Alberta Rainfall Runoff Response

Introduction

The runoff response to a rainfall event is a function of many complex hydrologic processes. Some of the major factors in the rainfall-runoff process are basin properties (e.g. infiltration capacity, surface storage, initial moisture, and stream conveyance) and storm properties (e.g. location, magnitude, timing, geographic distribution). As no two basins or storms are exactly the same, considerable variation in the rainfall runoff response can be expected. However, a systematic review of the observed runoff response in Alberta has been undertaken to see what trends exist and to assess the ability of the existing data-sets to assist in calibration of hydrologic models. Observed trends may be useful in confirming the identification of distinct hydrologic regions in the province.

Water Survey of Canada (WSC) has compiled and published daily flow data at many sites across the province for about 100 years. In Addition, Environment Canada have published daily rainfall data at many sites across the province over the same time period. Converting the daily flow data to runoff depth combined with calculation of mean rainfall input to each basin for each event will result in a database that can be used to analyse the hydrologic response throughout the province

Database Development

Previous studies on runoff depth mapping [1] and hydrograph travel analysis [2] 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. Hydrographs were graphically created for each event based on the published daily and instantaneous peak flow data. The direct runoff portion of each hydrograph was identified and the runoff depth calculated.

Likewise, examination of the rainfall database for Alberta has identified about 145 large historic storms [3]. For each of these storms, the total rainfall has been estimated as the largest sum of three consecutive daily rainfall values covering the date of the storm. These storms all have an eye covering several gauges with rainfall in excess of 100mm. Gauges from adjacent provinces and states were included in the analysis, to assist in definition of the geographic distribution of these storms. Text files containing the geographic coordinates of each gauge in operation and the total rainfall measured were prepared for each event.

Polygons of the drainage basin boundary for each runoff gauge were prepared, mostly based on a published PFRA GIS data-set. In many cases, the arcs defining portions of sub-basin boundaries were combined to form a continuous set of geographic coordinates. These coordinates were stored in text files for each basin.

All runoff hydrographs resulting from one of the large storms were identified, resulting in about 2300 events. An Excel VBA tool was developed to overlay a rainfall grid over each basin in the data-set to estimate the rainfall input. For each event, the appropriate rainfall and basin boundary text files were identified and loaded, with the coordinates converted to a transverse mercator coordinate system. A rainfall grid covering the extent of the basin was developed using an inverse distance weighting algorithm. The grid was set at 100 points by 100 points, as a sensitivity analysis showed that further refinement of the grid did not produce different results over the range of data-sets in the analysis. Each of the 10000 rainfall points was examined to see if it fell within the basin boundary, and the average of all values falling within the boundary calculated. This value represents the average rainfall value for that storm on that basin. Pairing each of these rainfall values with the corresponding runoff depth resulted in the rainfall runoff database used in this analysis.

The runoff data is subject to the accuracy of the rating curves used in the derivation of the flow values, as few flows are actually measured, but calculated from stage observations. It is suspected that the runoff depth for an event is likely more accurate than peak flow values, as there is less extrapolation involved. Rainfall data is likely more accurate than flow values, although some reporting errors have been noted in the published database. However, the geographic coverage of the gauges still results in significant interpolation when creating the rainfall grid, as can be seen in Figure 1. Analysis of large storms has shown significant variance over small areas near the eye of the storm, indicating that the gauge network can miss some significant high intensity rainfall values.

Results

Figure 2 shows all of the rainfall and corresponding runoff data for each of the six major basins that drain the eastern slopes of the Rockies. This represents most of the database, as there is much less rainfall or runoff data available for northern portions of the province. Lines of constant rainfall-runoff ratio (shown as Φ) after an initial loss have been added to the plot for reference. The initial loss appears to be in the 15 – 20mm range, and is to be expected due to factors such as interception, depression storage, and high initial infiltration rates. The rainfall-runoff ratio ranges from close to zero to about 0.9.

This plot shows a significant variance in response across each basin. This is to be expected as each basin covers a range of hydrologic regions. Additional scatter due to data error and variance in initial moisture conditions would also be expected. However, the overall plots for each basin are similar to each other. The range of magnitude and variance in runoff ratio are similar between all six major basins. This similarity is consistent with the findings in the flow envelope curve analysis [4] for these basins. Each of these major basins contain subbasins that range from very productive (in the foothills) to less productive (on the prairies). As a result, no significant difference in rainfall-runoff characteristics between these major basins is evident.

Plotting the results for basins that only cover the prairie portions of the province shows a much different range of runoff ratios (Fig. 3). While there is still significant scatter in the results, runoff ratio is generally in the range of 0.1, with a maximum of about 0.25. This is substantially less than the values from the eastern slopes of the Rockies, with a runoff ratio generally in the range of 0.4 and a maximum of about 0.9. These results are consistent with the findings in the development of the runoff depth map 1. Likely factors in the difference between these two regions are the reduced hydraulic network capacity and increased surface depression storage due to the flatter topography, and lower antecedent moisture due to higher annual water deficit in the prairie region. It is also apparent that there are much fewer data points for the prairie region, as the largest runoff processes tend to be related to snowmelt, rather than rainfall.

In order to assess the relationship between rainfall and runoff in more detail, the 20 gauges with the most data points were considered. The number of events at these sites range from 15 to 30. The results are shown in figures 4a, 4b, and 4c, based on the magnitude of the range of runoff ratio. Each of these gauges shows the typical scatter covering the range of runoff ratios for each plot. Therefore, while a basin may be categorized into a range based on these observations, a direct relationship between rainfall and runoff cannot be developed.

The categorization into each of the three ranges cannot be readily described by basin location. However, it is apparent that gauges located further downstream tend to fall into a lower runoff group. This can be seen for the Pembina and McLeod Rivers, which had upstream gauges in the high range and downstream gauges in the medium range. It can also be seen in the Little Red Deer gauges, with the upstream gauge in the high range, and the downstream gauge in the low range. This stream highlights the impact of the capacity of the conveyance system and associated routing on the runoff ratio. Gauge 05CB002 has a drainage area of about 450 km^2 and is located about 200km upstream of gauge 05CB001 which has a drainage area of about 2600km^2. Review of the runoff hydrographs for these two gauges shows a considerable lag in timing and little, if any, increase in peak flow between the two sites. Much of the runoff volume would have been stored on the floodplain during the direct runoff portion of the response, with some making it back into the channel after the peak, and some permanently lost to storage.

In addition of data error, another possible reason for the scatter that is seen on the runoff response plots for each of these basins is the variation in antecedent moisture across the basin. If the basin had recently seen a large runoff response, some of the initial losses may be reduced and infiltration capacity reduced. Accounting for antecedent moisture over large natural basins is difficult, especially with the available data. In order to investigate the influence of this parameter, it was decided to use the base flow (Q_b) at the start of the runoff hydrograph. This was further converted to a unit discharge (divided by drainage area (A)) to facilitate plotting the results for several basins on the same plot. The results for the six basins with the most events are shown on Figure 5. There does appear to be a trend between runoff ratio and base flow, but it is still small in comparison with the overall scatter in the results. Either the base flow is not a sufficient indicator of antecedent moisture for the basin, or the impact of antecedent moisture is obscured by other factors.

Conclusions

Analysis of the available rainfall and runoff records for Alberta shows a significant amount of scatter, both across major basins and for multiple events at a single basin. Some of this scatter is likely due to data error, particularly with the interpolation of rainfall data. Other possible reasons for the scatter include differences in antecedent moisture, storm location relative to the drainage network, temporal and geographic distribution of the rainfall, changes in basin routing parameters between events, and the possibility of rain on snow inputs for some events.

Even with the scatter, significant trends can still be seen. The runoff ratios for prairie areas are typically much lower than the ratios for the foothills. The range of runoff ratios is similar for each of the six major basins draining the eastern slopes of the Rockies. Categorization of the runoff based on magnitude indicates the impact of basin routing on the overall runoff ratio. Antecedent moisture is likely a factor in the variability of runoff response, but the magnitude appears to be masked by other factors.

As these rainfall and runoff data-sets are the basis for calibration of hydrologic models, the scatter suggests that calibration of any model to all of the recorded events is not possible. Also, the common assumption that once a certain amount of initial losses are accounted for that the runoff ratio approaches 1.0 appears questionable for many of the less productive basins. Therefore, hydrologic models will likely struggle to predict responses to storms within the range of historical observations, and will only introduce additional uncertainty when used to extrapolate to much more severe runoff conditions.

Figure 1 – June 5, 1995 Storm over Pincher Creek Basin (Gauge 05AA004)

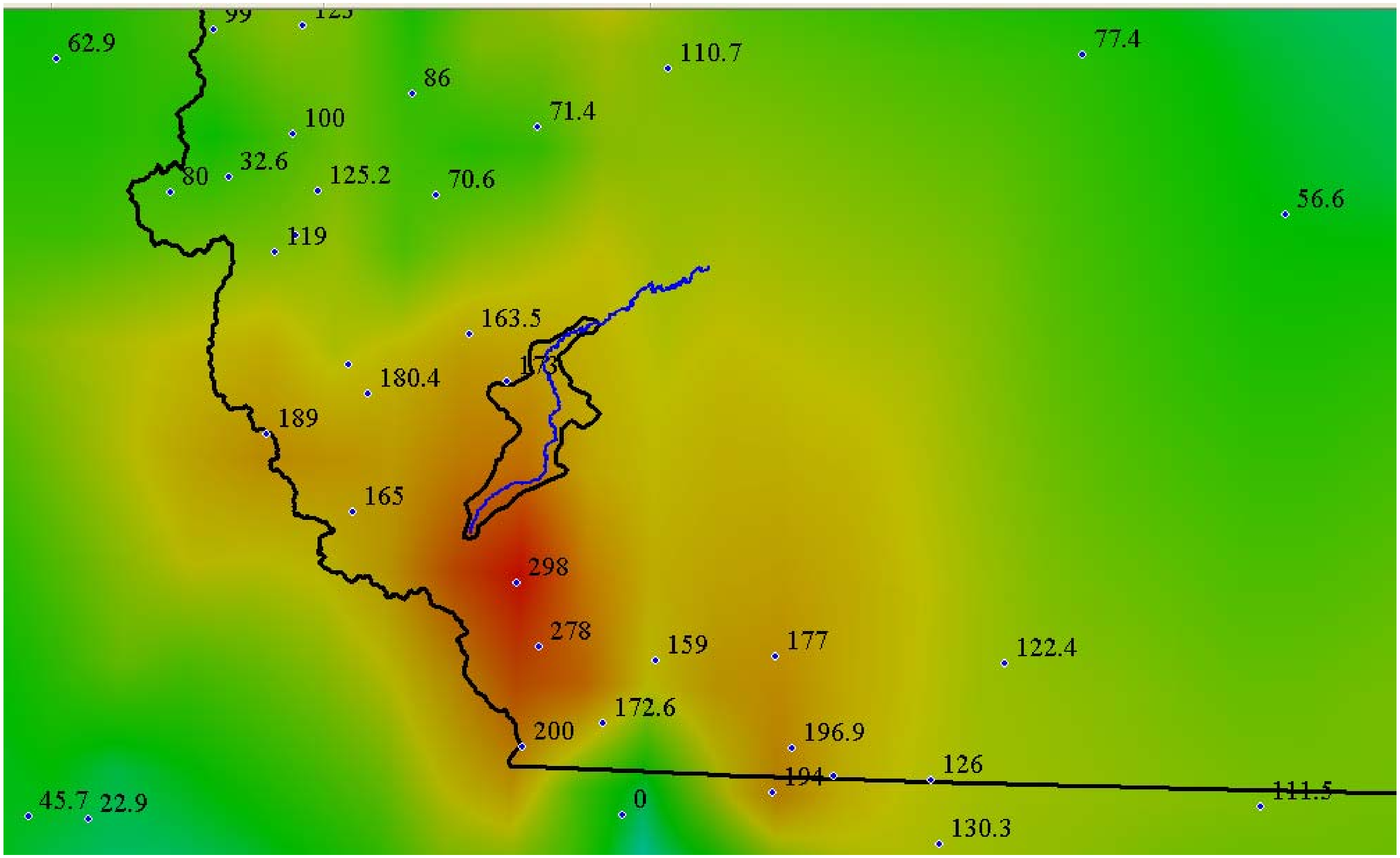


Figure 2 – All Data

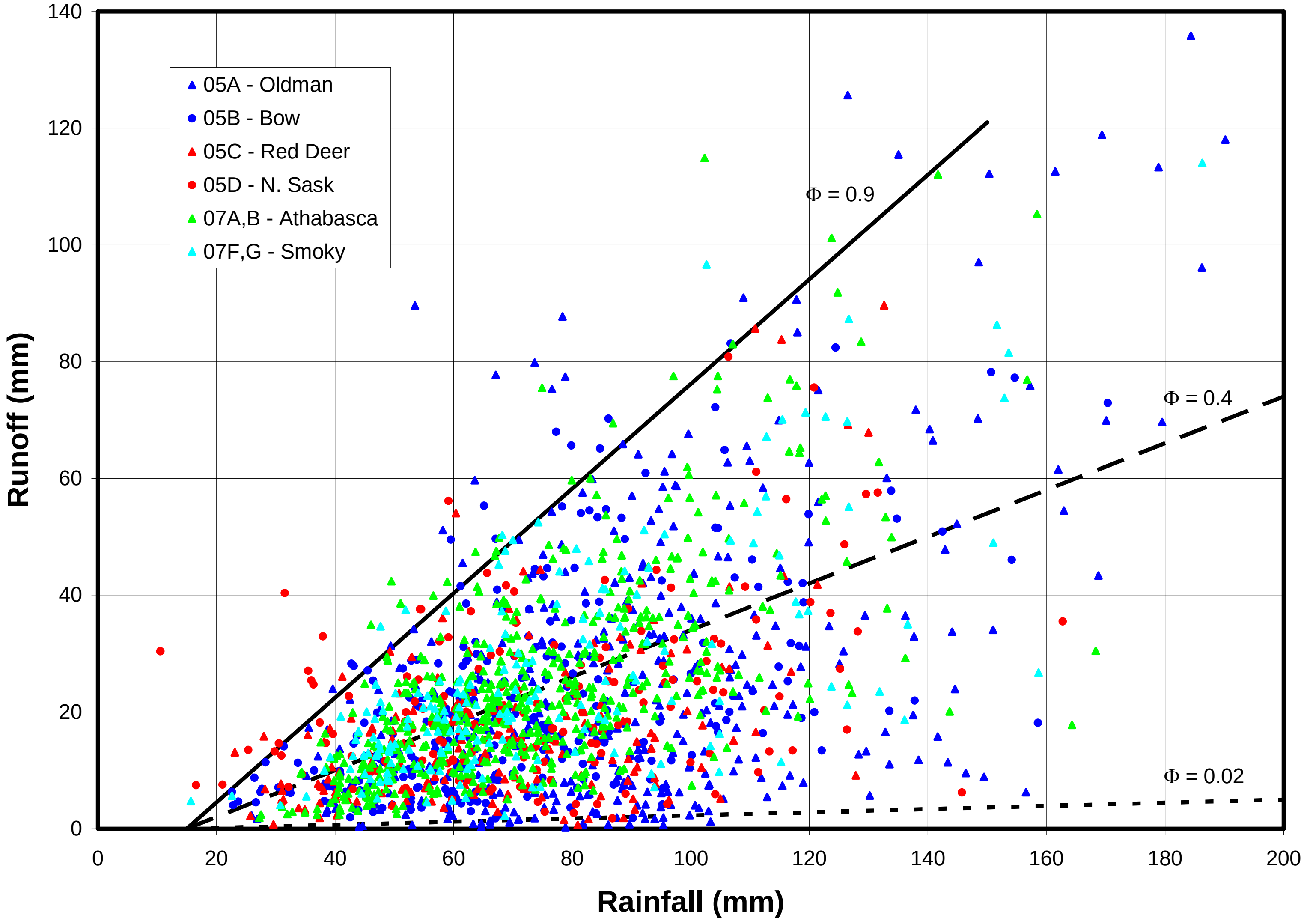


Figure 3 – Prairie Data

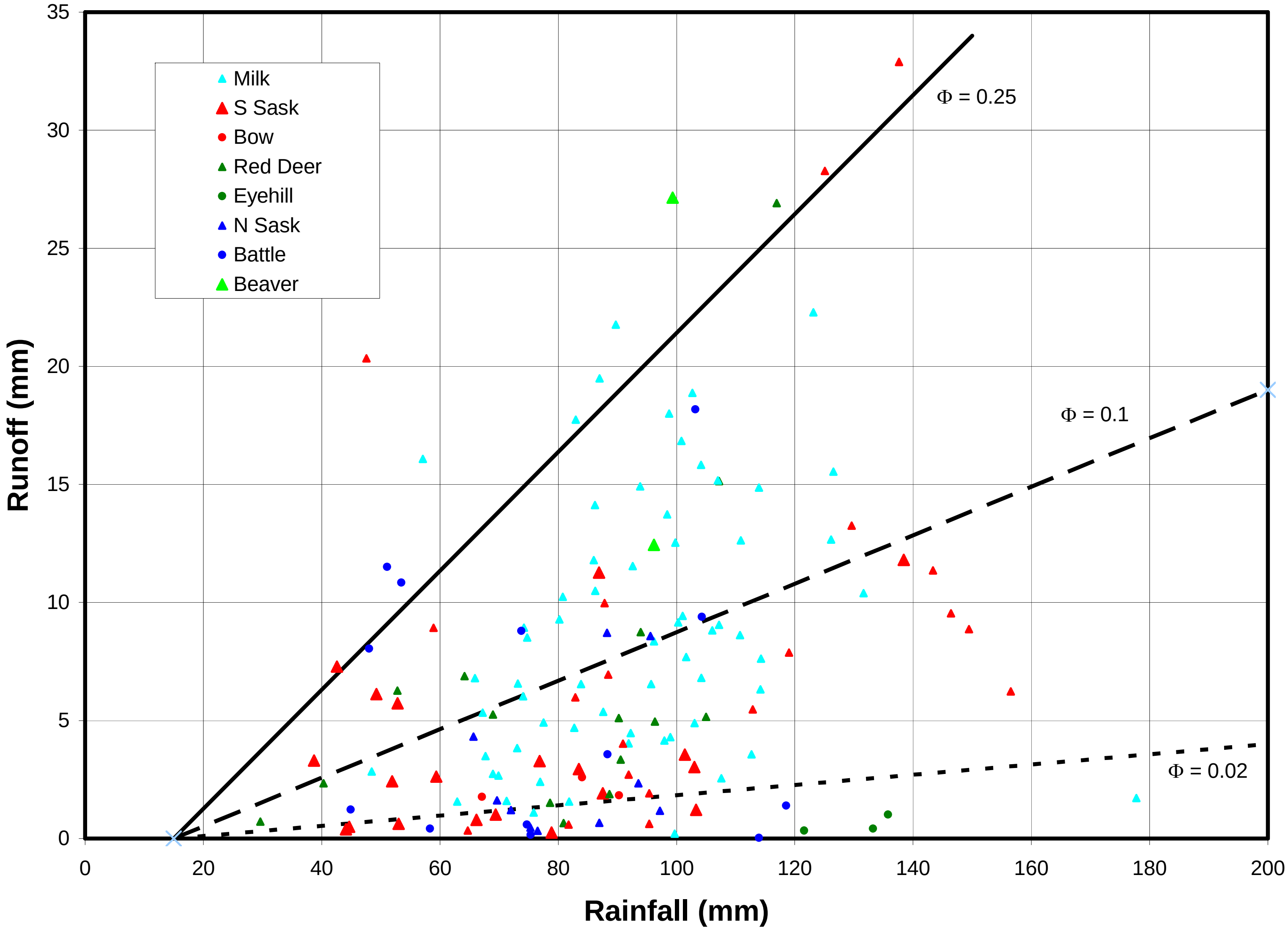


Figure 4a – High Runoff Basins

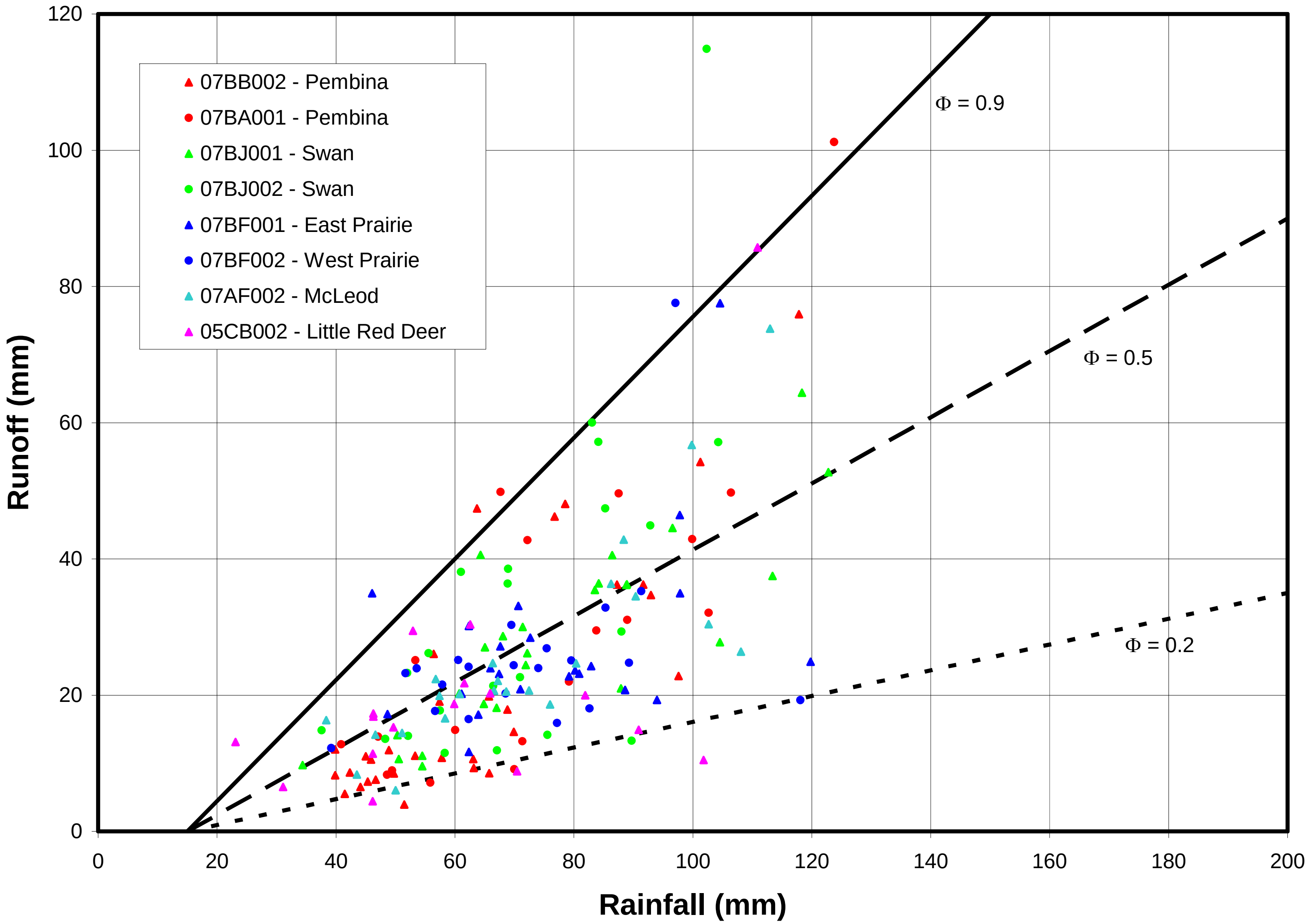


Figure 4b – Medium Runoff Basins

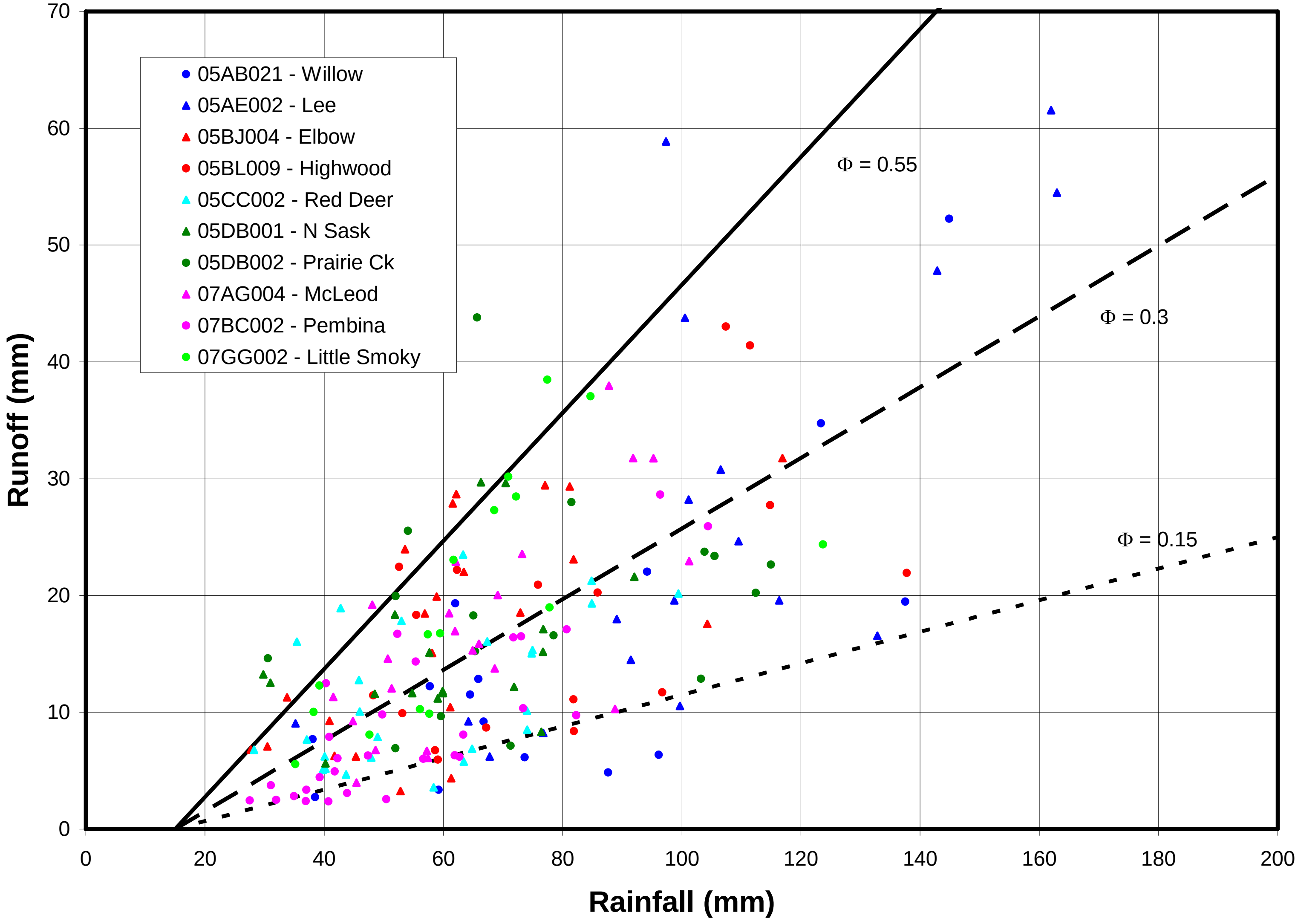


Figure 4c – Low Runoff Basins

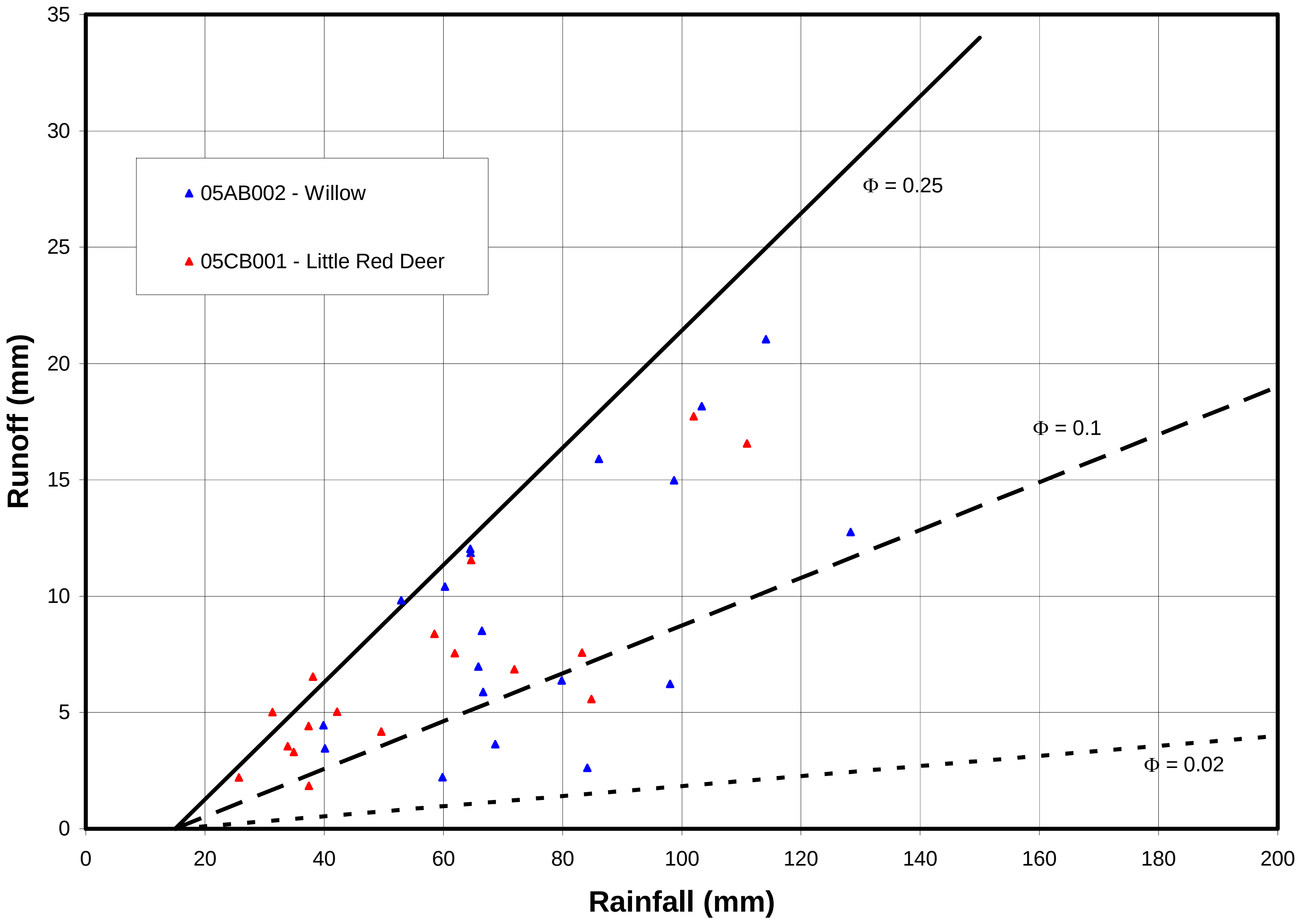
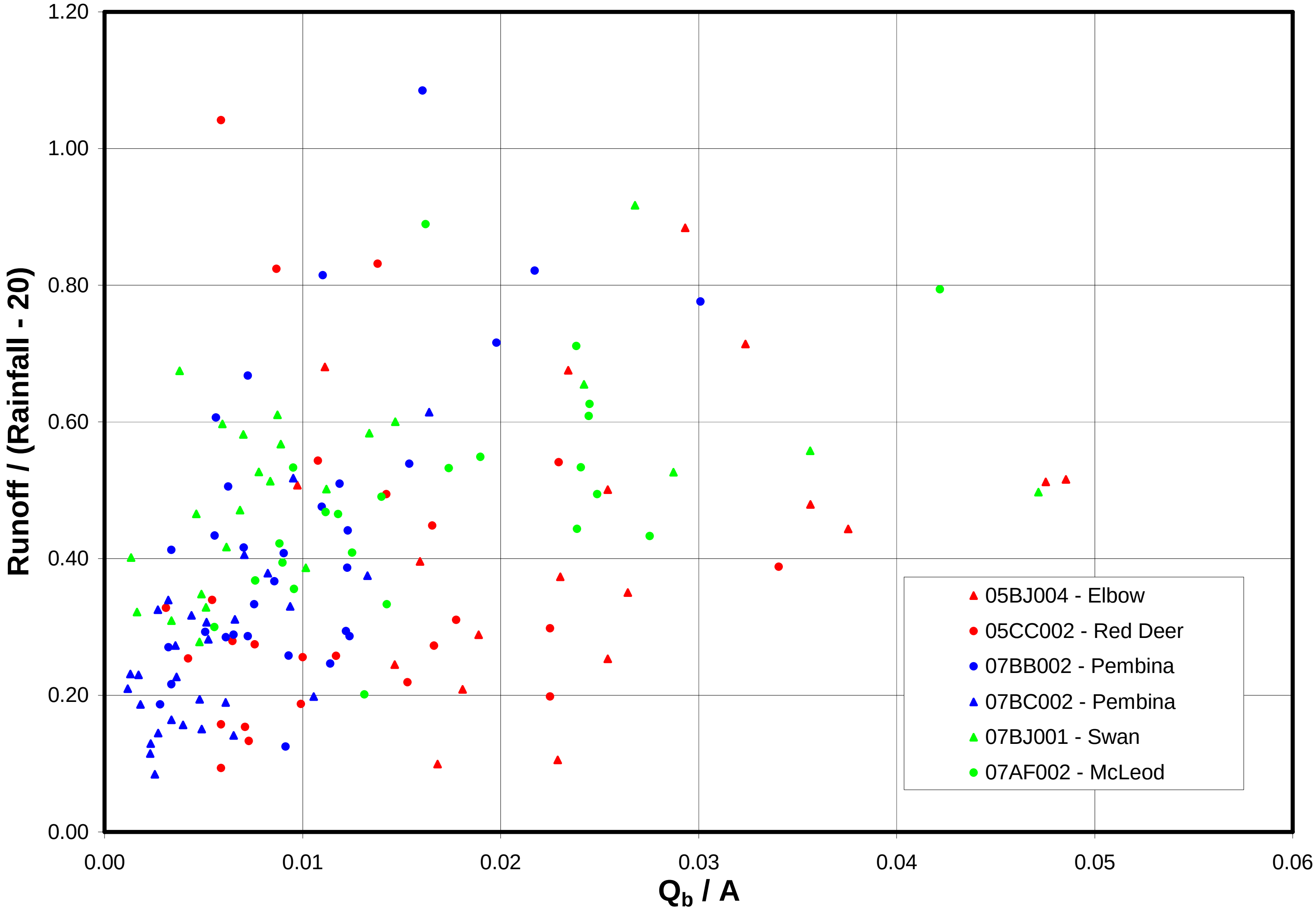


Figure 5 – Antecedent Moisture



References :

1. Alberta Infrastructure and Transportation 2006. Development of Runoff Depth Map for Alberta. (http://www.infratrans.gov.ab.ca/INFTRA_Content/docType30/Production/DvRnoffDMap.pdf).

2. Alberta Infrastructure and Transportation 2006. Hydrograph Travel Time Analysis. (http://www.infratrans.gov.ab.ca/INFTRA_Content/docType30/Production/HyGrTvTmAys.pdf).

3. Alberta Infrastructure and Transportation, Bridge Engineering and Water Management Section 2007. Large Alberta Storms. (http://www.infratrans.gov.ab.ca/INFTRA_Content/docType30/Production/lrgabstorm.pdf).

4. Alberta Infrastructure and Transportation, Bridge Engineering and Water Management Section 2007. Alberta Flood Envelope Curve Analysis. (http://www.infratrans.gov.ab.ca/INFTRA_Content/docType30/Production/fldenvcurv.pdf).