Equation E.1)}$$

Where: Q = peak flow (m^3/s)

C = runoff coefficient (dimensionless)

I = precipitation intensity (mm/hr)

A = effective drainage area (ha)

The simplicity of the equation has resulted in the method gaining widespread usage for more than 100 years. However, such simplicity was achieved by lumping the effects of a number of variables, namely soil conditions, surface cover, antecedent moisture, depression storage and land slope into a single input parameter referred to as the runoff coefficient. Extreme care should therefore be taken in the choice of the coefficient if reasonable accuracy is to be obtained. The Rational Method has been determined through comparisons, to typically overestimate flows so it is suitable for the design of erosion and sedimentation control measures. It is not applicable for bridge file designs.

The major limitation of the Rational Method is the output. While some other methods produce a runoff-time curve or hydrograph, the Rational Method produces only an estimate of the peak runoff. For erosion control works along roadways, this limitation is not significant, as all designs are done taking into consideration the peak discharge from an event having a particular design frequency. However, for larger sediment control structures, the peak inflow into the sediment basin may be modified by the storage effect of the reservoir resulting in a peak outflow that will be smaller than the inflow. In such a case, routing the inflow hydrograph through the basin will produce an outflow hydrograph that will be more appropriate for design. Routing procedures are not simple and should be performed by a qualified engineer.

E.2.1.1 Key Assumptions

Inherent in the use of the Rational Method are a number of key assumptions. Understanding these assumptions will lead to a better appreciation of the results provided by this method. These assumptions are presented as follows:

1. The rainfall intensity is uniform over the catchment for the duration of the storm. Rainfall events actually vary in both space and time. With very small catchments, the assumption may be true, but for larger catchments there will be a spatial variation in rainfall intensity and hence a tendency to overestimate runoff.
2. Maximum runoff occurs when rainfall lasts as long as or longer than the time of concentration (t_c). The t_c is the time for runoff to travel from the hydrologically most distant point in the watershed to the outlet or point of interest. The assumption is that every point within the catchment is contributing to runoff to the point under consideration. Again with small catchments, the assumption is likely to be true, but with larger catchments, there may be a divergence from the assumption due to channel routing and storage effects.
3. The design precipitation event has the same frequency as the runoff event being estimated. This is not necessarily true, as identical storm events can produce highly variable runoff hydrographs over the same catchment when conditions such as antecedent moisture, are different.

4. The effective drainage area should be used and it includes all areas that contribute runoff during major runoff events. Some areas of the province are internally draining sloughs and only evaporate or infiltrate runoff. These areas do not contribute runoff flows to the basin outlet.

E.2.1.2 Runoff Coefficient

Table E.2 provides guidelines for evaluating the value of the runoff coefficient, C. In areas having more than one soil type or land use, the effective coefficient is obtained by evaluating a coefficient for each sub-area and computing a "weighted" average for the entire catchment based on area served.

E.2.1.3 Rainfall Intensity

Statistical information relating to the intensity, duration, and frequency of rainfall events is currently collected at more than 150 stations within Alberta that record daily rainfall amounts. However, only about 20% of them continuously record rainfall data from which IDF curves can be derived. The locations of the recording stations are available through Environment Canada - Atmospheric Environment Service. Design intensity values for any selected duration and frequency can be read directly from the curves for the selected station. Locations in close proximity to any recording station can use the identical information extracted from the IDF curves. However, as important as close proximity is, the selected station should also have a similar elevation and surrounding terrain, as mountain and valley effects greatly influence precipitation data. Other sites may have to linearly interpolate data from two or more nearby sites. An alternative and more compact form of the information given by the IDF curves was published in 1985 by the AES as the Rainfall Frequency Atlas for Canada.

The rainfall intensity to be used in the design of erosion and sedimentation control measures is taken from a nearby intensity-duration-frequency (IDF) curve, t, for the particular watershed. Available methods to determine t_c from an IDF curve include the Airport Method, SCS Upland Method and Branby-Williams Method.

Table E.2: Rational Method Values

LAND USE	C	LAND USE	C
BUSINESS		**LAWNS**	
Downtown areas	0.70-0.95	Sandy soil, flat 2%	0.05-0.10
Neighbourhood areas	0.50-0.70	Sandy soil, average 2-7%	0.10-0.15
		Sandy soil, steep 7%	0.15-0.20
RESIDENTIAL		Heavy soil, flat 2%	0.13-0.17
Single family areas	0.30-0.50	Heavy soil, average 2-7%	0.18-0.22
Multi units, detached	0.40-0.60	Heavy soil, steep	0.25-0.35
Multi units, attached	0.60-0.75		
Suburban	0.25-0.40	**AGRICULTURAL LAND, 0-30%**	
		BARREN PACKED SOIL	
INDUSTRIAL		Smooth	0.30-0.60
Light areas	0.50-0.80	Rough	0.20-0.50
Heavy areas	0.60-0.90		
Parks, cemeteries	0.10-0.25	**CULTIVATED ROWS**	
Playgrounds	0.20-0.35	Heavy soil, no crop	0.30-0.60
Railroad yard areas	0.20-0.40	Heavy soil, with crop	0.20-0.50
Unimproved areas	0.10-0.30	Sandy soil, no crop	0.20-0.40
		Sandy soil, with crop	0.10-0.25
STREETS			
Asphalt	0.70-0.95	**PASTURE**	
Concrete	0.80-0.95	Heavy soil	0.15-0.45
Bricks	0.70-0.85	Sandy soil	0.05-0.25
Drives and walks	0.75-0.85	Woodlands	0.05-0.25
Roofs	0.75-0.95		
		BARREN SLOPES > 30%*	
		Smooth, impervious	0.70-0.90
		Rough	0.50-0.70

Note: The Designer must use judgment to select the appropriate value of C within the range. Generally, large areas with permeable soils, flat slopes and dense vegetation should have lowest C values. Smaller areas with dense soils, moderate to steep slopes and sparse vegetation should be assigned highest C values.

* From Portland Cement Association, *Handbook of Concrete Culvert Hydraulics*, 1964, p.45.