Development of Runoff Depth Map for Alberta

Introduction

Assessment of basin runoff potential is an important component of the "Hydrotechnical Design Guidelines" for highway projects interacting with streams. This component requires design hydrologic inputs to evaluate the potential water supply during a runoff event. This information is then used in combination with analysis of channel capacity and historic highwater data to establish design parameters for stream crossings and protection works.

Flow values are not readily transferable between basins because they are the product of the many unique runoff characteristics of each basin. However, runoff volumes can be more readily transferred between basins in the same hydrologic region. Therefore, these runoff volumes can be compared to others in the hydrologic region to establish design values. Combining design runoff volumes with design timing parameters provides a set of design runoff supply inputs. These can be used as unit discharge values for simple assessment of upper bound runoff potential, or as simplified design supply hydrographs in a hydrologic routing analysis.

Development of the design runoff volume and timing parameters is based on the largest runoff measurements collected by Water Survey of Canada (WSC). The design volumes are expressed as runoff depths 'd', calculated by dividing the runoff volume by the drainage area. The timing is expressed in terms of a time to peak (or centroid) 'T_c', and an assumed hydrograph shape. Ecodistricts, as identified by Environment Canada, have been used with these runoff measurements to define hydrologic regions and assign design parameters to them.

Runoff Database

In order to determine the design runoff depth and timing parameters, runoff hydrographs were built for the largest runoff responses in the WSC HyDat daily flow database. An Excel based tool was used to convert the daily flow and peak instantaneous values into a hydrograph using a graphical process. The start of the response was identified at the point where a sharp increase in flow occurs at the front end of the hydrograph. The flow value at this point is considered the base flow. The recession limb of the hydrograph was generally modified to account only for the direct runoff portion of the hydrograph. This was done by extending the hydrograph from the point of inflection down to the base flow following the slope of the hydrograph prior to the point of inflection. The direct response is that portion of the runoff that leaves the basin without going into storage or groundwater. The direct response portion of the hydrograph results in the peak water levels and velocities, and is of interest in establishing design parameters. An example of a hydrograph built using this process is shown in

Figure 1. The hydrograph tool reports the runoff depth and time to centroid for each event.

These hydrographs were built for about 3800 events. Most of these events occurred in March to April or June to August. The March to April responses are considered to be predominantly snowmelt responses, and the June to August responses are considered to be predominantly rainfall responses. This has been confirmed by examining rainfall records at the time of the response. Approximately 400 of the responses are in the snowmelt time frame.

Runoff Hydrographic Observations

In most cases, it was observed that the shape of the direct response hydrograph could be reasonably described by a symmetrical triangle. As a result, only the runoff depth 'd' and the time to centroid 'T_c' have been used in the analysis. Any hydrographs based on these values are assumed to have a symmetrical triangular distribution.

Plots of 'd' vs. 'T_c' were created for various regions to examine the nature of runoff responses in Alberta. It was apparent that a family of envelope curves could be drawn to fit the data for each distinct region. The envelope curves are of interest in establishing the design values for regions, as the observed runoff data are the result of various degrees of routing. The use of envelope curves accounts for the effect of this routing.

Typical rainfall response envelope curves start at about 'T_c' equal to 10 hours, and rise sharply until 'T_c' is about 20 hours (Figure 2). At this point, the envelope curves flatten considerably. The time lag before runoff is consistent with the observation that most of the losses to infiltration and storage occur before significant runoff results. This value also suggests that a minimum duration of storm is required before enough rainfall occurs to fill these initial losses. The break in slope at about 20 hours suggests that a certain minimum duration of storm is required to deliver the typical rainfall volume associated with large storms in Alberta. This is consistent with rainfall data observations discussed in "Large Rainfall Events in Alberta".

Typical snowmelt response envelope curves also start at about 'T_c' = 10 hours, but the rise is not as sharp and there is no well-defined break in the slope of the line (Figure 3). The flatter slope of the envelope curve suggests that the peak rate of runoff supply from snowmelt events is lower than that of rainfall events. The lack of a break in slope suggests that there is no minimum duration for a large event, likely because the runoff supply will continue until the snowpack is depleted.

An additional observation for rainfall-runoff response events, is that runoff depth decreases with increasing drainage area. This can be seen in Figure 4. This is likely due to rainfall values decreasing with distance from the eye of the storm, and the storm and basin not being perfectly aligned with each other.

Geographic Assignment

Due to the variance in observations across the province, hydrologic regions with like runoff and meteorological conditions must be identified. Environment Canada have done a substantial amount of work on identifying like areas as part of the Soil Landscapes of Canada project. The country has been broken up into ecozones, ecoregions, and ecodistricts. An ecodistrict is an area with similar characteristics in the following categories : "regional landform, local surface form, permafrost distribution, soil development, textural group, vegetation cover/land use classes, range of annual precipitation, and mean temperature."

The ecodistrict has been adopted in this study as the building block for areas of like hydrologic response potential. There are over 100 ecodistricts in Alberta. However, many adjacent ecodistricts have similar hydrologic characteristics and can be combined to form hydrologic regions.

Environment Canada have published water deficit values for each of these ecodistricts based on long-term precipitation records and theoretical evapotranspiration equations. The values range from about –100mm (water surplus) in some areas of the Rocky Mountains to about 700mm in the semi-arid areas of south-east Alberta. These water deficit values are valuable in identifying like ecodistricts that can be combined to simplify the creation of a map with design values.

Response Analysis

Due to the significant difference between the runoff depth envelope curves for rainfall and snowmelt response, the two processes have been analysed separately. Design values have been developed from the observations for both cases, and the governing condition assigned for each identified hydrologic region. In general, snowmelt values govern for the eastern portion of the province, which typically has a significant annual water deficit (> 200m). The rainfall values govern for the areas closer to the Rocky Mountains with smaller annual water deficits or surpluses.

Two levels of snowmelt response have been observed in the province. The higher response curve is for areas with lower water deficit values. For these areas, rainfall response will govern design. The lower response envelope curve covers the high water deficit areas and this curve will govern design conditions, as it exceeds the largest rainfall responses in these areas. Although there is no distinct break in slope of this envelope curve, the point of highest unit discharge is about 'd' = 35mm at 'T_c' = 40 hours. These values have been adopted as design conditions for all areas identified to be governed by snowmelt response.

The only historic observation that exceeds this envelope curve is that on West Arrowwood Creek (Gauge 05BM018) in 1996. The snowmelt response value of ‘d’ at ‘T_c’ = 20 hours (design value for rainfall response) is 15mm. This value may be of interest for basins that cover both snowmelt and rainfall response areas.

The break in slope for rainfall response envelope curves is consistently in the range of ‘T_c’ = 20 hours. However, ‘d’ varies considerably across the province. Querying the assembled runoff database for values that exceed the snowmelt response curve yields 166 events at 95 gauges. As mentioned previously, these points fall over ecodistricts with smaller water deficit values. This area is typically located west of 114° longitude and south of 56° latitude.

The envelope curves for rainfall events can be approximately fit with the equation :

$$d = K \ln (T_c - 9)$$

Use of this equation allows calculation of one parameter ‘K’ to describe the magnitude of the rainfall response for all events (covering a range of ‘d’ and ‘T_c’). ‘K’ ranges from about 10 near the snowmelt curve to about 60 for the largest events. For design value assignment, ‘K’ can be converted to a ‘d’ value at ‘T_c’ of 20 hours, which is close to the point of maximum discharge potential on the curve. The ‘d’ values range from about 40 mm to 150mm.

Assigning the largest value of ‘K’ to each ecodistrict shows a distinct geographic trend. Some geographic anomalies are evident due either to lack of observed data or an extreme event. Geographic extrapolation based on location, number of observed events, and ecodistrict water surplus data has been performed to account for these anomalies. This results in a more consistent geographic distribution of rainfall-runoff event magnitudes.

The recorded values that exceed the current design assignments are :

- 07BG004 - Lily Ck, 1988 - 614
- 05CC008 - Blindman R, 1990 - 703, 630
- 07GF001 - Simonette R, 1987 - 618, 610, 621
- 05BK001 - Fish Ck, 1915 - 631
- 05AA003 - Castle R, 1923 - 1019, 1018
- 07GH005 - Wabatanisk R, 1990 – 611

These events appear to be outliers based on the rest of the event data in the vicinity. All of these events are within 30 to 40% of the design assignments.

Much of the northern part of the province has little extreme runoff data on record. As a result, a default design value at the lower end of the rainfall range (‘d’ =

40mm) has been assigned to most of this area. This assignment is based largely on the water deficit values for these areas. However, some ecodistricts in the northern part of the province have been assigned higher values based on non-WSC observations and lower water deficit values. An example is the ecodistrict covering the Buffalo Head Hills, in which highwater estimates in 1987 for Rat Creek result in a 'K' of about 30 ('d' = 70mm). Other significant rises in the north with similar water surplus values include the Clear, Whitemud and Hawk Hills and the Birch and Caribou Mountains. These areas have also been assigned 'd' of 70mm.

Application

The runoff depth parameter assignment is shown on Figure 5. This map shows the design runoff depth based on rainfall response. This map is also available separately as a PDF file and a JPG to facilitate zooming to locate a basin with respect to the shown hydrologic regions. The latitude and longitude grid should be sufficient to estimate the design parameters for any given basin. These runoff depth values should be paired with 'T_c' = 20 hours. Design runoff supply hydrographs can be built using 'd', 'T_c', and an assumed symmetrical triangular distribution.

The region assigned 'd' = 15mm is the region that will be governed by snowmelt response. For basins totally within this region, the design parameters are 'd' = 35mm and 'T_c' = 40 hours. Basins with significant areas in both the rainfall and snowmelt zones may require assessment under both cases to identify the governing case.

For large basins in the rainfall response zone, the effect of drainage area may be considered. The envelope curve in Figure 4 can be fit by the following equation :

$$d_A = d_{25} * (1 – 0.0033 (A – 25)^{0.517})$$

Where d_A is the runoff depth for drainage area 'A' (km^2), and d_{25} is the runoff depth at an area of 25 km^2. This equation should be applied for larger basins in the rainfall response zone. This adjustment does not apply to snowmelt response design parameters.

Details on the application of these design parameters to assess basin runoff potential are discussed in the "Hydrotechnical Design Guidelines" document.

Figure 1 – Hydrograph Build Example

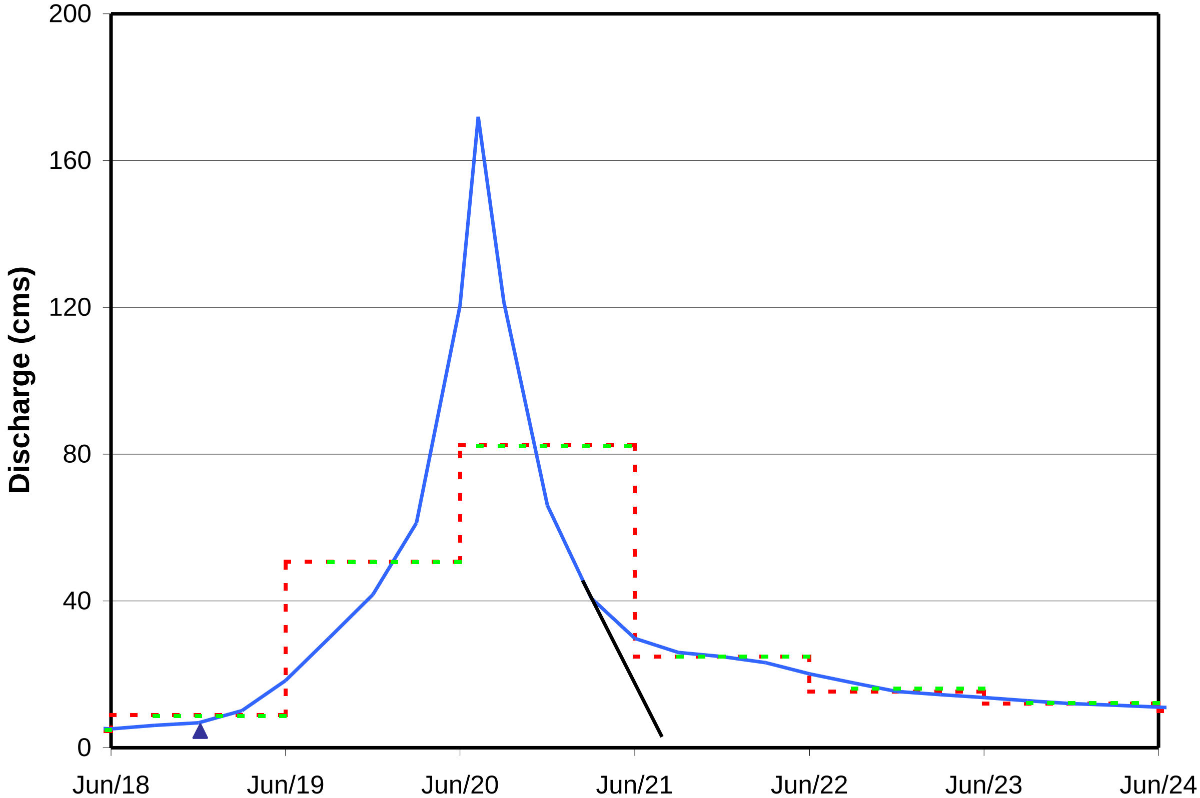

Figure 2 – Rainfall Response Plot

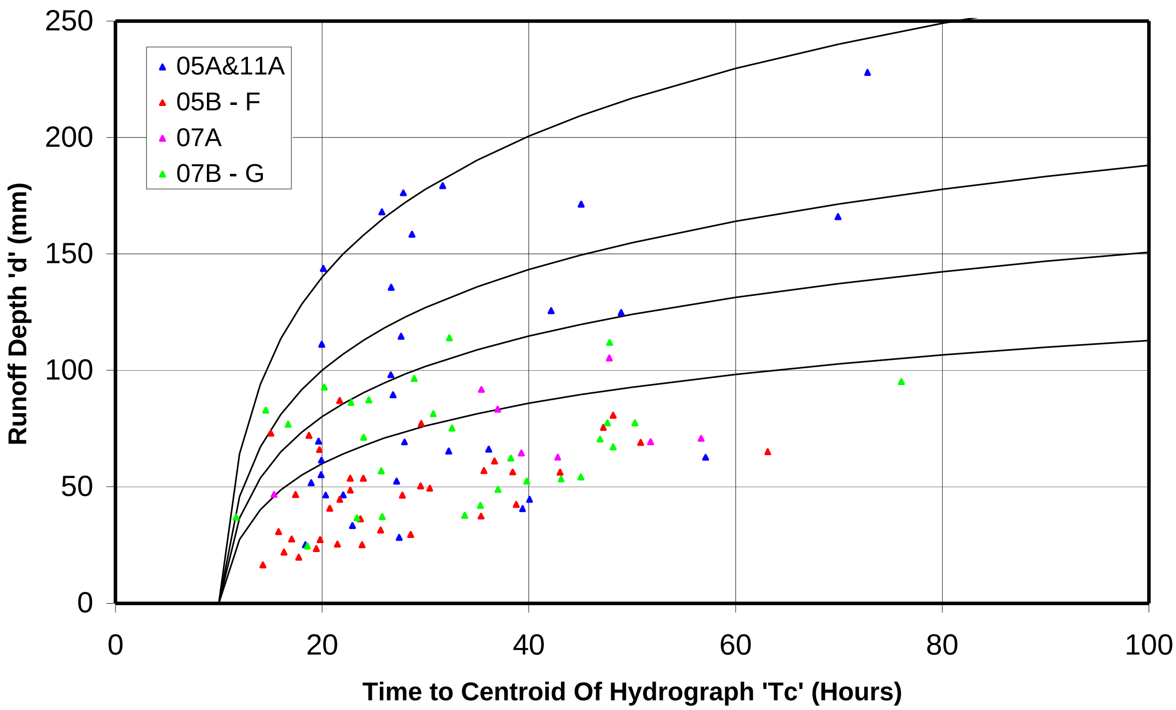

Figure 3 – Snowmelt Response Plot

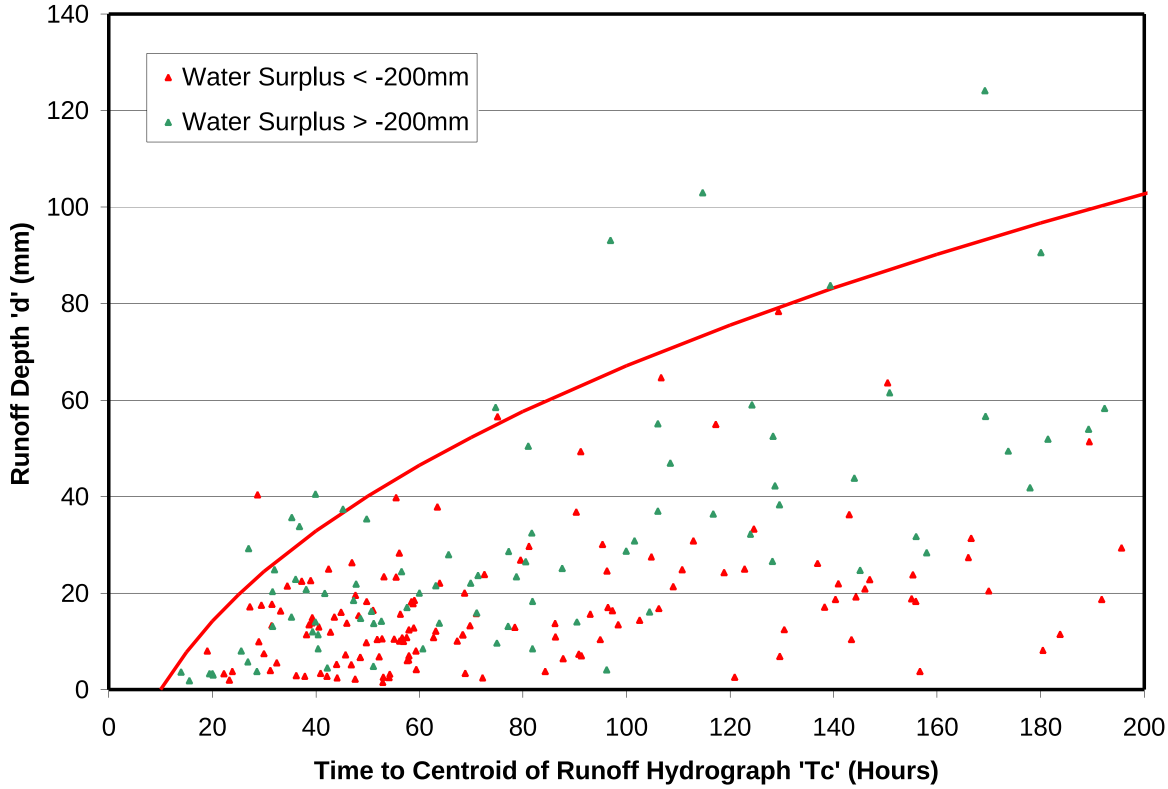

Figure 4 – Runoff Depths For Large Basins

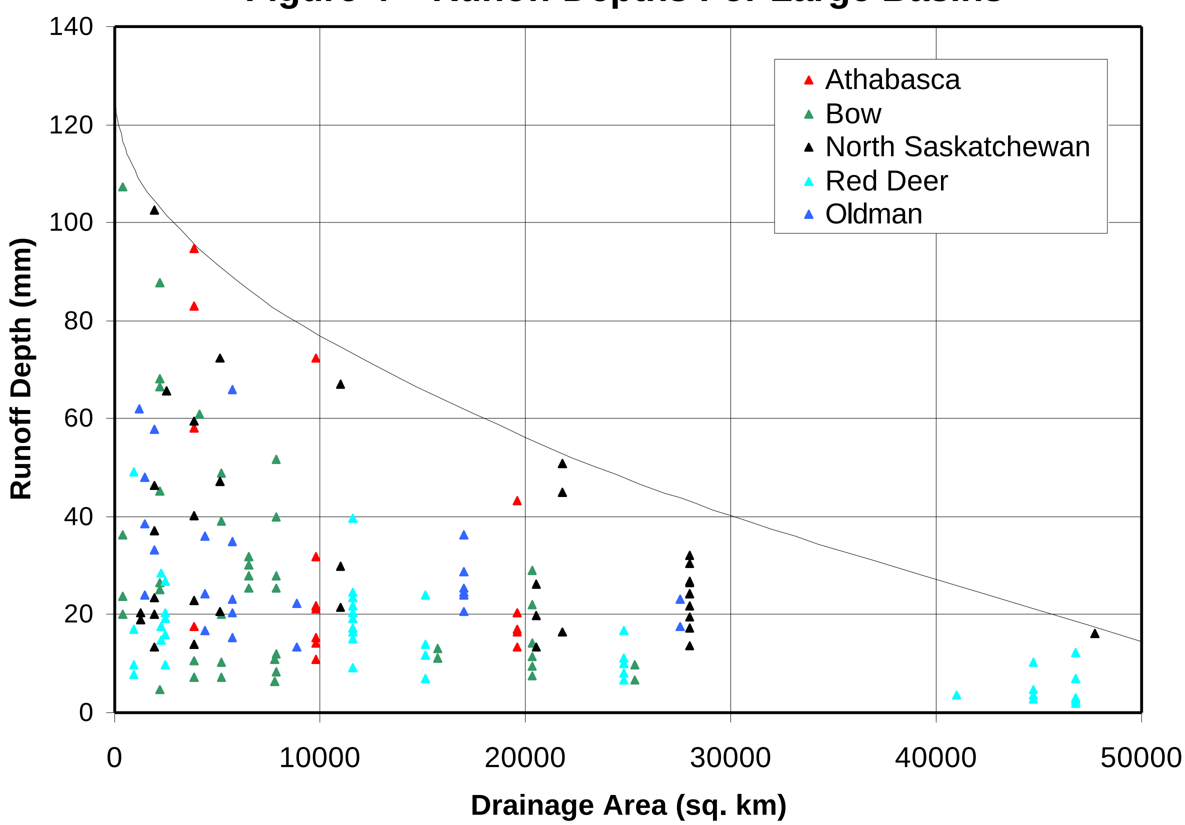

Figure 5 – Design Runoff Depth Map