Alberta Flood Envelope Curve Analysis – North America Context

Introduction:

Alberta Transportation (AT) has published a document[1] that discusses observed inconsistencies between the Creager equation and peak flows measured in Alberta. Recently, the USGS[2] have published a report documenting peak flow estimates for some extraordinary flows in the US. It was observed that a plot of the 30 flow estimates in this report appear to fit the Creager equation reasonably well. Based on this observation, it was decided to examine flood envelope curves for Alberta with the added context of selected data from the US and provinces neighbouring Alberta. This report documents the analysis undertaken, and provides some observations and recommendations on the use of flood envelope curves on Alberta Transportation projects.

Data and Methodology:

Analysis of flood envelope curves requires assembly of large peak flow data sets that have been collected by water measurement agencies. For Alberta and surrounding areas, these agencies are the Water Survey of Canada (WSC) and the United States Geological Survey (USGS). Both agencies publish their peak flow data in several ways. WSC data was exported from the HyDat CD, and USGS data was downloaded as text files from the USGS web site (http://nwis.waterdata.usgs.gov/nwis).

These published peak flow data-sets represent the results of the best efforts of these agencies to provide accurate numbers. However, it is recognized that obtaining accurate estimates of peak flows under flood conditions is difficult due to factors such as difficult gauging conditions and large extrapolations in rating curves (or assumptions used in other numerical estimation techniques). For this comparison study, it has been decided to include all data on the plots. The accuracy of points that appear as outliers can be debated, as they may be the result of extreme runoff conditions or inaccurate estimation and measurement techniques. Rigorous assessment of the upper fringe data should be undertaken in the development of flood envelope curves intended for use in hydrotechnical design, such as the basin runoff potential component of the AT Hydrotechnical Design Guidelines[3]. In this application, extreme peak flows were evaluated using rating curves, gauging records, and hydrograph re-building. Additional effort was also applied to the distribution of the envelope curves to like hydrologic regions rather than logical drainage basins.

Analysis of the flood envelope data requires grouping the data into relevant sub-basins. This is greatly facilitated by use of published GIS data-sets which delineate basin boundaries for gauged areas in specified hydrologic regions. GIS data for the WSC basins were obtained from the GeoBase web site (http://www.geobase.ca/) and the PFRA section of the Agriculture Canada web site (http://www.agr.gc.ca). GIS data for the USGS gauges was obtained from the National Hydrography Dataset web site (http://www.horizon-systems.com/nhdplus/).

The flood envelope curve analysis approach involves preparation of log-log plots of flow in cubic metres per second (Q) versus Drainage Area in square kilometres (A). All peak flow data for each region have been added to the plots, showing both an upper fringe that can be used to generate flood envelope curves, and a visual indication of the typical magnitude and trend of Q versus A for that region.

The plots start at a minimum drainage area of $10km^2$, as peak flow estimates for lower drainage areas are expected to be subject to greater inaccuracy due to the potentially short durations of runoff. These basins may also respond to very short duration storms rather than the large regional storms (or snow melt events) that typically generate extreme floods on rural basins.

Flood envelope curves have been added to each plot by visually matching the upper fringe of the data with a line composed of two segments. The segment that covers the lower drainage area portion of the plot has a slope of 1.0 on the log-log plot, resulting in an exponent of 1 in the power equation that represents the line. In all cases, the best visual fit would result in an exponent that slightly exceeds 1.0, but 1.0 is the maximum value physically possible as the unit discharge for a basin cannot exceed the maximum unit discharge for its sub-basins. The segment that covers the higher drainage areas is based on the best visual fit to the upper fringe of the data. These envelope curves can be described by the values of ‘A’ and ‘Q’ at the upper end of the lower line segment, and the slope of the upper line segment.

The best fit envelope based on the Creager equation is also included on each hydrologic region plot for comparison. Additional summary plots that compare the flood envelope curves for different regions have also been prepared.

Observation of the data in the USGS report indicates that much of the extreme data reported was collected on the eastern slopes of the Rockies, draining either towards the Mississippi River or the Texas portion of the Gulf of Mexico. Alberta shares the eastern slopes of the Rockies topography, and many of the larger storms in Alberta have resulted from systems that developed in the Gulf of Mexico and moved northwards along the eastern slopes. It was therefore decided to prepare flood envelope curves for each major US hydrologic region that has its headwaters in the eastern slopes of the Rockies (Figure 1a). In addition, the major drainage basins in Alberta cover portions of British Columbia to the west, and Saskatchewan and Manitoba to the east. Therefore, data for these provinces has been included in the generation of flood envelope curves for the major basins (Figure 1b). Further subdivision of the province Alberta, based largely on the steepness of topography, has also been employed to examine the differences in flood envelope curves (Figure 1c).

Results:

The ‘Q’ vs ‘A’ plots for each of the major US east slopes basins are shown in Figures 2a to 2d. Similar plots for the 2 major basins that drain the east slopes of the Rockies and cover most of Alberta can be seen in Figures 3a and 3b. Figure 4 shows a comparison of the flood envelope curves for all of the east slopes regions.

Figures 5a to 5d show flood envelope curves for the 2 Alberta east slope regions separated between the relatively steep areas adjacent to the Rockies and the relatively flat areas further downstream. Figure 6 shows the flood envelope curve for another major hydrologic region in Alberta that does not drain the east slopes of the Rockies. Figure 7 shows a comparison plot of each of the 5 flood envelope curves for these Alberta regions.

In general, it can be seen from these plots that the 2 segment envelope curve can fit the upper fringe of the data relatively well for all regions. One possible exception is for very large drainage areas where the upper line segment tends to pull away from the data. However, the magnitude of the flood envelope curves varies greatly between the various regions examined.

The Creager curve is unable to reasonably fit the full range of data for any given region. It does, however, provide a reasonable fit to the data examined in the USGS study from various locations across the US (Figure 8). However, the 2 line segment envelope curve for US Zone 12 (south east Texas) also covers the USGS data relatively well.

Discussion:

As noted above, the 2 segment envelope curve appears to fit all areas considered relatively well. The first segment has a slope of 1 on the log-log plot, signifying a constant unit discharge up until the end of the first segment. This line segment is apparent for all regions, although there is significant variance in the value of the unit discharge and the drainage area at the upper end of this line segment. The plots for flatter portions of Alberta show values in the 0.1 to 0.3 cms/km^2 range. The steeper portions of Alberta show values in the 2 – 3cms/km^2 range. The Texas Gulf region (US Zone 12) has a value of more than 30cms/km^2. This observation suggests that in the lower drainage area range, the rate of runoff for the most productive basins in an area is mostly a function of the intensity, geographic distribution, and temporal distribution of the storm combined with storage losses. Hydrologic routing appears to be relatively minor.

The value of ‘A’ at the upper end of the lower line segment is in the 200 – 400km^2 range for the east slopes basins in the US, but is significantly higher for the east slopes basins in Alberta, particularly those that drain to the Mackenzie River (WSC Basin 07) where it exceeds 2000km^2. A major factor in the value of this transition ‘A’ is likely the combination of storm geographic distribution and the amount of drainage area with relatively limited routing features. The lower values for the higher unit discharge regions in the US is likely due to the very sharp runoff hydrographs from smaller basins being more sensitive to hydrologic routing. Values for the flatter regions in Alberta also show a significant variance, with a value of less than 500km^2 for the Nelson River basin (WSC 05) and more than 5000km^2 for the Churchill River basin (WSC 06). The relatively higher values of ‘A’ at the upper end of the lower line segment may be partially explained by the inclusion of snowmelt runoff events among the peak flows, as the higher runoff volumes will be less sensitive to hydrologic routing.

The slope of the upper line segment shows somewhat less variance between the regions investigated. The US east slopes basins show slopes in the 0.2 range, while the Alberta east slopes basins show slopes in the 0.3 range. The flatter Alberta regions also show a slope in the 0.3 range. The lower value for the upper line segment slope for the US basins is likely due to the increased influence of routing on the sharper runoff hydrographs from smaller drainage areas.

Some of the plots suggest that at some point, 'Q' stops increasing with 'A', resulting in the upper line segment pulling away from the data. This is likely due to the effect of hydrograph routing overcoming the influence of additional flow inputs from adjacent areas in the lower portion of the basin, resulting in attenuation of the flood waves. There is insufficient data on the plots to add a third line segment to cover this range of drainage areas. This attenuation is also more likely to be related to the physical properties of the channel near the gauging station, than those of the basin from where the runoff water came from.

The Creager equation appears as a smooth curve with a changing slope throughout the entire range of drainage areas. The overall trend is consistent with flood envelope curve observations, with a relatively steep slope for smaller drainage areas, and much flatter slope for larger drainage areas. However, it is clear that this curve shape cannot closely match the upper fringe of runoff data over the entire range of drainage areas for any of the regions investigated. The Creager curve appears to fit relatively well for the lower drainage area ranges of the US east slope regions, but over-predicts for the higher drainage area range. However, the opposite is true for the Alberta regions, where the Creager curve tends to match the higher drainage area portions well, but over-predicts the lower drainage area range. This difference appears to be due to the lower value of unit discharge at lower drainage areas for the Alberta regions, as well as the higher values of the transitional drainage area for these basins. The observation that the Creager curve appears to fit the 30 US data points may be due to it acting as the envelope to a family of curves for different regions.

Although the 2 line segment curve appears to be a reasonable fit as flood envelope curves for most regions, the usefulness appears to be only limited to analysis of trends. The variance between the different eastern slopes regions shows that each flood envelope curve has a limited geographic range of applicability. The variance between the steep and flat regions of the large Alberta basins shows that there is still a great range of diversity between sub-basins. In both cases, only some of the basins in an area influence the flood envelope curve, with many basins plotting well below the envelope for the region.

Conclusions:

Comparison of flood envelope curves for the hydrologic regions investigated shows some interesting trends. Some of these trends appear to be consistent with the expected hydrologic response for the different regions. The range in response covers several orders of magnitude.

A 2 line segment flood envelope curve appears to fit the upper fringe of the peak runoff data for all regions considered. However, the parameters for these curves vary greatly over the regions considered. This observation suggests that it is difficult to compare extreme flow values for basins in different regions, and for sub-basins within the same larger basin.

The Creager equation appears to fit some aggregate extreme flow data-sets well. However, it does not fit the upper fringe of data for any given region over the full range of drainage areas. Therefore, the Creager does not appear to be a drainage area neutral indicator of the magnitude of flooding, even for a region with similar hydrologic properties.

In summary, flood envelope curves indicate some interesting trends and can be used to compare various hydrologic regions. In some cases, the 2 line segment curves may be useful as an empirical check of flood magnitude for a given hydrologic region. The Creager curve, however, has limited value in this application as it only provides an indication of flood severity for a given hydrologic region and over a limited range of drainage areas.

Figure 1a – United States Eastern Slopes Basins

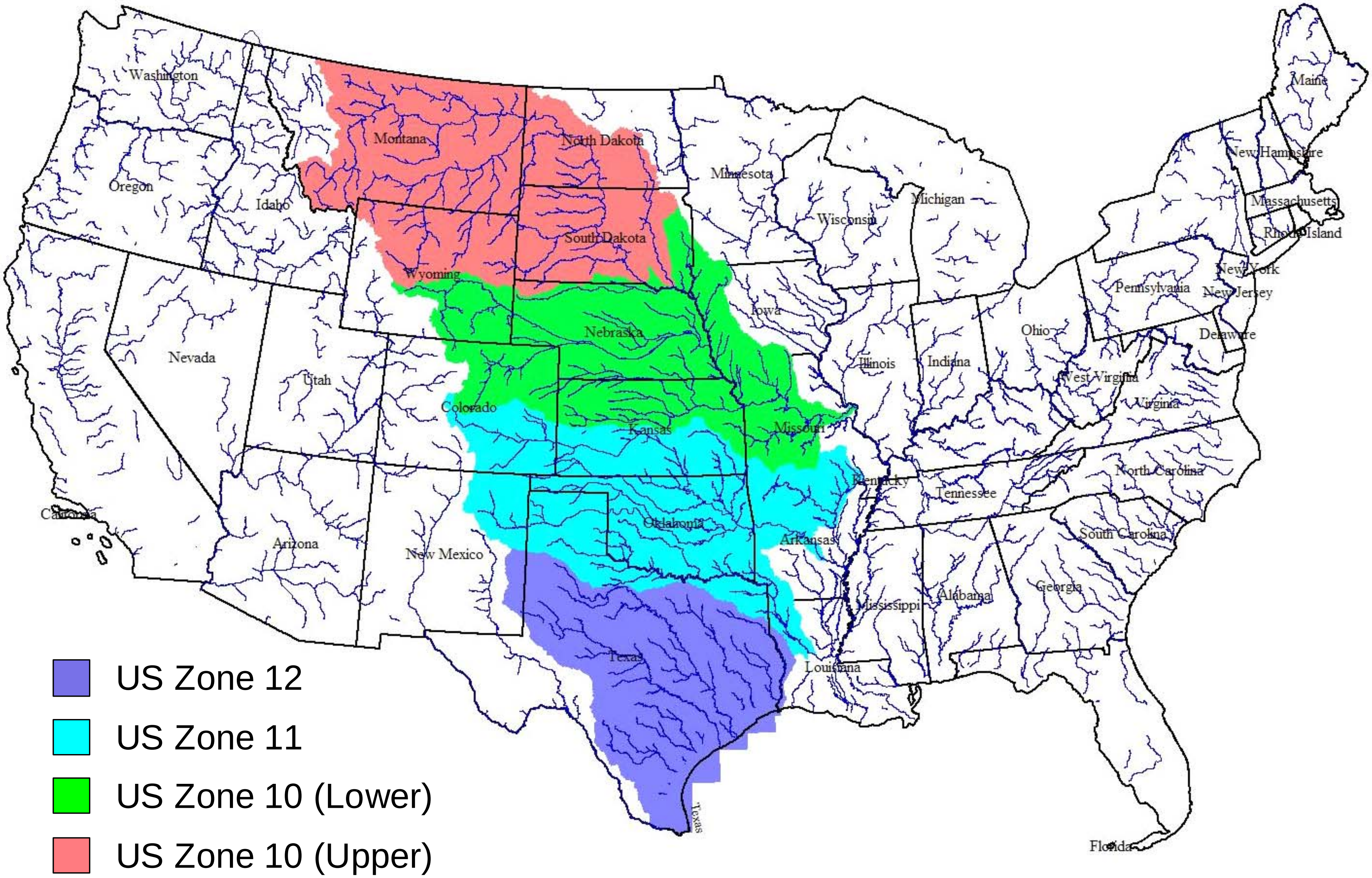
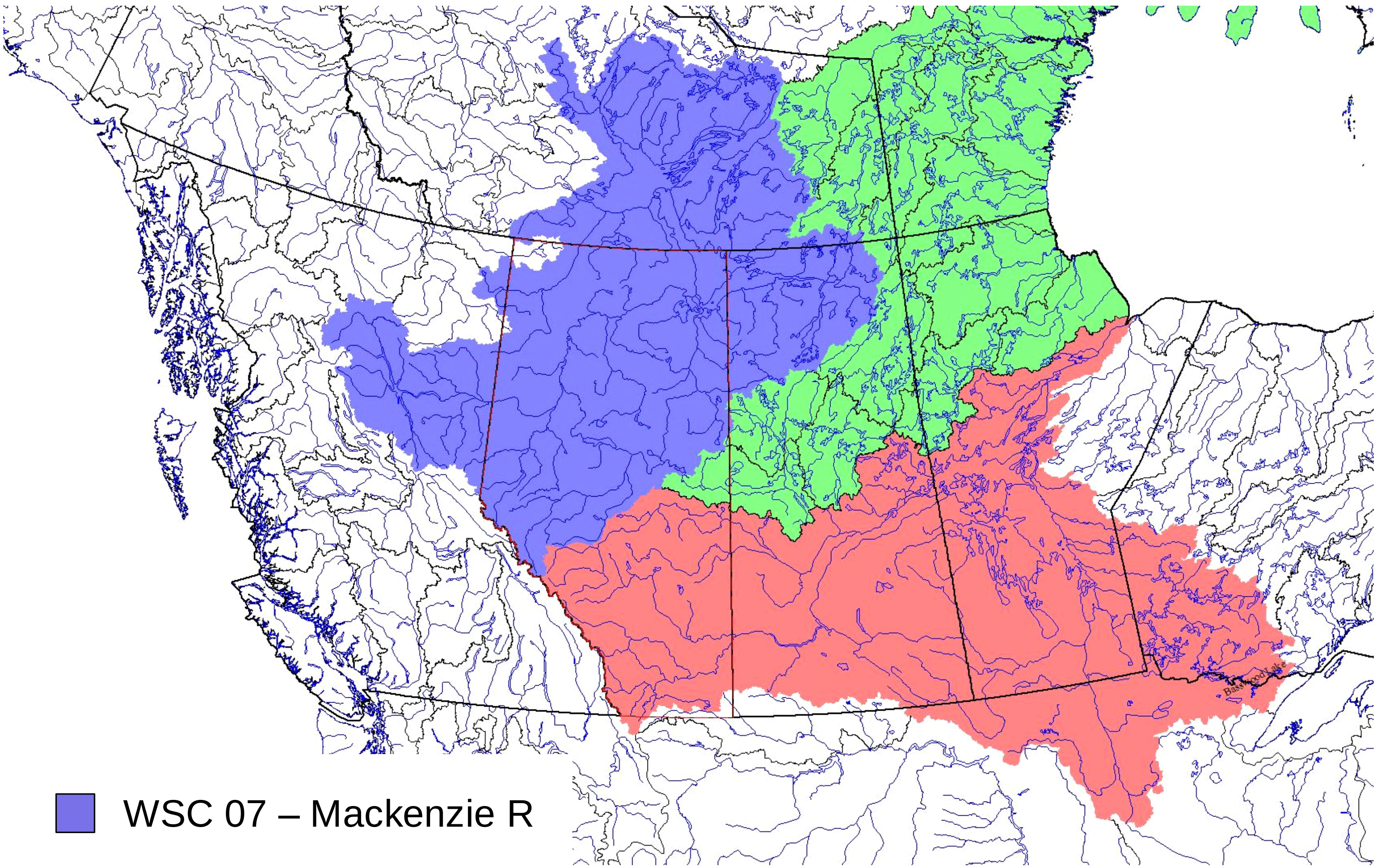


Figure 1b – Western Canada Basins



WSC 07 – Mackenzie R

WSC 06 – Churchill R

WSC 05 – Nelson R

Figure 1c – Alberta Basins

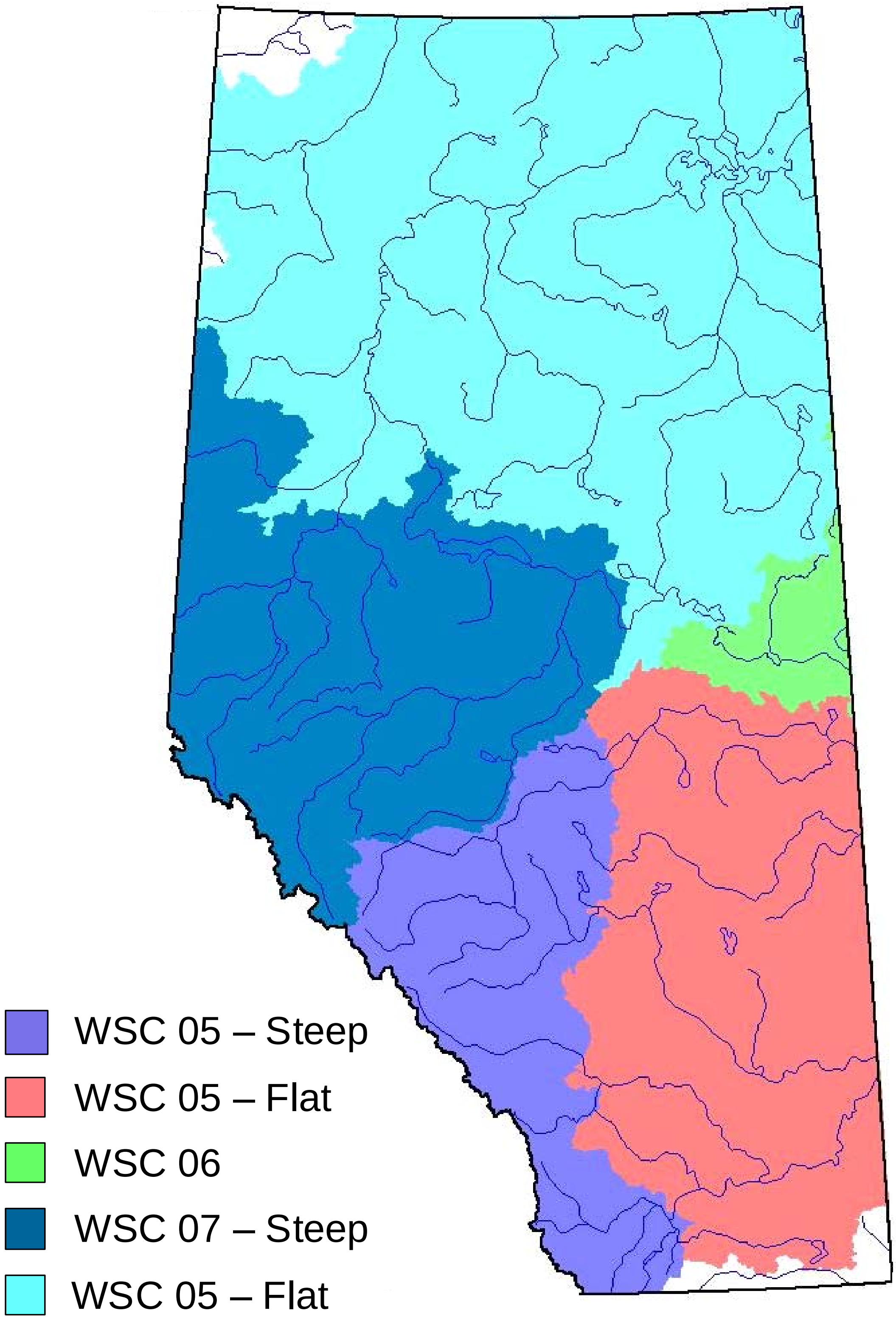


Figure 2a - Flood Envelope Curve – US Zone 12

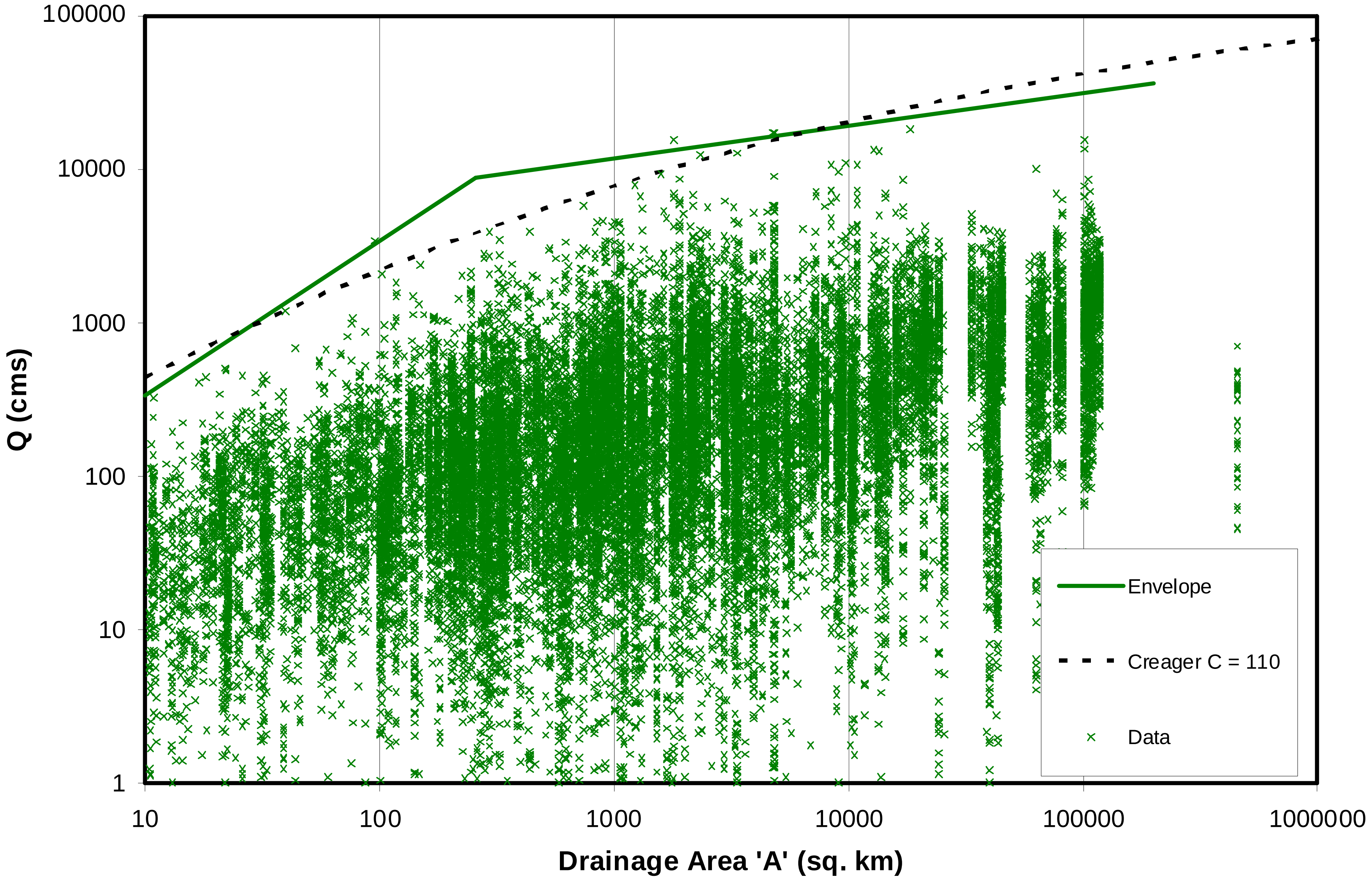


Figure 2b - Flood Envelope Curve – US Zone 11

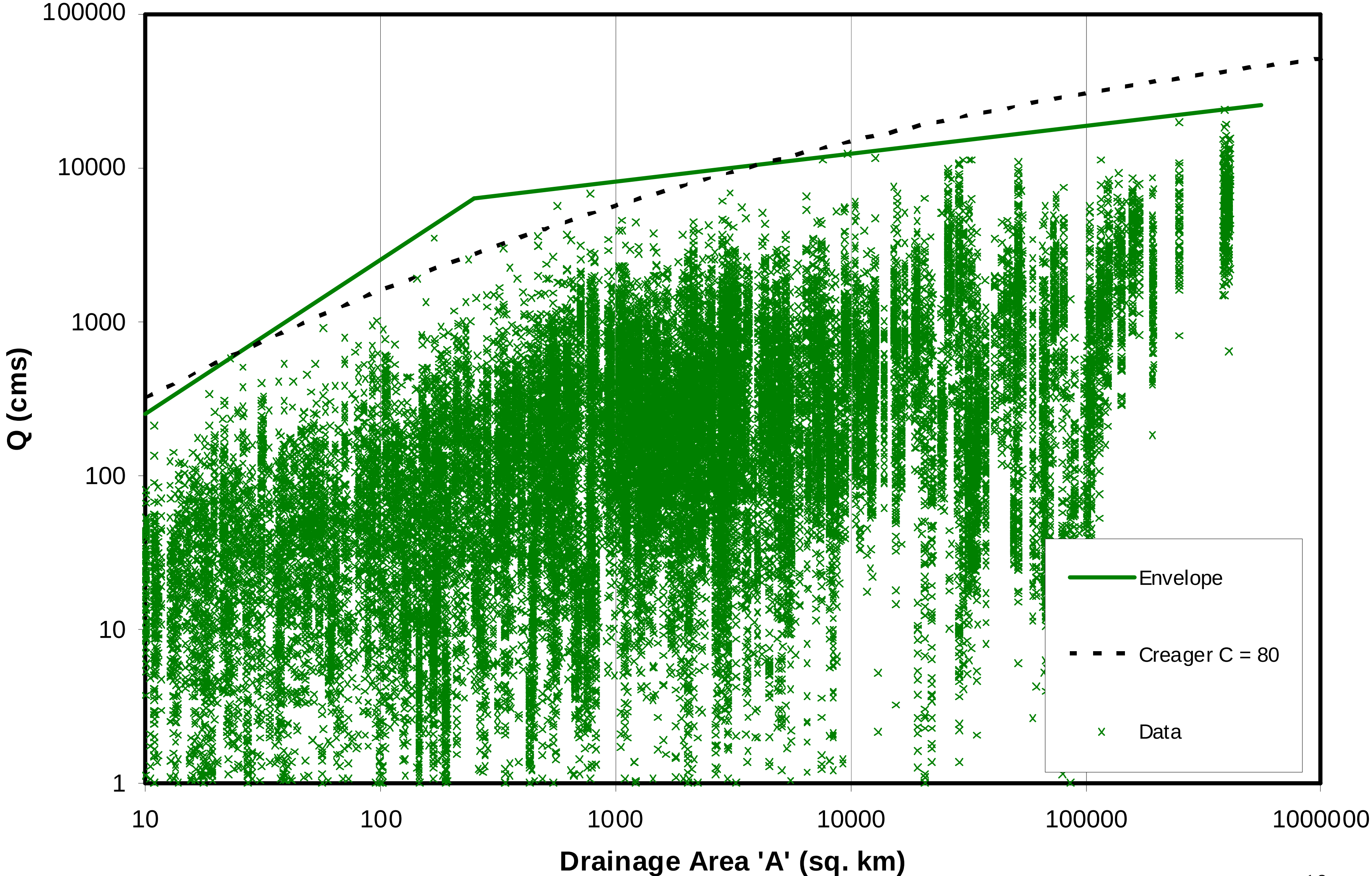


Figure 2c - Flood Envelope Curve – US Zone 10 (Lower)

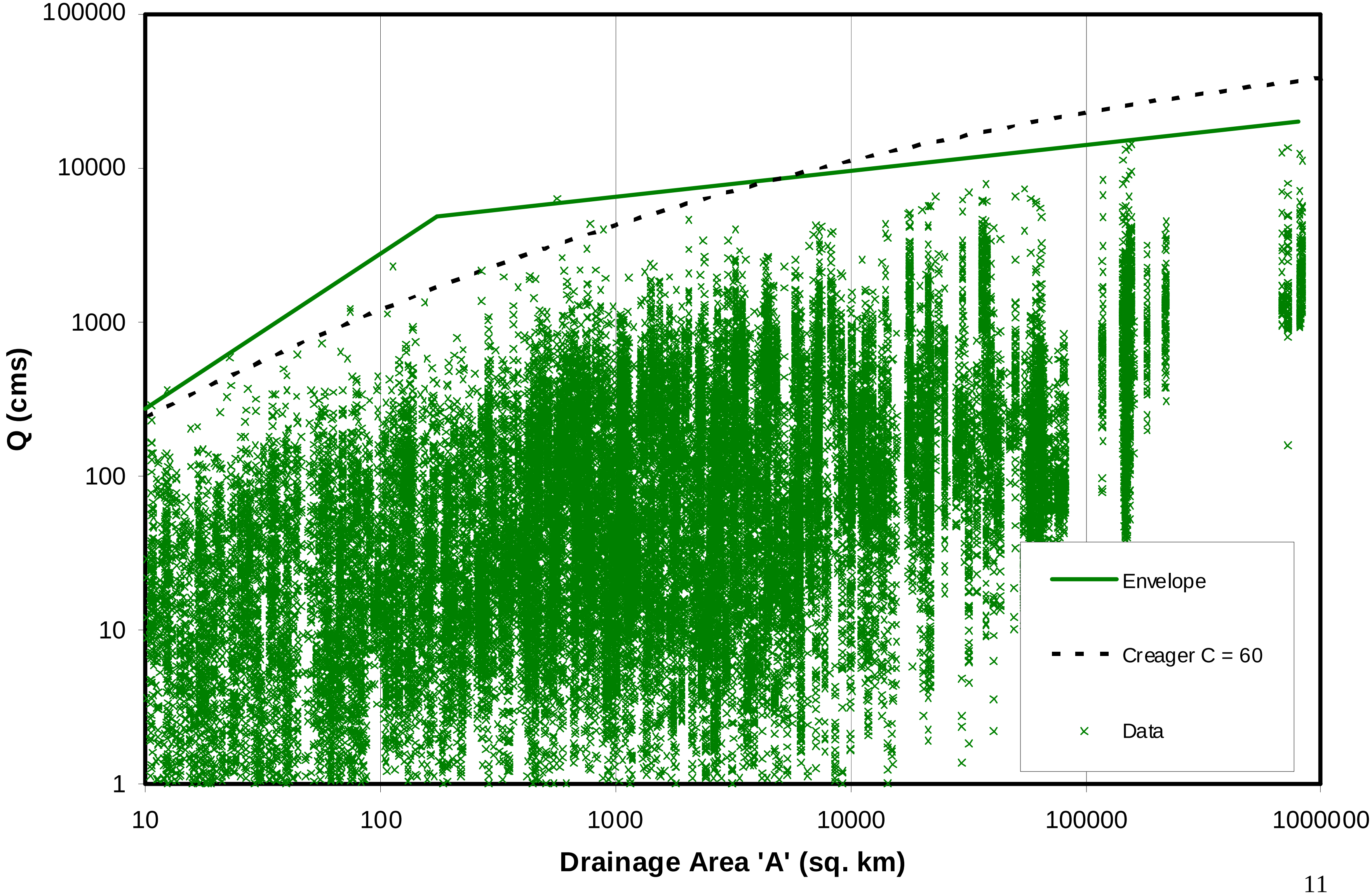


Figure 2d - Flood Envelope Curve – US Zone 10 (Upper)

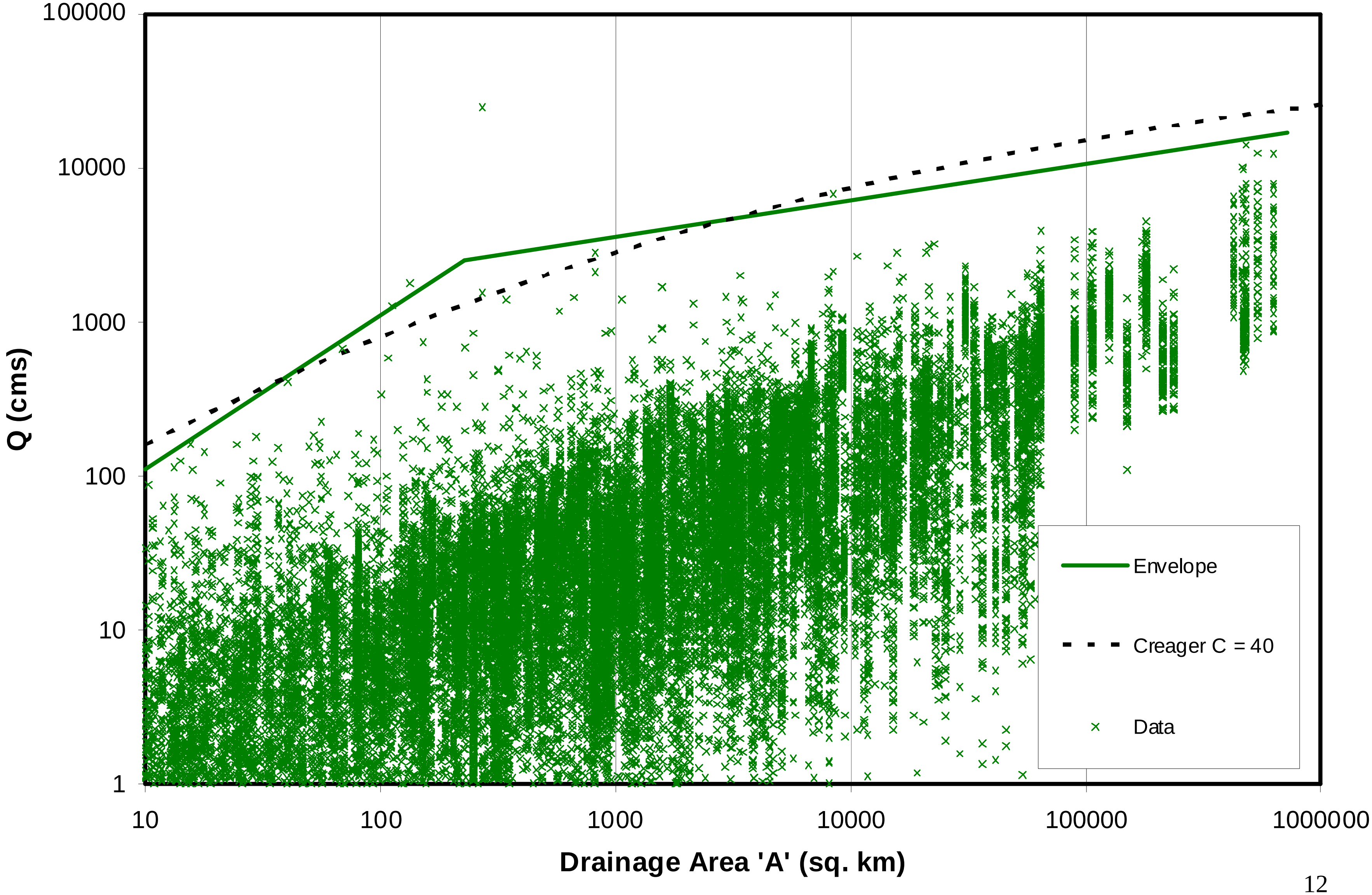


Figure 3a - Flood Envelope Curve – WSC 05

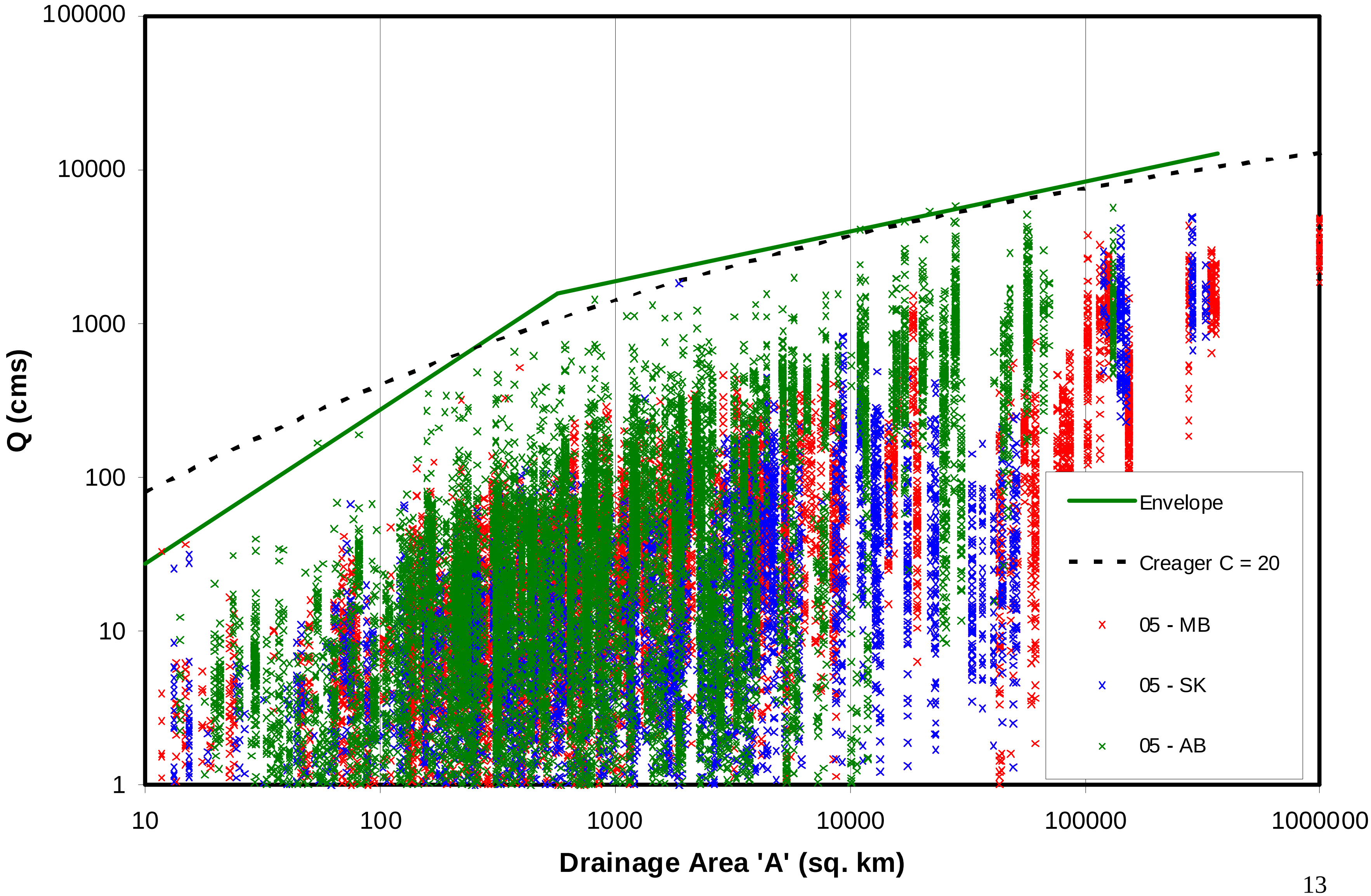


Figure 3b - Flood Envelope Curve – WSC 07

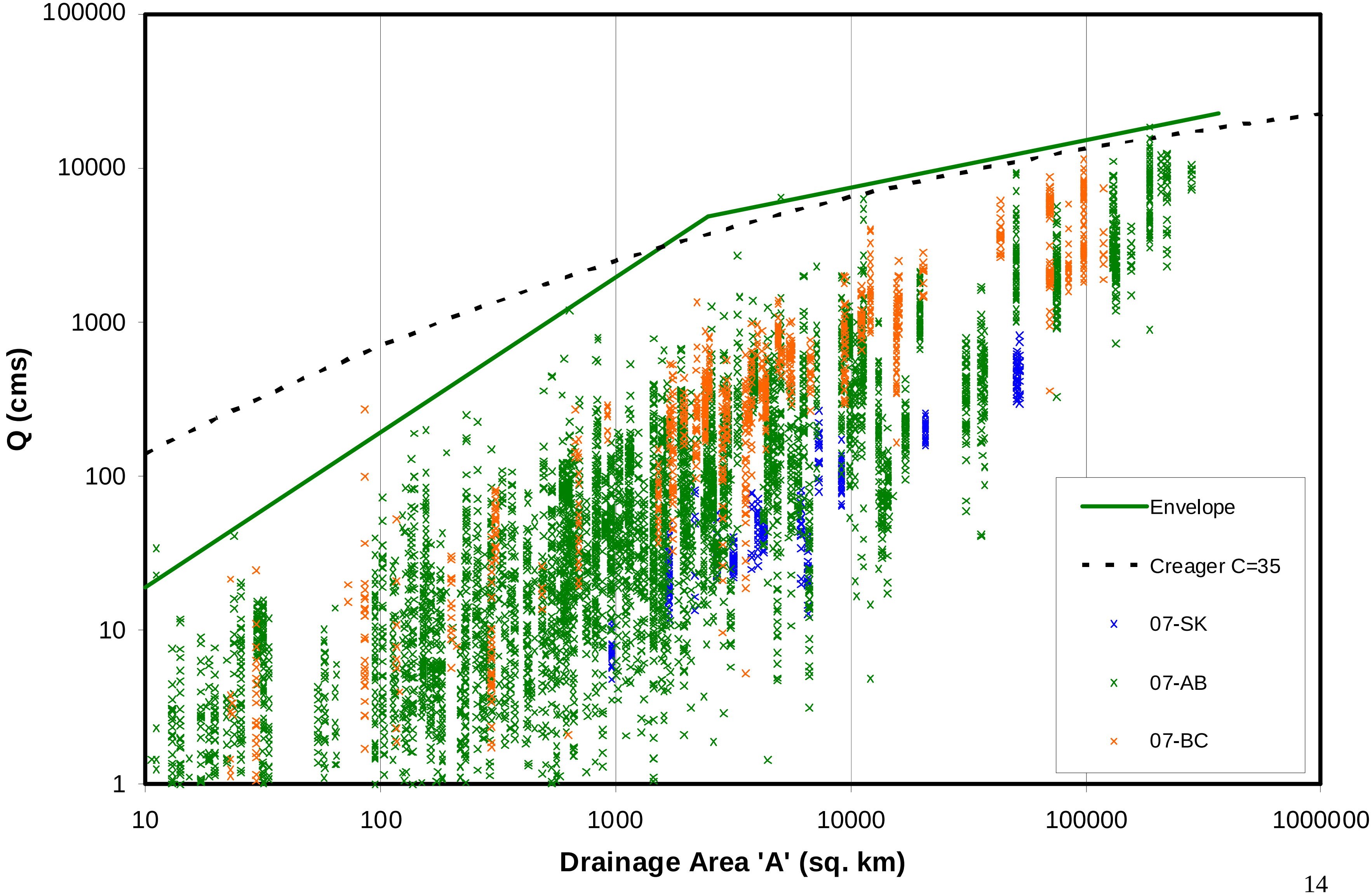


Figure 4 - Flood Envelope Curve – All Eastern Slopes Regions

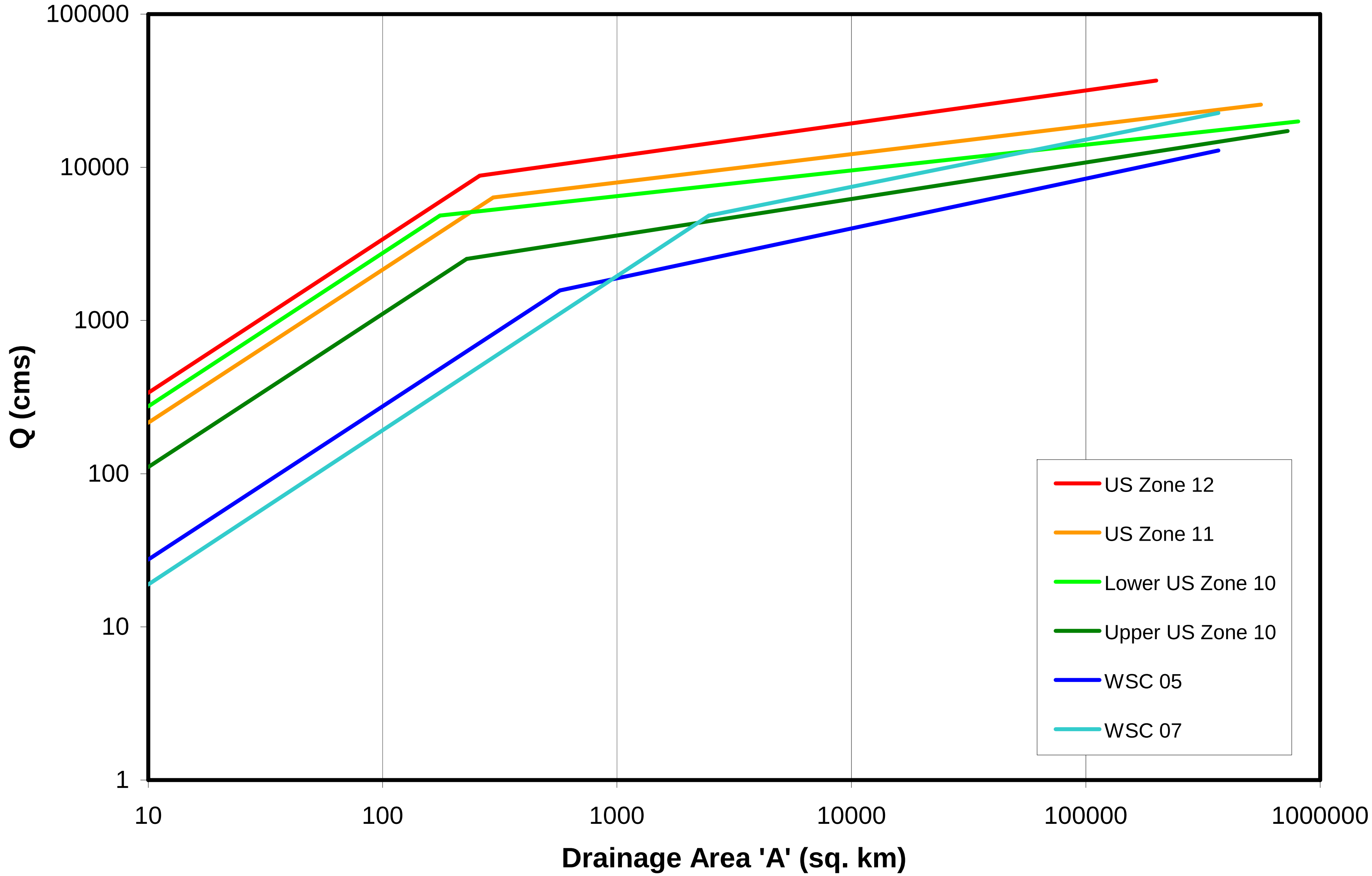


Figure 5a - Flood Envelope Curve – Alberta WSC 05 – Steep

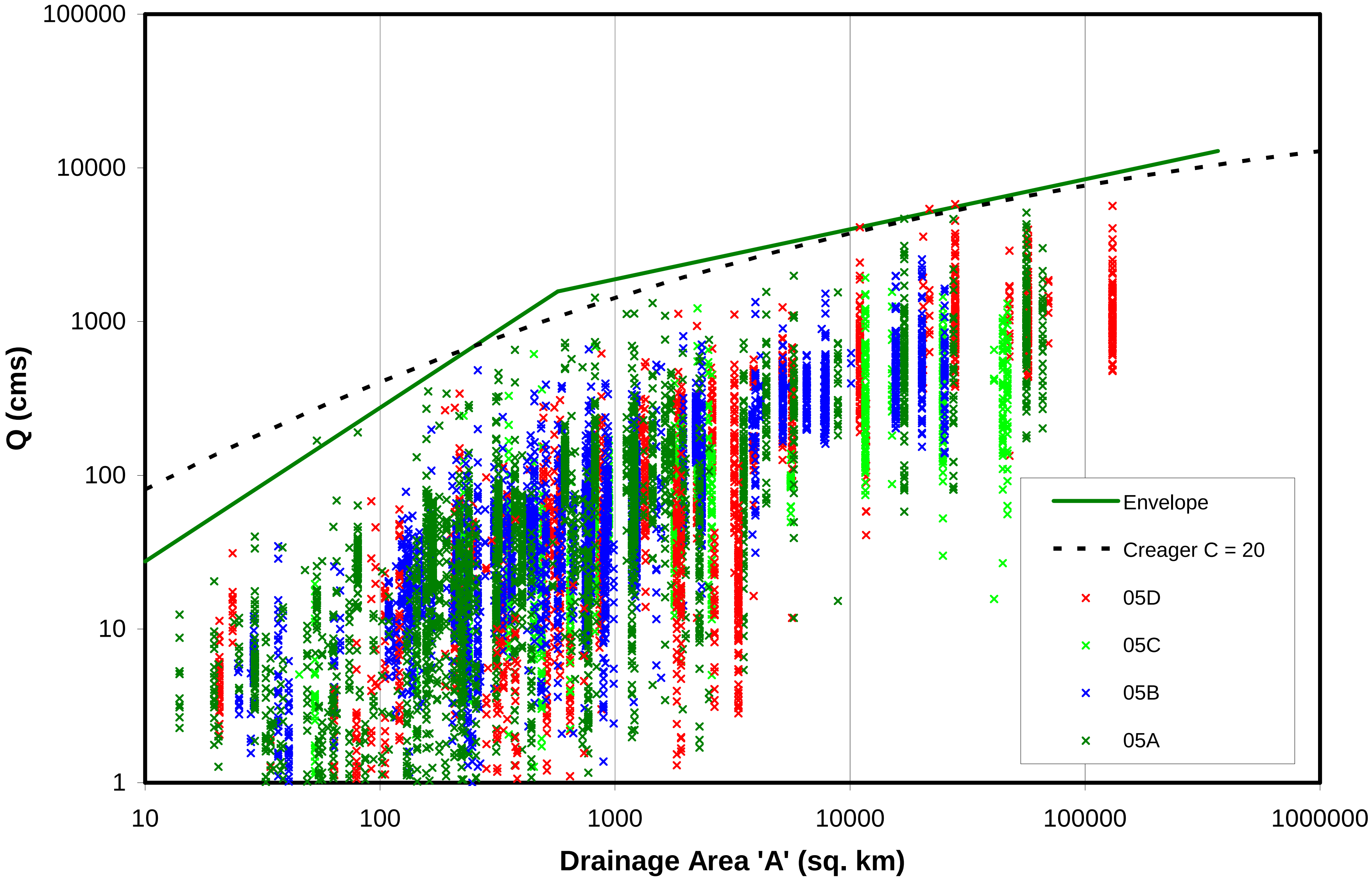


Figure 5b – Flood Envelope Curve – Alberta WSC 05 - Flat

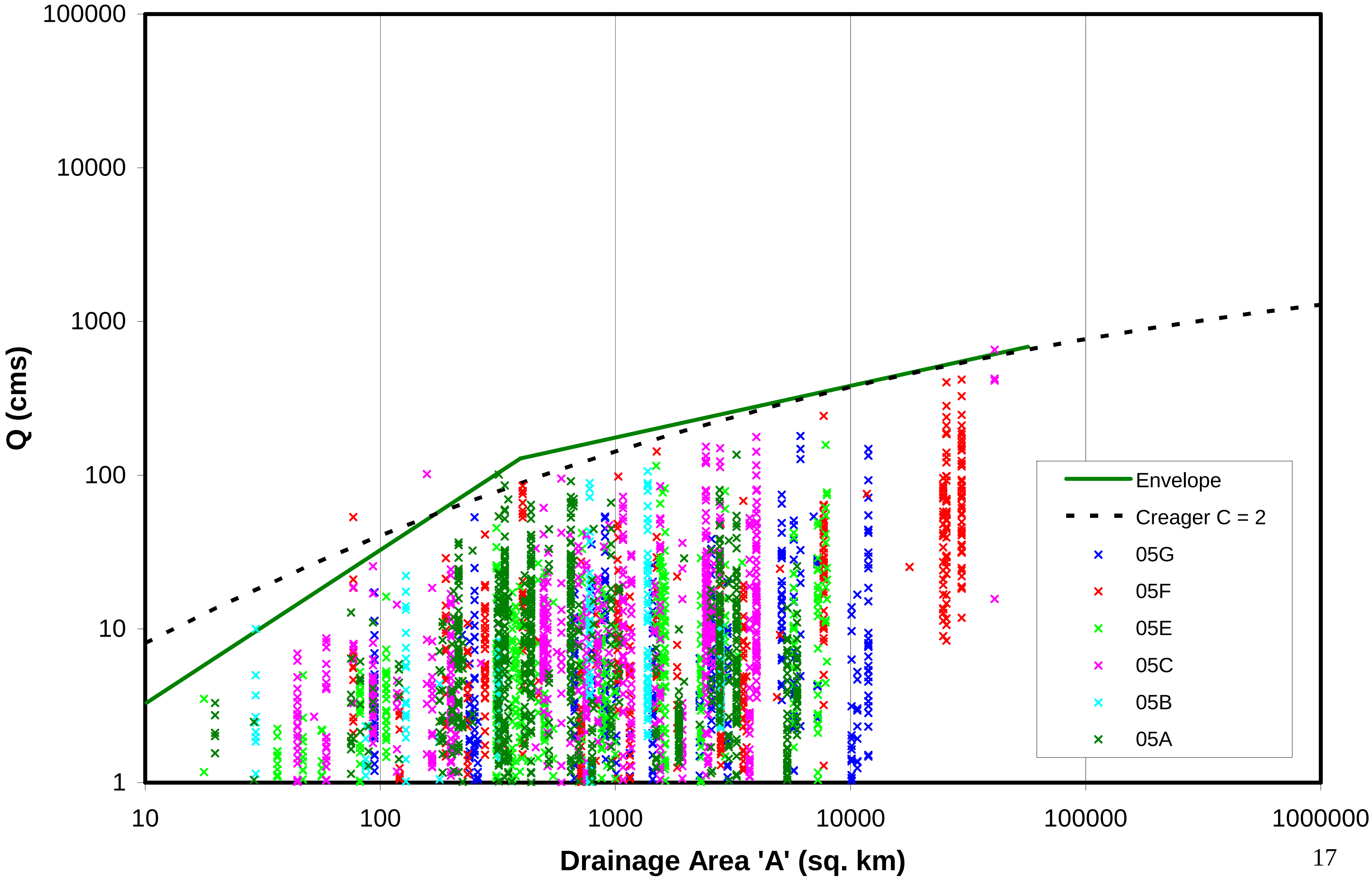


Figure 5c – Flood Envelope Curve – Alberta WSC 07 - Steep

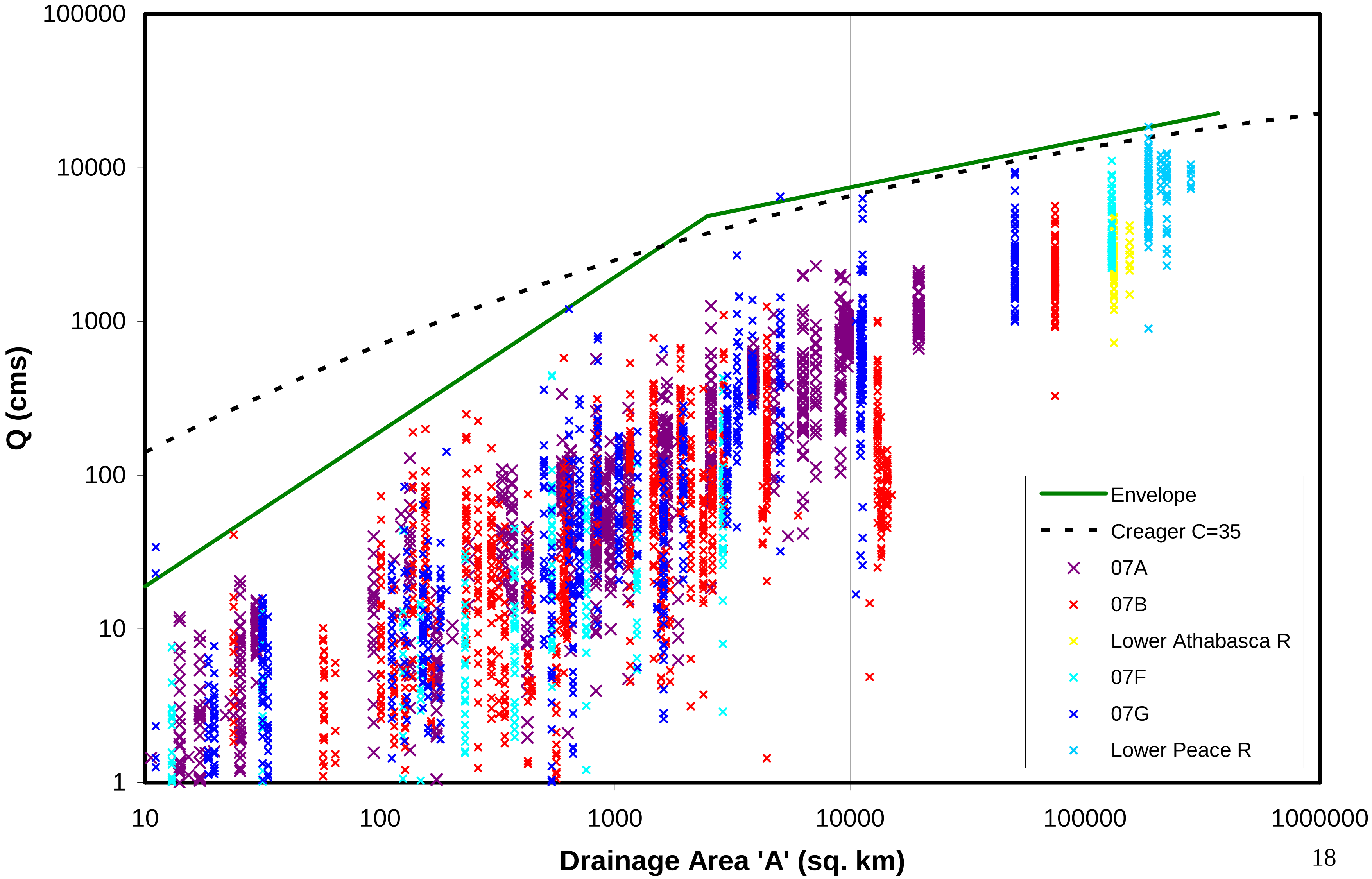


Figure 5d - Flood Envelope Curve – Alberta WSC 07 - Flat

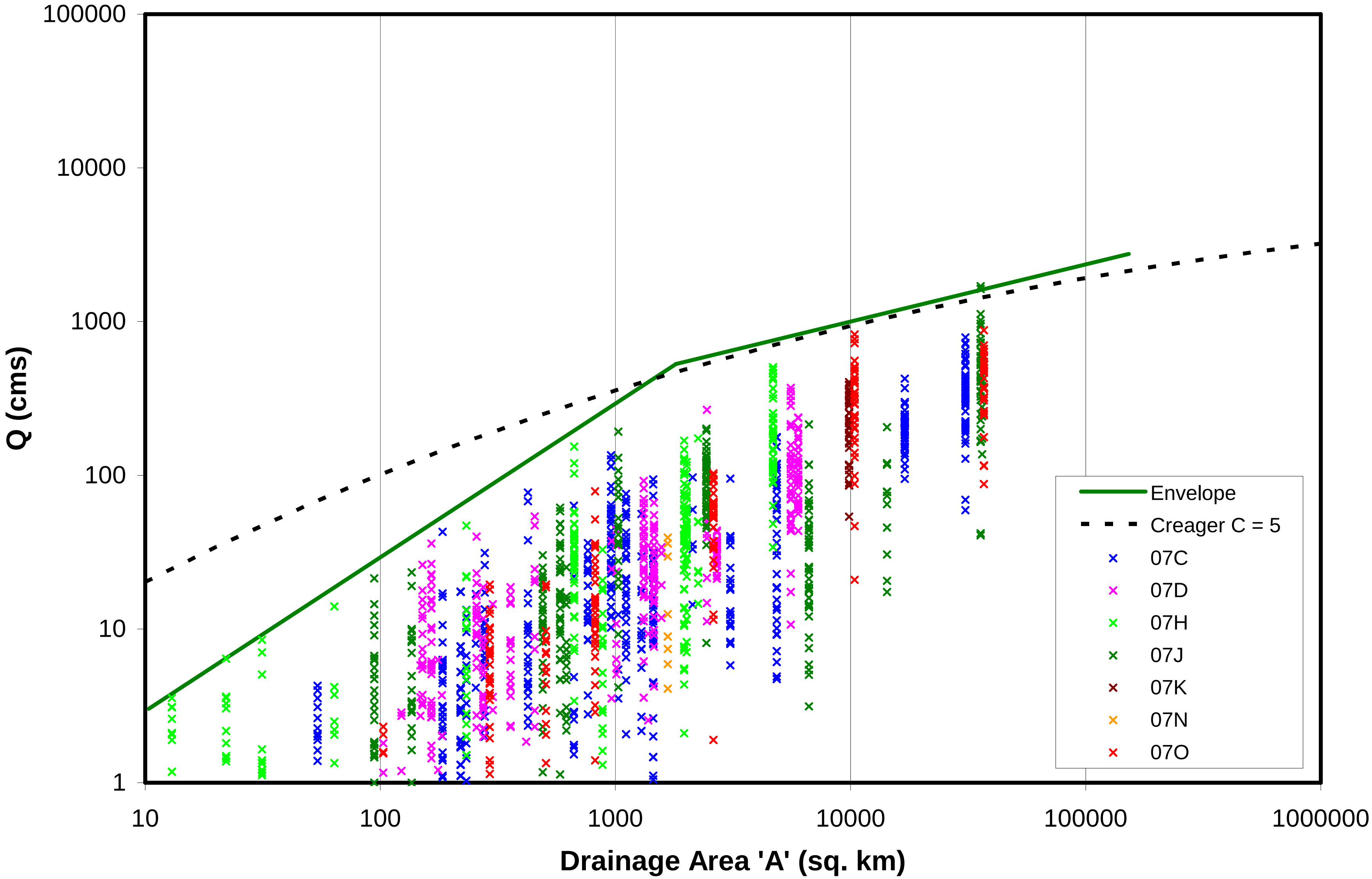


Figure 6 - Flood Envelope Curve – Alberta WSC 06

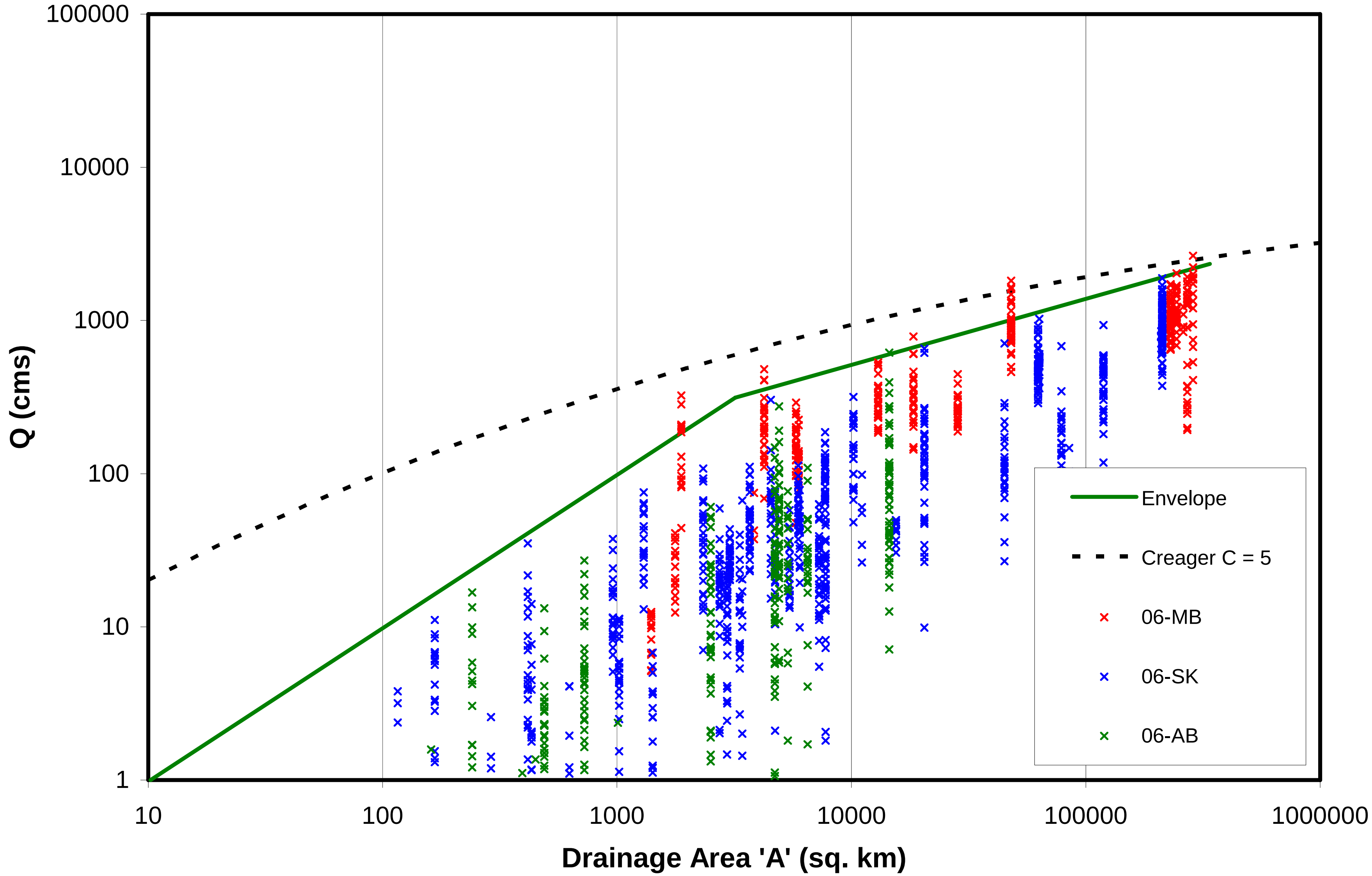


Figure 7 - Flood Envelope Curve Comparison – All Alberta

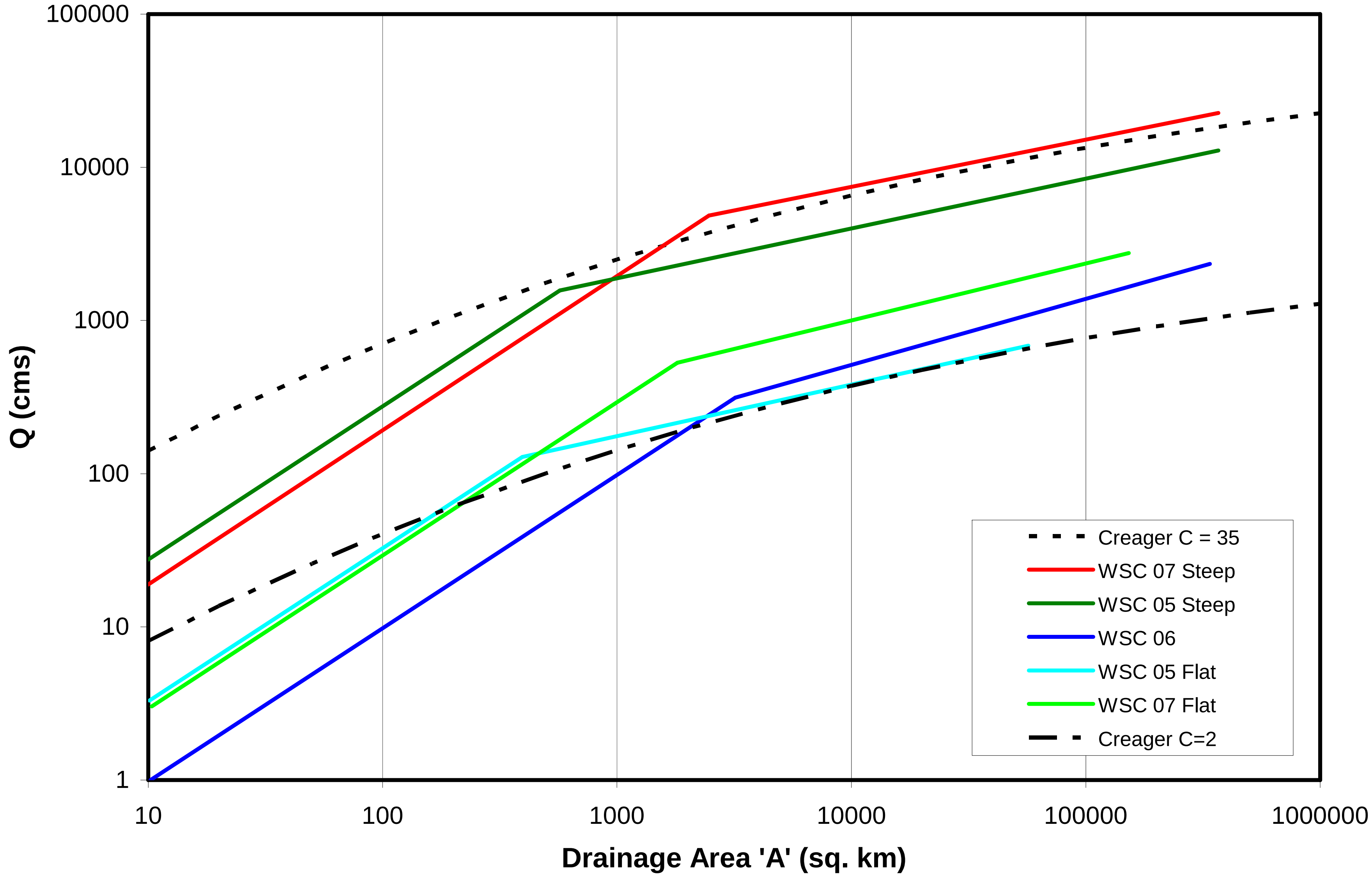
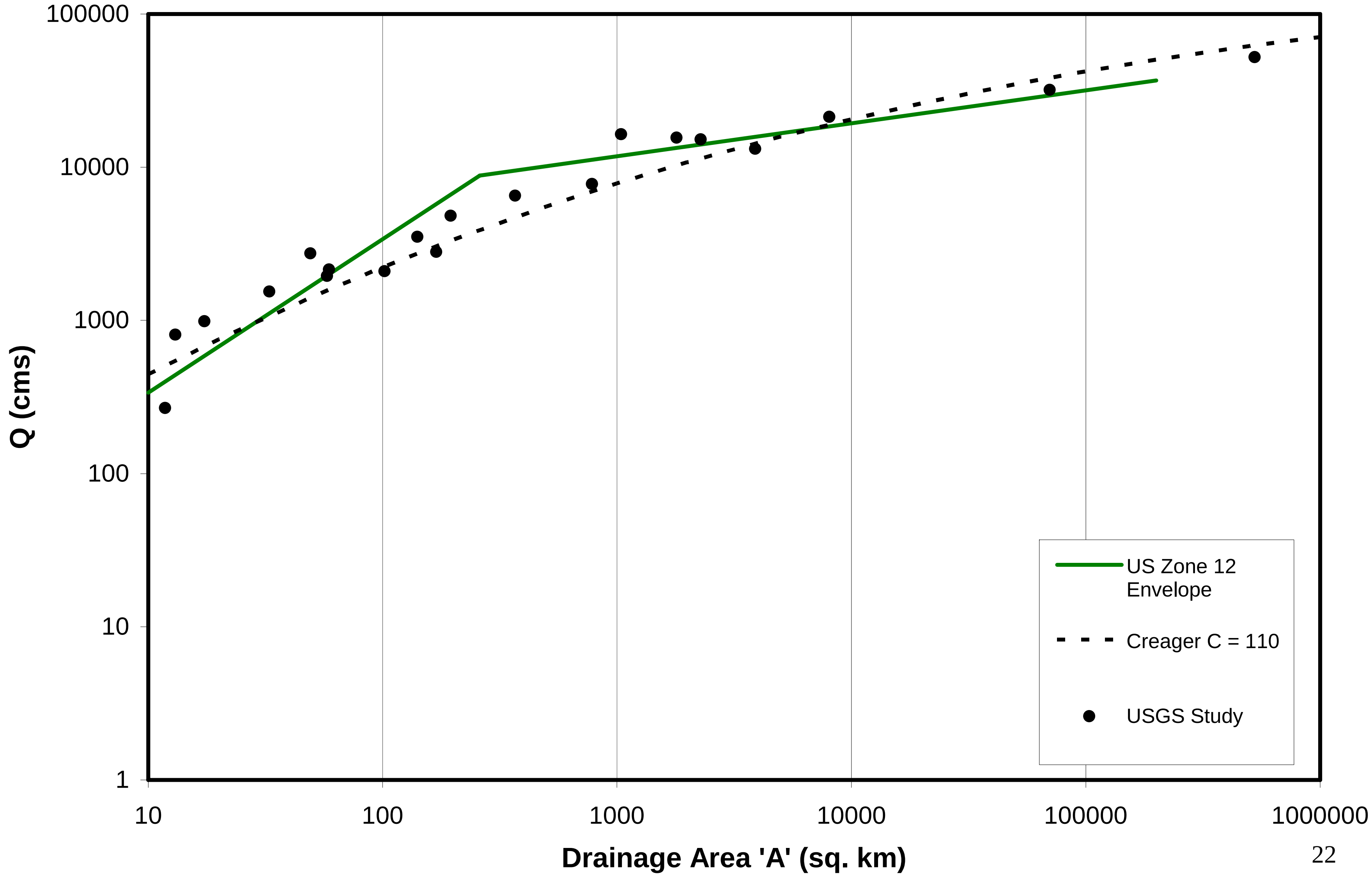


Figure 8 - Flood Envelope Curve Comparison – Creager and USGS Data



References :

1. Alberta Transportation 2007. Alberta Flood Envelope Curve Analysis. (http://www.infratrans.gov.ab.ca/INFTRA_Content/doctype125/Production/gdlnextrmfld.pdf).

2. Costa, J.E., and Jarrett, R.D., 2008. An Evaluation of Selected Extraordinary Floods in the United States Reported by the U.S. Geological Survey and Implications for Future Advancement of Flood Science. USGS Scientific Investigations Report 2008-5164.

3. Alberta Infrastructure and Transportation 2006. Hydrotechnical Design Guidelines for Stream Crossings.
(http://www.infratrans.gov.ab.ca/INFTRA_Content/docType30/Production/HyDgnGLStCr.pdf).