Alberta Flood Envelope Curve Analysis

Introduction :

Flood envelope curves have been used for many years as an attempt to provide context on the magnitude of flood events or design values. One common envelope curve is the Creager diagram, first published in 1945 [1]. The original diagram was based largely on U.S. data. Updated versions with data added for some extreme flood data from Canada have been published [1, 2].

The Creager diagram shows a relationship between unit discharge (q) and drainage area (A) that has a concave down shape on a log-log plot. The basic shape of the Creager curve implies a strong relationship with drainage area at smaller drainage areas, and a much weaker relationship at larger drainage areas. The curve has a coefficient (C) applied to it, ranging from 30 to 100 in the original publication. This coefficient is often considered to be a “practically area-neutral measure of flood severity” [3].

Plotting of runoff data from Alberta on this curve shows some values in the C = 30 range for rivers with large drainage areas ($A > 10000 km^2$). However, there are no values close to the C=30 line for smaller drainage areas ($A < 1000 km^2$). This suggests that the basic curve shape of the Creager line may not be applicable over the entire range of drainage areas, meaning that the Creager coefficient may not be a true measure of flood severity. This study examines known Alberta runoff data to assess the nature of flood envelope curves in the province and evaluate the applicability of the Creager curve.

Methodology :

Water Survey of Canada (WSC) has compiled and published peak flow values at many sites across the province for about 100 years. Previous studies on runoff depth mapping [4] and hydrograph travel analysis [5] have resulted in identification of all of the significant runoff hydrographs in the Alberta portion of the WSC database, with more than 3800 hydrographs identified. The hydrograph analysis undertaken in these studies facilitates estimation of instantaneous peak flow values where they are not provided. This WSC based data-set has been supplemented with some estimates of peak flow response at certain sites, based on highwater observations and dam operation data.

An additional source of data is the inventory of design values for stream crossings stored in the Alberta Infrastructure and Transportation Hydrotechnical Information System (HIS) database. The values have been derived using the Hydrotechnical Design Guidelines [6], based on channel capacity, historic highwater, and runoff depth techniques. This data-set is not completely independent, as the runoff depth component and some of the historic highwater data are derived from the WSC data-set. Also, historic highwater data are converted to flows using synthetic rating curves, as opposed to the WSC rating curves that are based on actual measurements. However, this data-set does add many more data points to the analysis (currently about 1300), which should be of interest in reviewing flood envelope curves.

Plots of q vs. A on a log-log plot were prepared for each of the major rivers that drain the eastern slopes of the Rockies. Points that stood out from the crowd were evaluated to assess the confidence in the data. Most peak instantaneous flows reported by WSC are based on extrapolation of rating curves that are defined by actual gauging measurements. Most of the underlying measurements have been gathered and entered into a database as part of a previous evaluation of open channel flow equations [7]. The nature of most rating curves is such that a small increase in stage can result in a significant difference in discharge at the upper end. Therefore, confidence in the accuracy of flows that are based on significant extrapolation from the well defined portion of the rating curve is reduced. Any points that fell into this category were plotted separately due to the reduced confidence, but not eliminated as they generally do represent significant runoff events. A few additional peak instantaneous flow values were eliminated from the plots due to questionable data, such as peak flows that are not consistent with the overall runoff hydrograph.

Creager envelope curves were added to each of the plots. Additional envelope curves were added based on both a simplified model and a visual fit. The simplified model is a combination of two straight intersecting lines. The first line is a line of constant q covering the lower range of drainage areas, representing the peak unit discharge for the most productive part of each basin. The second line is a line that follows the section of the major river for which the runoff hydrograph is translating in the downstream direction with no additional runoff input. In this range, discharge (Q) is no longer a function of A, and q varies inversely with A. The visual fit is a curve that transitions between these two lines, while still providing an envelope to the runoff data.

In order to examine some physical properties that may affect the shape of the flood envelope curves for each basin, a map with the basin outlines superimposed on ecoregions was prepared. Ecoregions are defined by the Canadian Soil Information System [8]) as areas “characterized by distinctive regional ecological factors, including climate, physiography, vegetation, soil, water, and fauna”. There are about 20 ecoregions in Alberta. Of the various properties published for each ecoregion, annual water deficit has been shown to be useful as an indicator of runoff potential [4]. Other factors, such as drainage system capacity and basin storage should also affect runoff potential, but are likely accounted for somewhat in the delineation of the ecoregions. Therefore, published annual water deficit values were used to colour code the ecoregions.

Results :

The q vs A plots for each of the major river basins are shown in Figure 1a to Figure 1f. These plots show a Creager curve that envelopes all of the data for the basin. It is evident that the Creager shape of curve does not accurately fit as an envelope for any of these basins. Figure 2 shows a similar plot with all of the data for the province combined into one plot. Again, the Creager shape of curve does not fit well as an envelope. With the Creager coefficient set to match the envelope of q for larger values of A, the resulting curve significantly over-predicts q for smaller values of A.

Figure 3 shows the AIT bridge data together with the WSC data. This plot shows that all of the current bridge design data falls within the flood envelope of the WSC data. This suggests that none of the flow estimates from observed highwater marks at these additional sites would result in modification to the flood envelope curves developed based on the WSC data. This is not surprising for the larger drainage area sites where the WSC gauges have long record sets and there are a limited number of bridge crossings. However, the bridge data-set provides many additional data points in the range of smaller drainage areas.

Figure 4 shows the envelope curves for each basin on one plot. Based on the Creager curve, the largest events on the three northern rivers (Smoky River, Athabasca River, and North Saskatchewan River) would denote more severe floods than those on the three southern rivers (Oldman River, Bow River, and Red Deer River). However, the highest values of q for each basin are similar, with possibly a reduction as latitude increases. The largest events on each of these rivers have shown similar physical indicators [6] of flood severity, such as extent of flooding, infrastructure damage, and changes to the river system. Also, each of these rivers has seen more than one event in the range of the largest event recorded, suggesting that the severity of flooding on each river is similar (see Table 1). This comparison of flood envelope curves shows that the Creager curves do not provide an accurate assessment of flood severity for either a range of drainage areas within a basin, or for similar drainage areas over a range of basins.

Figure 5 shows the map of all basin outlines overlain on a map of ecoregions grouped by annual water deficit. It is apparent from this map that there is a significant variance between basins on the area that drains the ecoregions with higher runoff potential (annual water deficit < 100mm). Table 2 presents a comparison of basin area draining the high runoff potential ecoregions and the envelope curves (represented by q at $A = 10{,}000km^2$). A direct correlation would not be expected, due to the impact of alignment of the storm over the basin and other basin routing effects. However, it appears that the reduced high runoff potential drainage areas in the three southern basins have impacted the shape of the flood envelope curves. Of the three southern basins, the Oldman basin has a relatively high envelope curve, likely due to the high q values in the upper portion of the basin. The Bow basin has a relatively low envelope curve, which is likely due to a significant portion of its upper basin being at a high elevation where rainfall runoff response is likely somewhat reduced. Of the three northern basins, the Athabasca basin appears to have a relatively low envelope curve. This is likely due to factors such as the geographic spread of the high potential runoff areas, major routing features, and a large portion of the upper basin being at a high elevation.

The other aspect of the flood envelope curves that remains to be explained is the peak value of q at lower values of A. As stated previously, the peak q values at small drainage areas for each of the basins is somewhat similar, with $q \sim 1cms/km^2$ for most basins except for portions of the Oldman and Bow River basins. The similarity is likely due to the fact that each of these basins drains a portion of the high runoff potential areas on the eastern slopes of the Rockies. Therefore, a similar storm over a similarly configured sub-basin in each of these large basins should produce similar results. The higher peak q values on the Oldman basin do appear to be based on valid data, but can not be explained by factors considered in the current analysis.

The two envelope curve models shown on Figures 1a to 1f do appear to be a better fit for each basin than a Creager curve. A reduction in q with increasing A would be expected, even in the lower range of A, due to the shape of the storm and the routing of flows together in the downstream direction. However, this expected trend is not readily visible in the current data-sets. A slight decrease in Q vs. A would also be expected for larger values of A due to flood wave attenuation, which would result in the envelope curve being a little steeper than the simplified model. However, the magnitude of this attenuation appears to be relatively small.

Figure 6 shows runoff data for areas of low runoff potential in the six basins separately. The data clustering shows a clear difference between high and low runoff potential areas, with the peak values of q being much lower for the low runoff potential area. There are insufficient large basins with the water source in the low runoff potential area to adequately define the full flood envelope curve for these areas. This figure shows that although the flood envelope curves shown for each basin fit better than the Creager curve, they are still not applicable throughout each basin as a measure of flood severity.

Conclusions :

This analysis of flood envelope curves for Alberta shows that the Creager curve does not fit well as an envelope curve to Alberta runoff data. Creager coefficients for the six basins studied suggest different levels of flood severity. However, consideration of physical flooding indicators and historic context suggests that the flood severity for each basin is similar. As such, the Creager coefficient is not an accurate measure for assessing flood severity. This is true for comparisons between sites within the same basin as well as sites in different basins.

The shape of envelope curves observed can be described as a transition from a peak q value for lower values of A to an inverse relationship between q and A at higher values of A. The peak value of q is likely a function of the highest runoff potential area in the basin. The breadth of the envelope curve appears to be related to the amount of high runoff potential area in the basin.

The envelope curves presented fit better for each basin than a Creager curve. However, the difference in the curves for each basin shows that these curves still do not present an accurate assessment of flood severity between basins. The curve for any given basin is still of limited value as the basin may cover areas of variable runoff potential. Also, the runoff response for any sub-basin is a function of many parameters other than just drainage area, such as drainage system capacity and channel and storage routing effects.

Flood envelope curves do provide some context to the upper range of flows observed in a basin. As such, they are useful for identification of data points that require additional scrutiny, due to inconsistency with the remainder of the data-set.

Table 1 Historic Context of Largest Runoff Events

Stream	Location	Gauge Record	A (km^2)	Year	Q (cms)	Stage (m)
Oldman	Lethbridge	1912 - Present	17000	1995	4700	8.5
				1908	4500*	8.3
				1953	3100	7.1
Bow	Calgary	1911 - Present	7800	1879	2250*	4.5
				1897	2250*	4.5
				1902	2250*	4.5
				1932	1500	4
Red Deer	Red Deer	1913 - Present	11600	1915	1900	6.6
				2005	1500**	5.9
				1954	1500	5.9
North Saskatchewan	Edmonton	1911 - Present	28000	1915	5800	12.8
				1899	5100*	12.2
				1986	4500	11.6
Athabasaca	Athabasca	1913 - Present	75000	1954	5700	7.1
				1944	5000	6.8
				1971	4600	6.5
				1986	4500	6.5
				1980	4300	6.3
Smoky	Watino	1916 - 1921 1955 - Present	50000	1990	9400	10.4
				1972	9200	10.2
				1982	9000	10
				1987	7100	8.8

* Estimated from HWM
** Peak attenuated by Dickson Dam, peak u/s similar to 1995

Table 2 Comparison of High Runoff Potential Area with Flood Envelope Curves

Basin	High Runoff A (km^2)	q @ A = 10000km^2
Oldman	7000	0.45
Bow	10500	0.25
Red Deer	5500	0.2
North Saskatchewan	21500	0.6
Athabasaca	48000	0.6
Smoky	38500	1

Figure 1a - Flood Envelope Curve – Oldman Basin

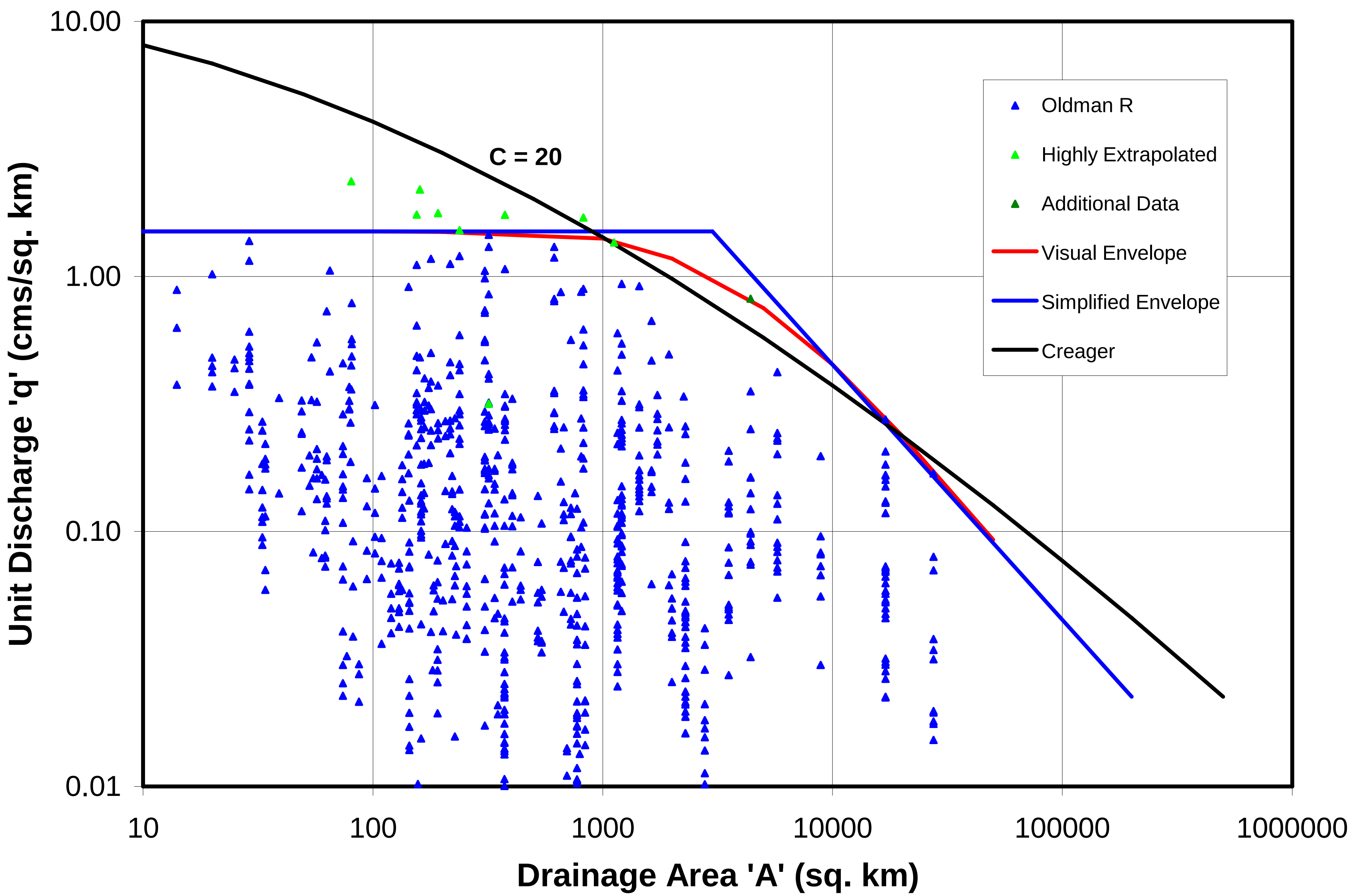


Figure 1b - Flood Envelope Curve – Bow Basin

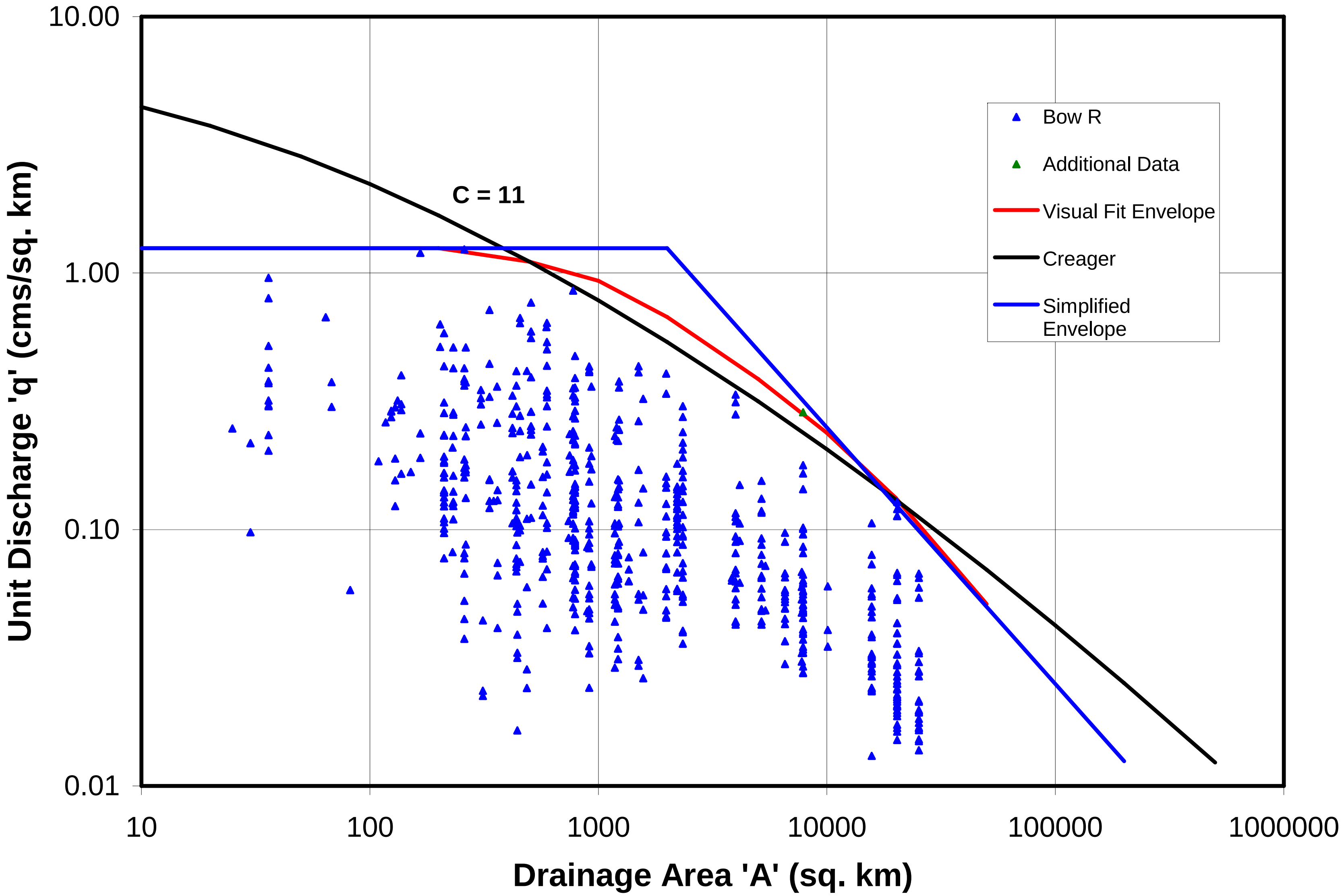


Figure 1c - Flood Envelope Curve – Red Deer Basin

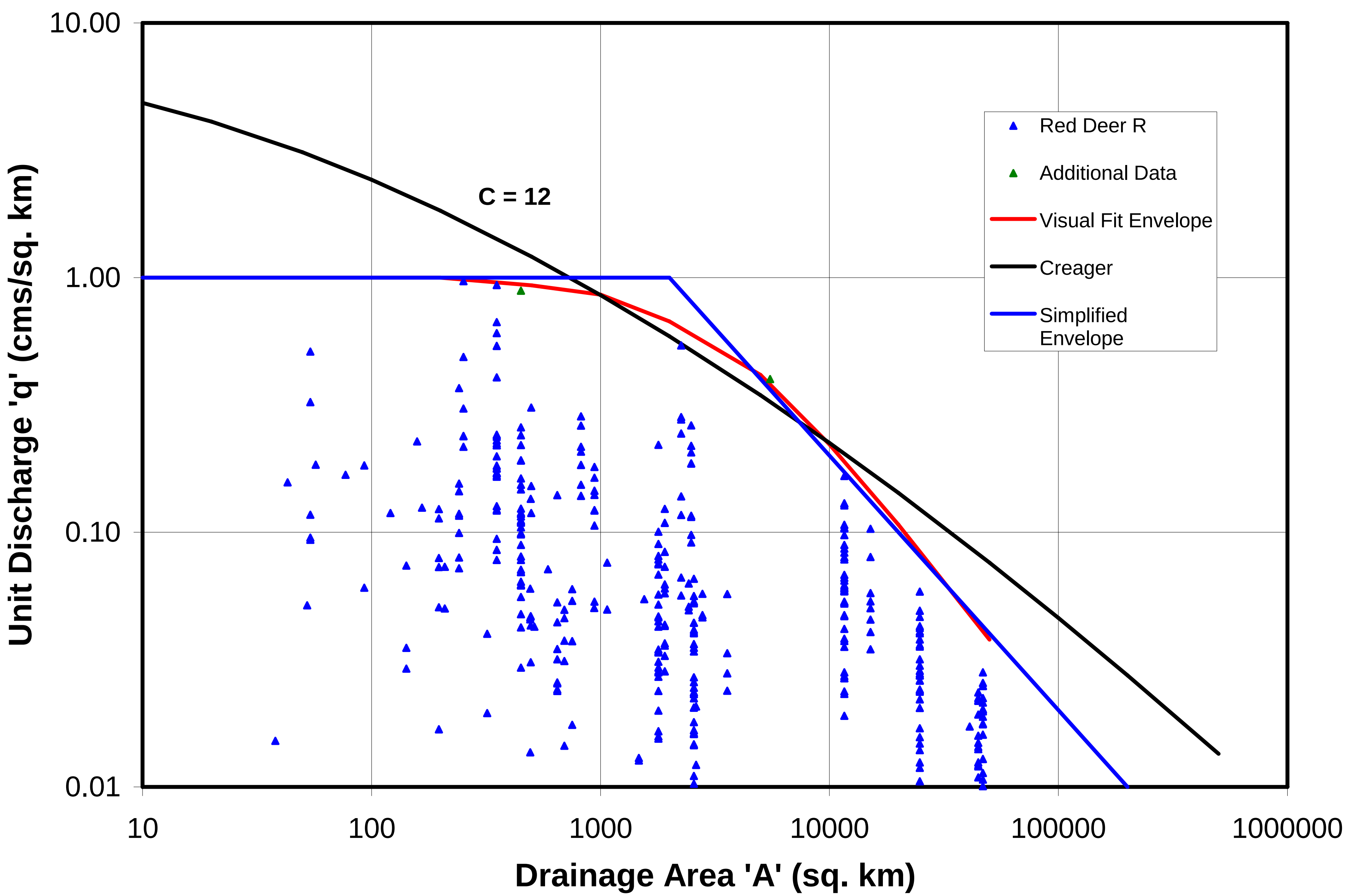


Figure 1d - Flood Envelope Curve – North Saskatchewan Basin

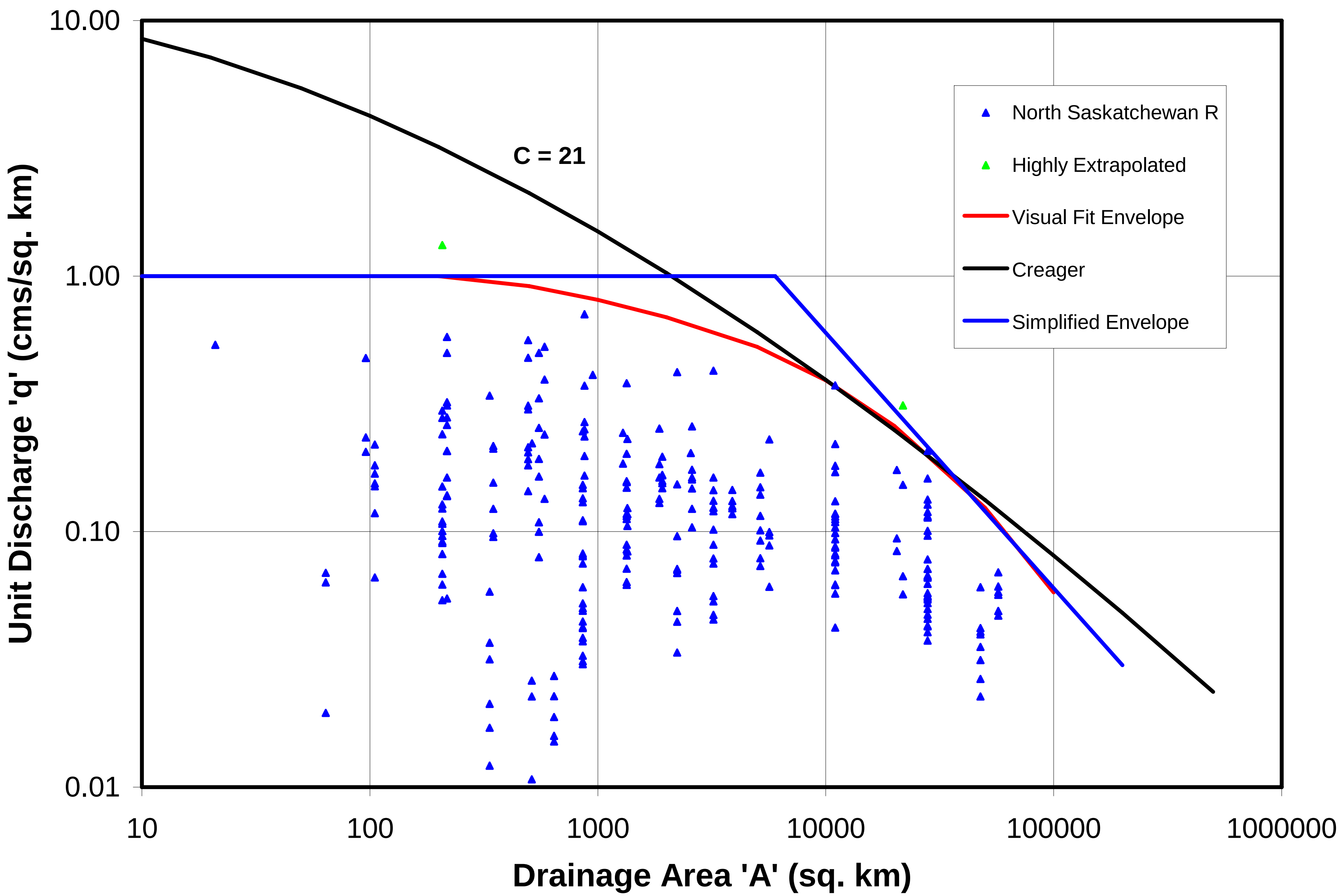


Figure 1e - Flood Envelope Curve – Athabasca Basin

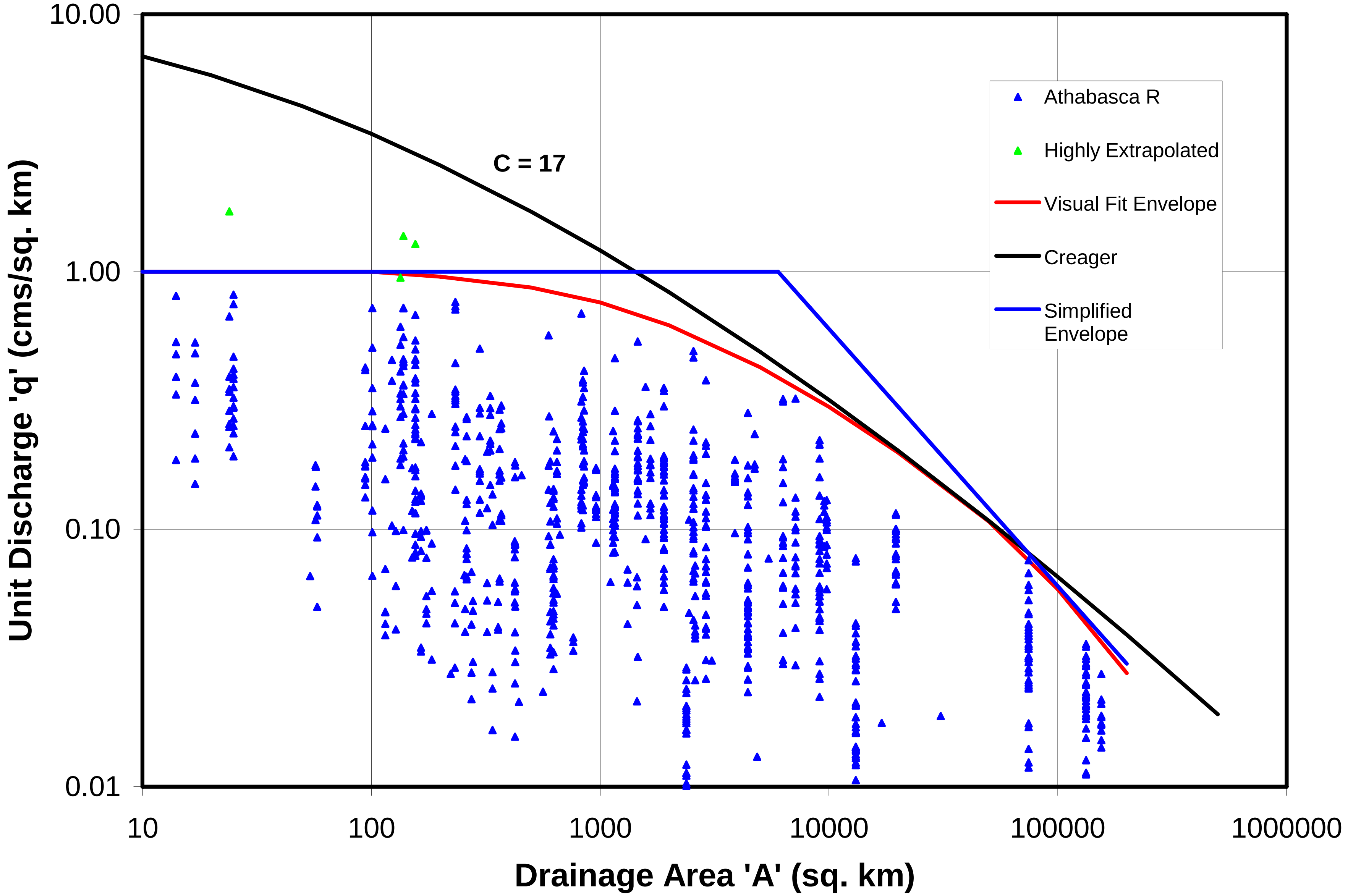


Figure 1f - Flood Envelope Curve – Smoky Basin

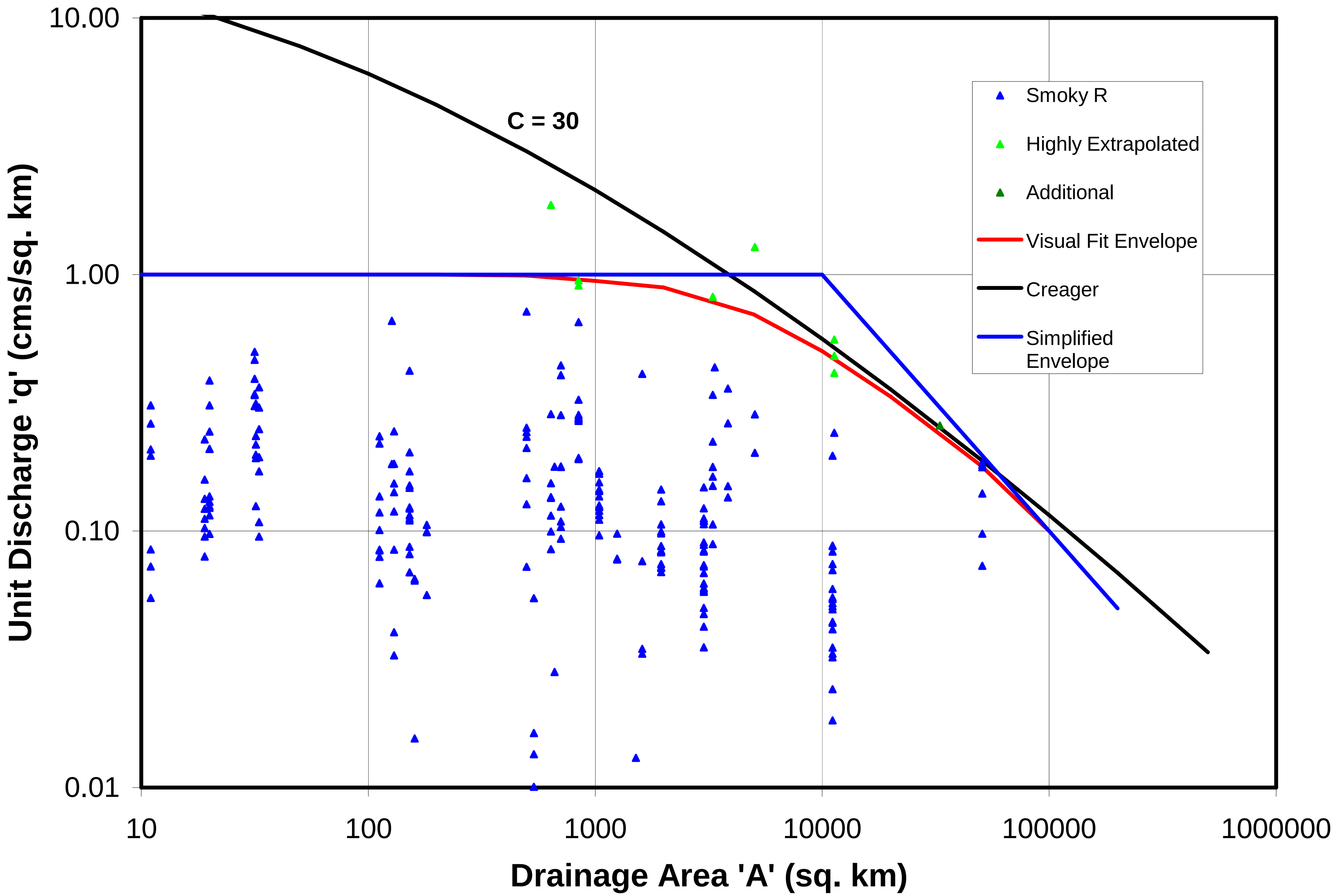


Figure 2 - Flood Envelope Curve – All Alberta Data

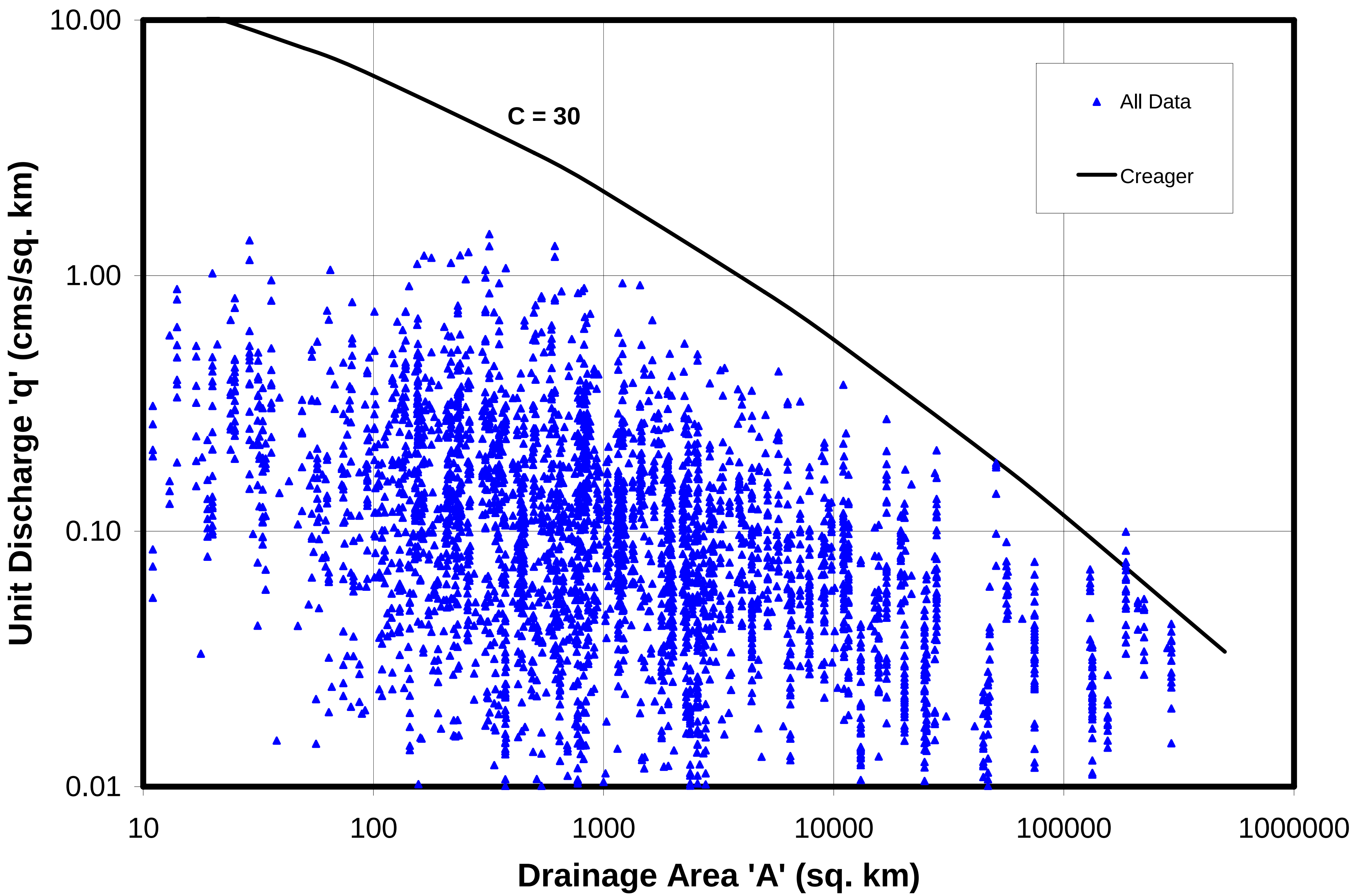


Figure 3 - Flood Envelope Curve – All WSC + AIT Bridge Data

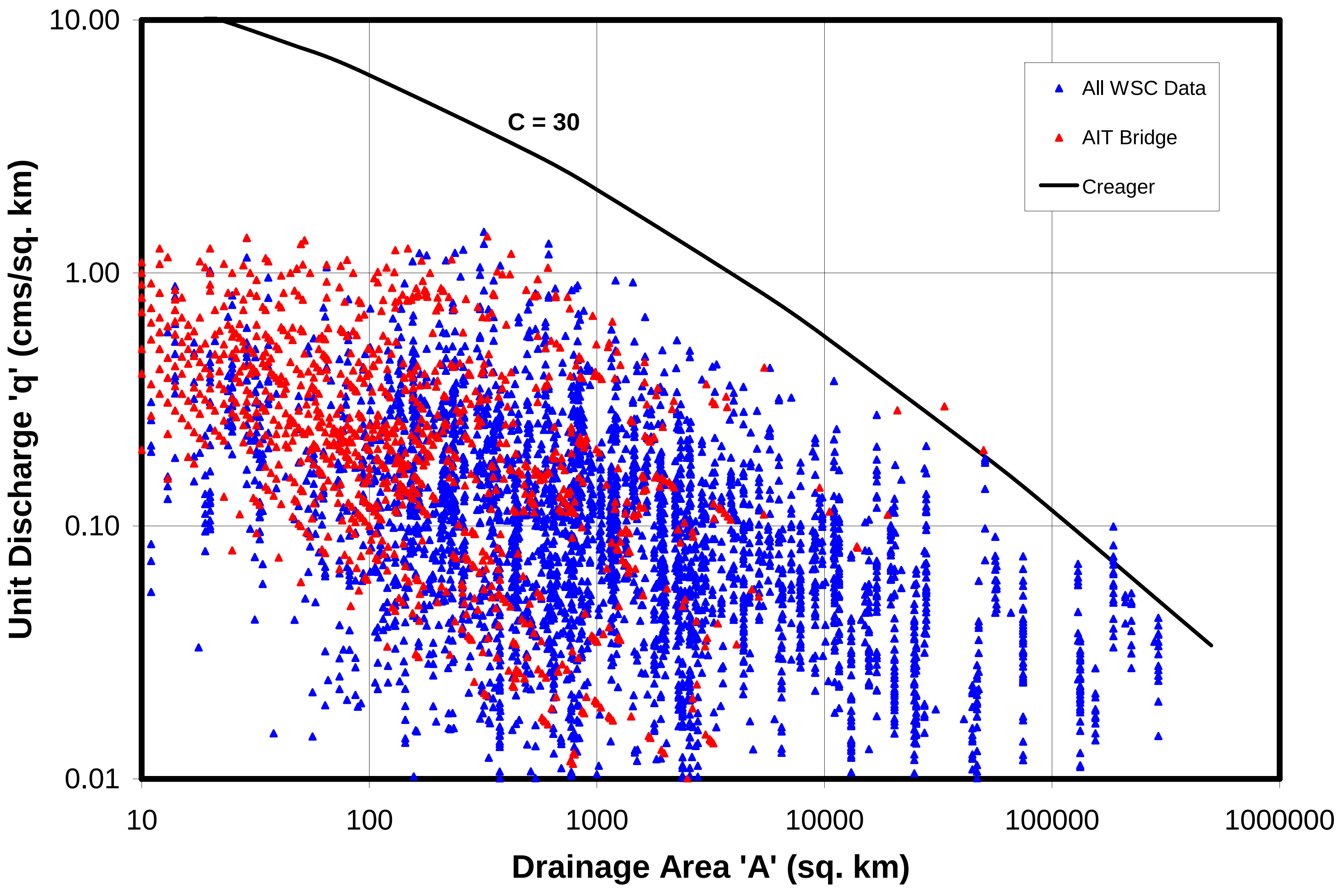


Figure 4 – All Flood Envelope Curves

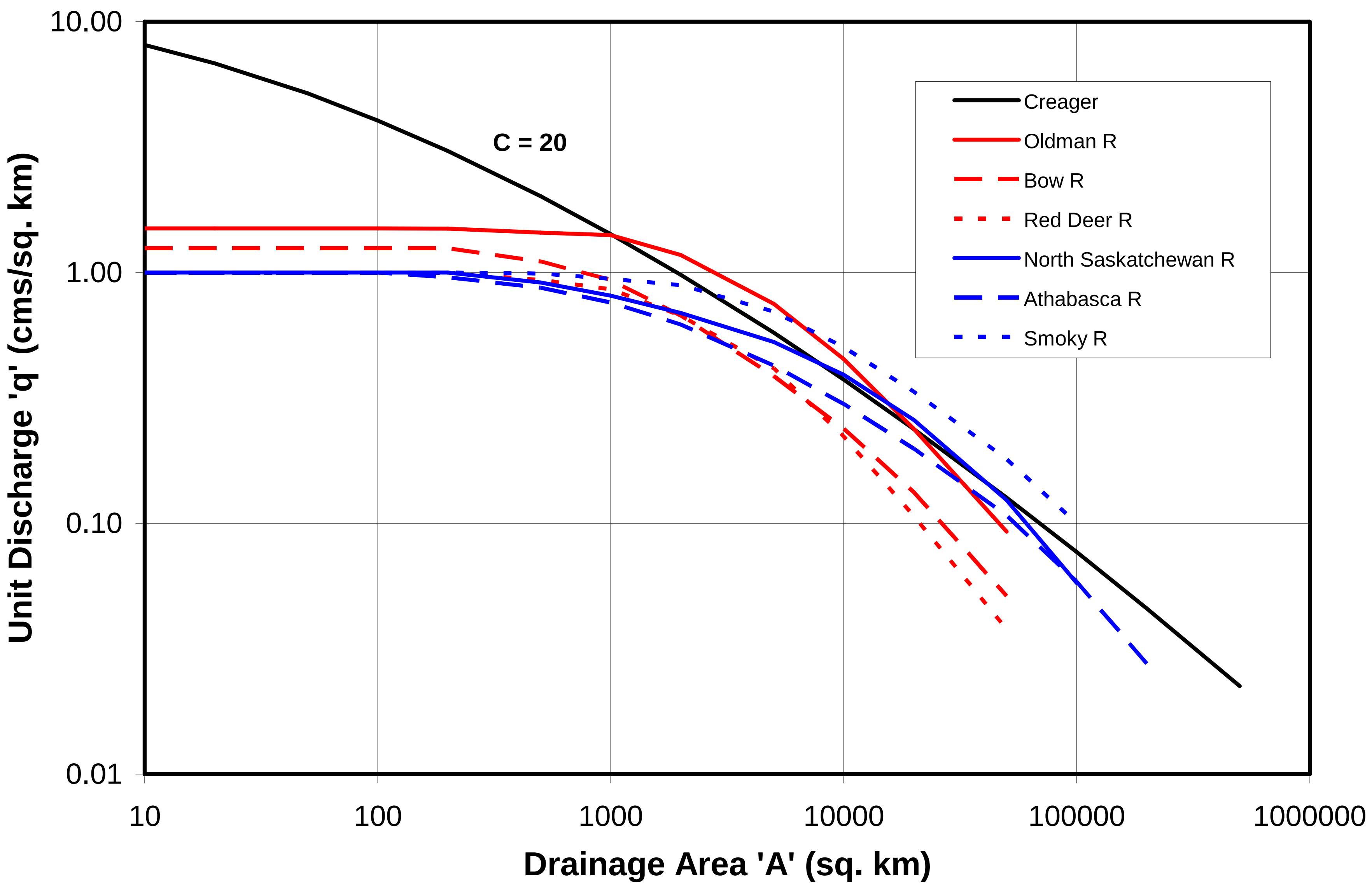


Figure 5 – Basin Map

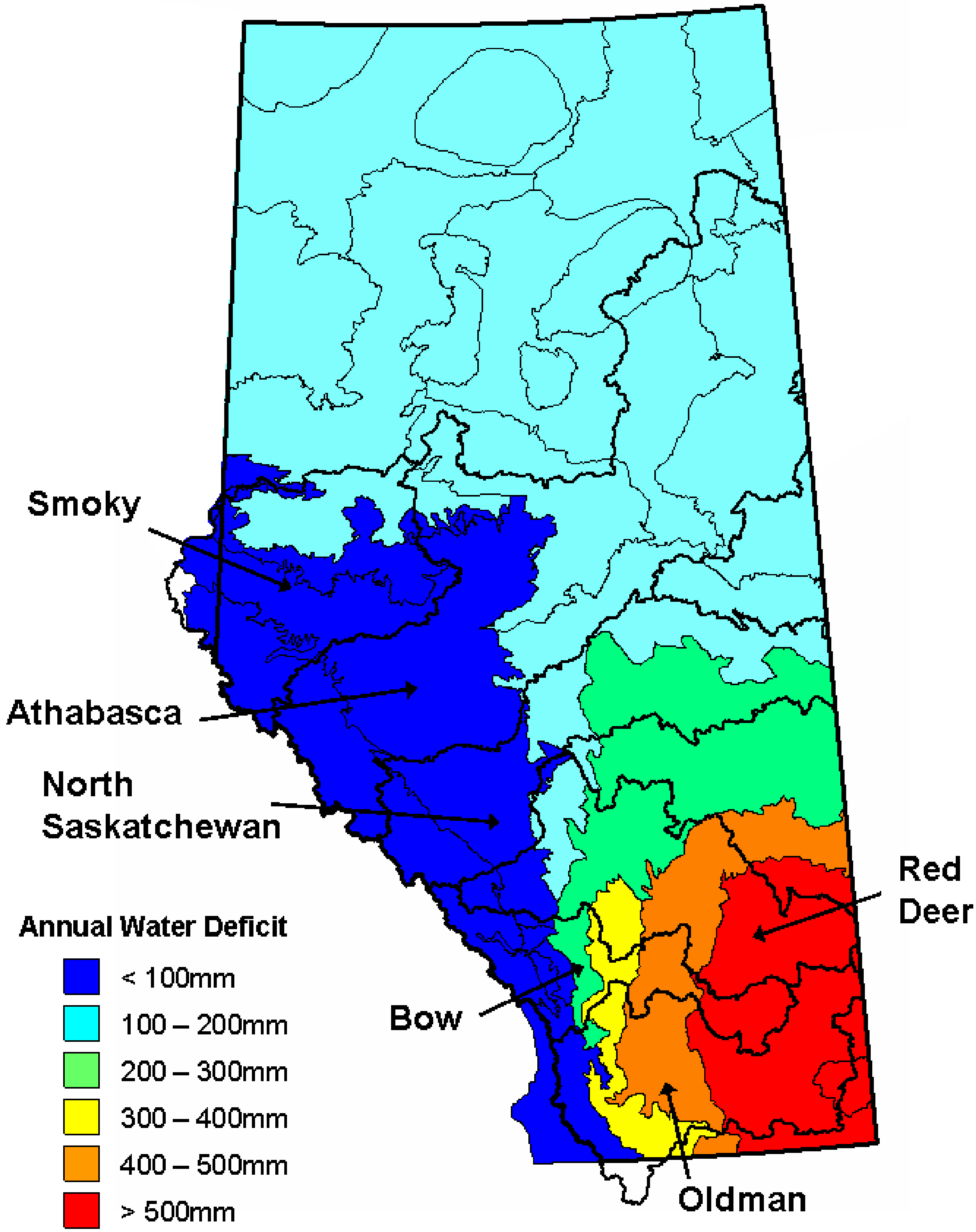
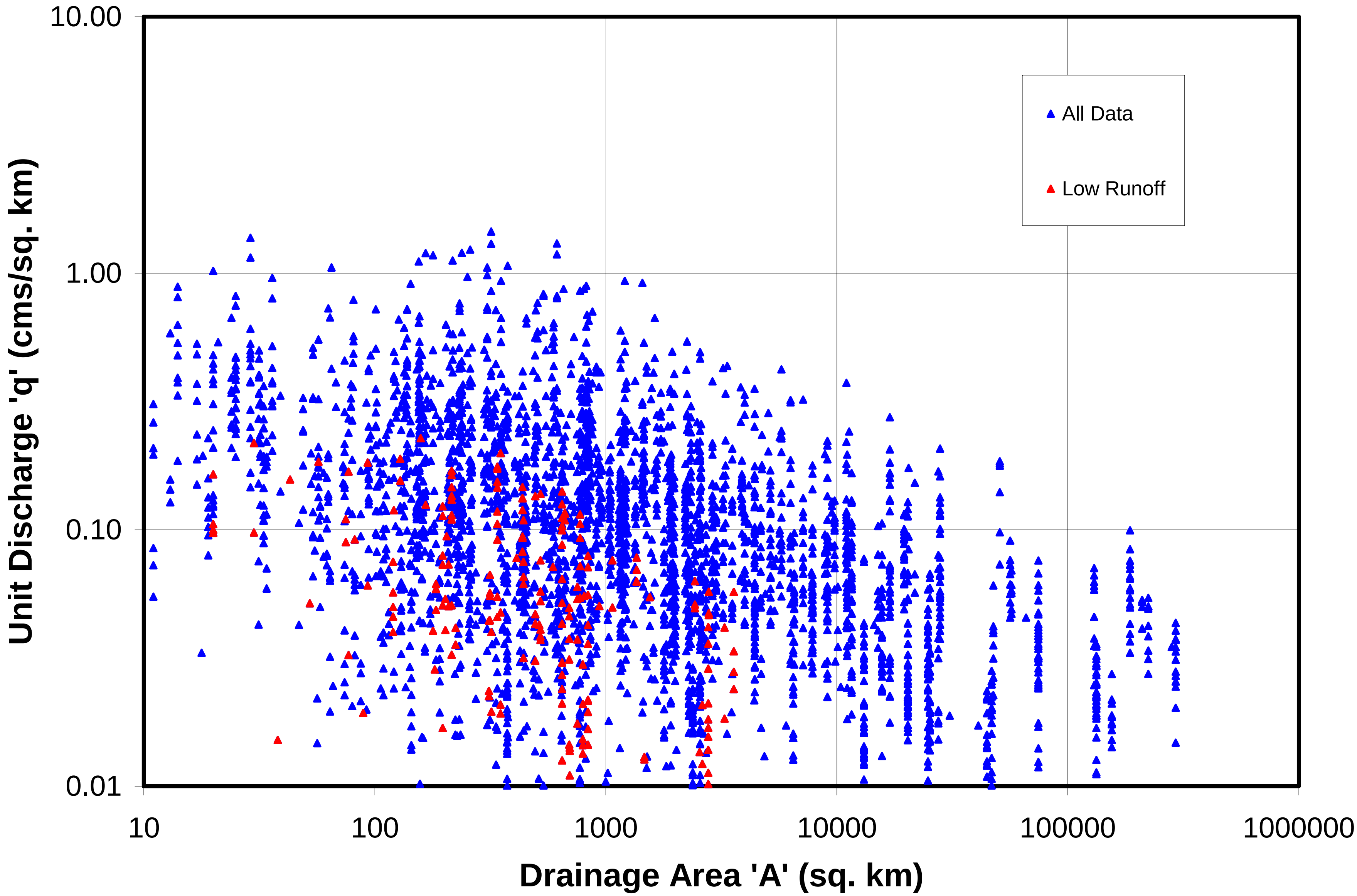


Figure 6 - Flood Envelope Curve – All Alberta Data – Low Runoff Potential Areas



References :

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