Analysis of loadings

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1 Data

Description The data in this report comes from four Wisconsin streams that were monitored (with some gaps in data collection) between 1989 and 2007. The streams and the period during which each was monitored are:

Stream	Monitored
Eagle	1991-1994, 2003-2007
Joos Valley	1990-1994, 2002-2007
Otter	1990-1997, 2000-2002
Brewery	1989, 1994-2002, 2004-2005

Each entry in our data set represents one loading event, which is defined based on the hydrograph - the event begins when the loading rises from a base level toward a peak, and ends when the loading falls back to its new base level. Two kinds of load are measured for each event - the sediment load and the phosphorus load. There are two typical ways that sediment and phosphorus get into streams - they can be carried either by runoff during a rainstorm or by melting snow.

Not all of the data can be collected for each event. For instance, rainfall is measured only when the ground is free of snow because snow interferes with the rain gauges. And the amount of snowmelt is estimated by multiplying the water content of the snow by the change in snow depth a warm snap, which is inaccurate when additional snow falls during that event. Broadly, there is one set of measurements that are made during rainfall-driven events and a different set of measurements that are made during snowmelt-driven events. Because of this, the two types of event are modeled separately.

Exploratory Analysis Our anaysis targets the phosphorus and sediment loads carried by each stream. Using Rainmaker software, each load can be broken into two parts: base load and storm load. We will consider models of the storm load and of the total load.

We investigated splitting the rainfall-driven events into early and late events on May 15th of each year. If vegetation serves to hold the soil together, and to increase both evapotranspiration and infiltration, then erosion may be more common early in the spring before most of the summer's vegetation appears. If so, the relationship between rainfall and the stream's loading might change during the summer.

The investigation was done by making linear models to describe the sediment and phosphorus loading during the two subseasons and comparing them to a single model fit to the entire snow-free period. Because the split makes the model more flexible, it will certainly improve the model's fit - the question is whether that improvement is enough to justify making the model more complex. At all four streams, the model improvement was statistically significant but too small to matter (the split models explained about 1%-2% more of the loads). We will not use the split in the rest of the analysis.

	snowmelt-driven	rainfall-driven
eagle	27.0%	73.0%
joosvalley	26.9%	73.1%
otter	35.4%	64.6%
brewery	32.8%	67.2%

Table 1 – Proportion of total suspended solids loading contributed by each type of event

Over the course of the monitoring period, the majority of the total load (both of sediment and of phosphorus) was carried during just a few major events. Just 10% of the events carried between 73.1% (at Otter) and 93.4% (at Joos) of the total sediment load and 64.6% (at Otter) and 88% (at Joos) of the total phosphorus load.

Table 3 shows that, except possibly at Eagle and Joos, the proportion of major events is roughly in line with the proportion of all events during each season.

	snowmelt-driven	rainfall-driven
eagle	32.8%	67.2%
joosvalley	36.4%	63.6%
otter	46.5%	53.5%
brewery	49.6%	50.4%

Table 2 – Proportion of total phosphorus loading contributed by each type of event

Proportion of events driven by:

	Snowmelt		Rainfall	
Creek	All Events	Major Events	All Events	Major Events
Eagle	42%	30%	58%	70%
Otter	41%	42%	59%	58%
Joos	46%	31%	54%	69%
Brewery	56%	52%	44%	48%

Table 3 – Each pair of columns represents either snowmelt-driven or rainfall-driven events. The column on the left of each pair is the proportion of all events in the study that occured during this period; the column on the right is the proportion of major events that occured during this period.

2 Analysis

2.1 Variable selection

In order to make a model of the load carried by the stream, we need to select the predictor variables that have explanatory power. We used stepwise regression with the Bayesian Information Criterion (BIC) to screen the potential predictor variables.

Rainfall-driven events The predictors that survived the screening at each stream are listed in Table 5. The variables are listed in the order of their importance to the model.

In every case, the theisen rainfall is the most important predictor, followed usually by antecedent baseflow. Using just those two predictors results in an R^2 greater than 0.7 in most models (the exception is at Brewery Creek - see Table 4.) Since the antecedent baseflow is considered an indicator of how wet is in the watershed before each event, we conclude that the amount of sediment and phosphorus washed into a stream by each event is mainly a function of the quantity of water in the system.

Snowmelt-driven events We had less success modeling the loading produced by the snowmelt-driven events. The predictors that survived the screening process were different from stream to stream and those variables that did survive at most sites weren't always selected in the same order, like they were for the rainfall-driven events. The models selected by the BIC range in R^2 from 0.24 to 0.53, with most in the 0.45 range.

At most sites, the most important predictor was a temperature measurement, either the maximum or the mean temperature during the loading event. The antecedent baseflow also appears to be important at most sites. It seems likely that, as in the case of rainfall-driven events, the loading is driven by the quantity of water that moves through the watershed during the event.

2.2 Major events

References

[1] M.E. Danz, S.R. Corsi, D.J. Graczyk, and R.T. Bannerman. Characterization of suspended solids and total phosphorus loadings from small watersheds in wisconsin. Scientific Investigations Report 2010-5039, United States Geological Survey, 2010.

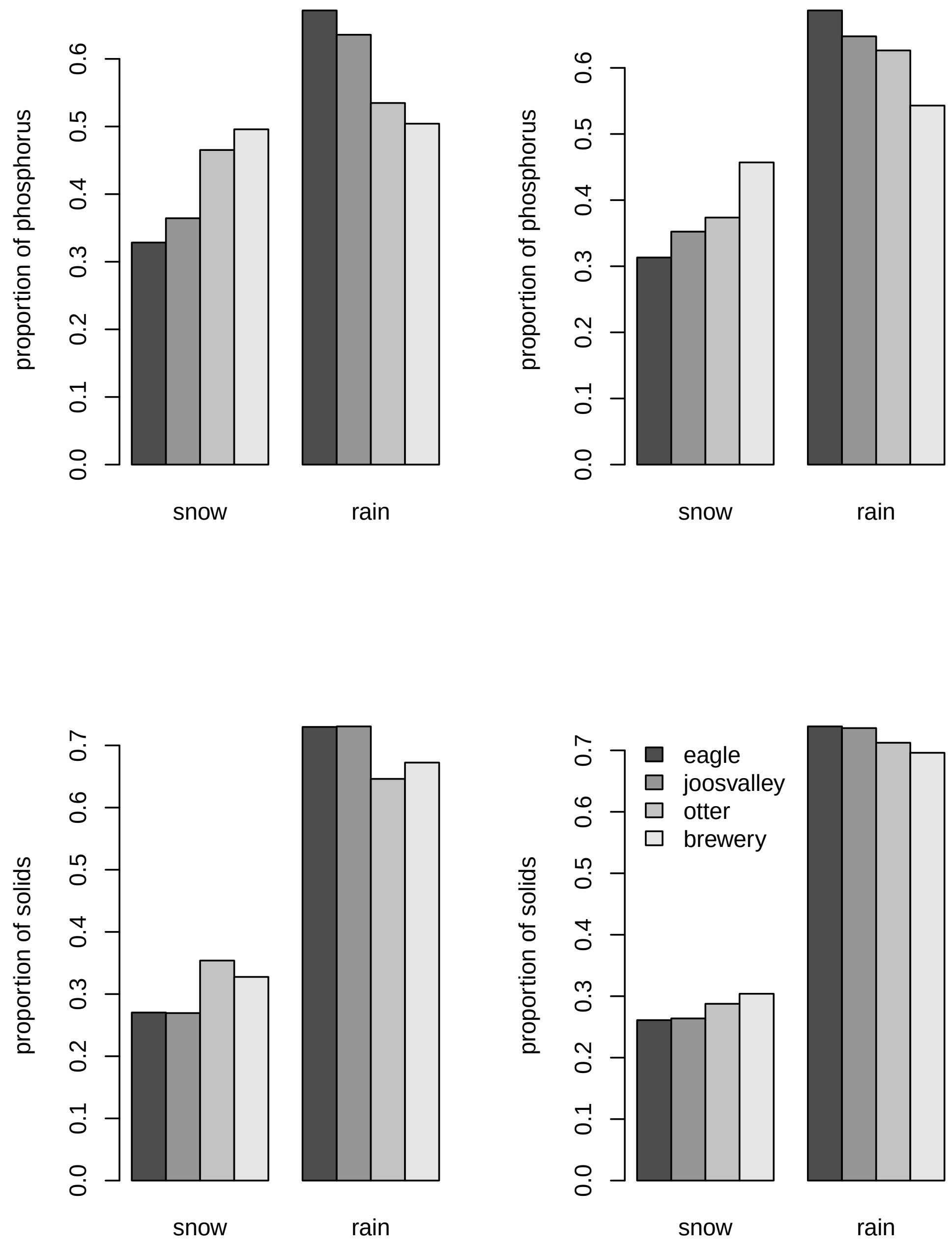
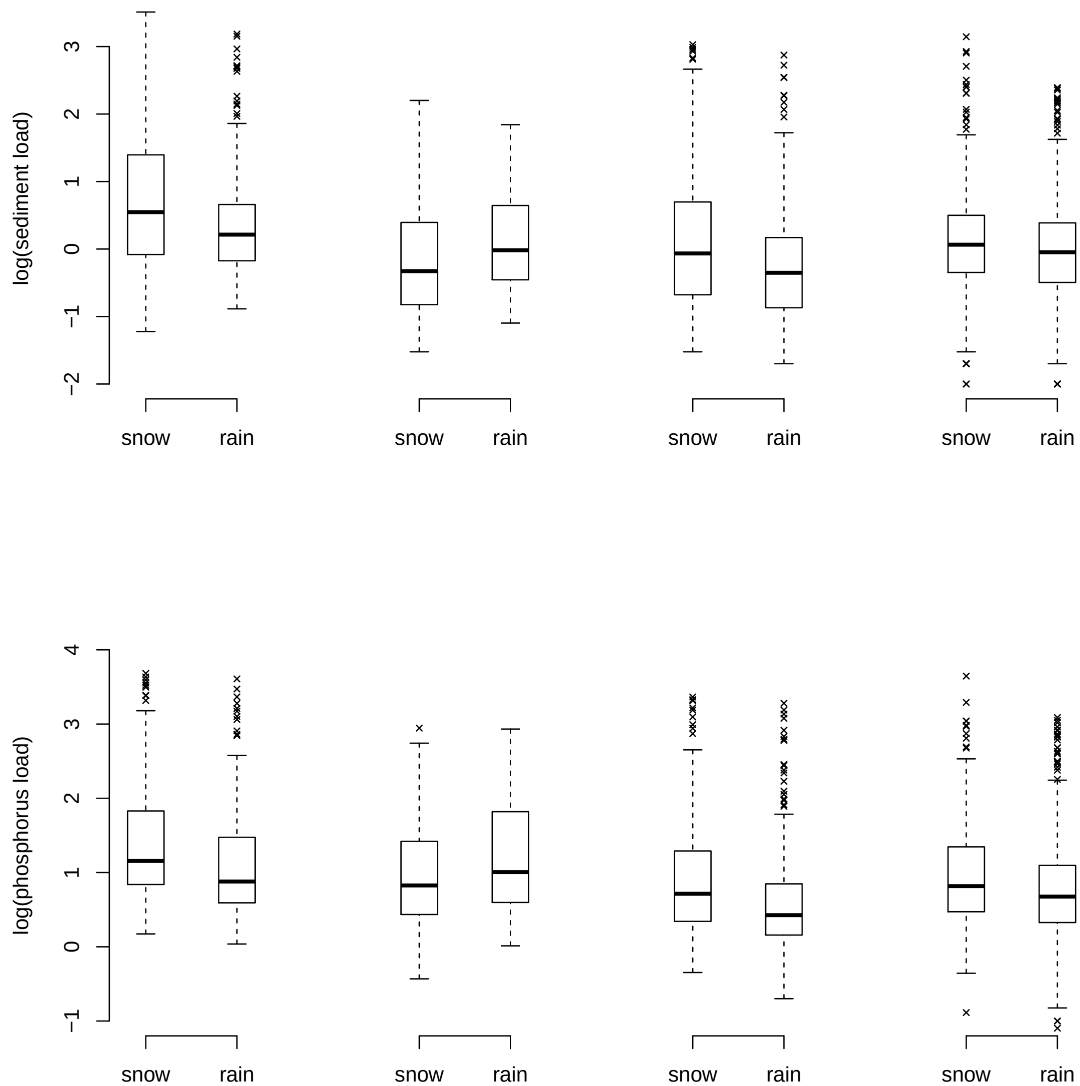


FIGURE 1 – Cumulative storm loadings at the four creeks.



log(sediment load)
3
2
1
0
−1
−2
snow
rain
snow
rain
snow
rain
snow
rain
log(phosphorus load)
4
3
2
1
0
−1
snow
rain
snow
rain
snow
rain
snow
rain

Sediment	R^2	Model terms
Eagle	0.503	theisen
	0.755	theisen + antecedent_qbase
	0.756	theisen + antecedent_qbase + tmean
	0.762	theisen + antecedent_qbase + tmean + tmax
	0.762	theisen + antecedent_qbase + tmean + tmax + p15max
	0.762	theisen + antecedent_qbase + tmean + tmax + p15max + p30max
Joos	0.49	theisen
	0.665	theisen + antecedent_qbase
	0.692	theisen + antecedent_qbase + p15max
	0.701	theisen + antecedent_qbase + p15max + cos_julian
	0.701	theisen + antecedent_qbase + p15max + cos_julian + antecedent_tmean
	0.701	theisen + antecedent_qbase + p15max + cos_julian + antecedent_tmean + ap_2day
Otter	0.486	theisen
	0.738	theisen + antecedent_qbase
	0.762	theisen + antecedent_qbase + sin_julian
	0.781	theisen + antecedent_qbase + sin_julian + antecedent_tmean
	0.781	theisen + antecedent_qbase + sin_julian + antecedent_tmean + ap_3day
Brewery	0.433	theisen
	0.459	theisen + p30max
	0.511	theisen + p30max + tmean

Phosphorus	R^2	Model terms
Eagle	0.579	theisen
	0.783	theisen + antecedent_qbase
	0.782	theisen + antecedent_qbase + tmean
	0.792	theisen + antecedent_qbase + tmean + tmax
	0.792	theisen + antecedent_qbase + tmean + p5max
	0.792	theisen + antecedent_qbase + tmean + tmax + p5max + p30max
Joos	0.543	theisen
	0.715	theisen + antecedent_qbase
	0.733	theisen + antecedent_qbase + p15max
	0.755	theisen + antecedent_qbase + p15max + ap_2day
Otter	0.483	theisen
	0.737	theisen + antecedent_qbase
	0.762	theisen + antecedent_qbase + tmin
	0.776	theisen + antecedent_qbase + tmin + sin_julian
	0.776	theisen + antecedent_qbase + tmin + sin_julian + ap_3day
Brewery	0.602	theisen
	0.636	theisen + ap_3day
	0.654	theisen + ap_3day + tmin + p60max

TABLE 4

			Sediment		Phosphorus	
Creek	Period	All events	Loading	Major events	Loading	Major events
Aggregated	Snowmelt	48%	28%	40%	39%	48%
	Post-snow	52%	72%	60%	61%	52%
Eagle	Snowmelt	42%	27%	30%	33%	37%
	Post-snow	58%	73%	70%	67%	63%
Joos	Snowmelt	46%	27%	31%	36%	35%
	Post-snow	54%	73%	69%	64%	65%
Otter	Snowmelt	41%	35%	42%	47%	58%
	Post-snow	59%	65%	58%	53%	42%
Brewery	Snowmelt	56%	33%	52%	50%	60%
	Post-snow	44%	67%	48%	50%	40%

Solids

Eagle:	theisen, antecedent_qbase, tmean, tmax, p15max, p30max
Joos:	theisen, antecedent_qbase, p15max, cos_julian, antecedent_tmean, ap_2day
Otter:	theisen, antecedent_qbase, sin_julian, antecedent_tmean, ap_3day
Brewery:	theisen, p30max, tmean

Phosphorus

Eagle:	theisen, antecedent_qbase, tmean, tmax, p5max, p30max
Joos:	theisen, antecedent_qbase, p15max, ap_2day
Otter:	theisen, antecedent_qbase, tmin, sin_julian, ap_3day
Brewery:	theisen, ap_3day, tmin, p60max

TABLE 5 – The most important variables in the models for rainfall-driven loading. The variables are ordered by their importance to the model of the load.

Solids	
Eagle:	nws_prec, tmax, nws_snow, antecedent_qbase, num_days, sin_julian
Joos:	num_days, tmax, nws_prec, antecedent_qbase, tmean, nws_snow, sin_julian
Otter:	tmean, tmin, nws_prec, antecedent_qbase, nws_snow, num_days, sin_julian
Brewery:	num_days, nws_prec, sin_julian, antecedent_qbase
Phosphorus	
Eagle:	tmax, nws_prec, nws_snow, num_days, antecedent_qbase, sin_julian
Joos:	num_days, nws_prec, antecedent_qbase, sin_julian, nws_snow, tmax
Otter:	tmean, tmin, antecedent_qbase, nws_prec, nws_snow, num_days, sin_julian
Brewery:	num_days, nws_prec, sin_julian

TABLE 6 – The most important variables in the models for snowmelt-driven loading. The variables are ordered by their importance to the model of the load.

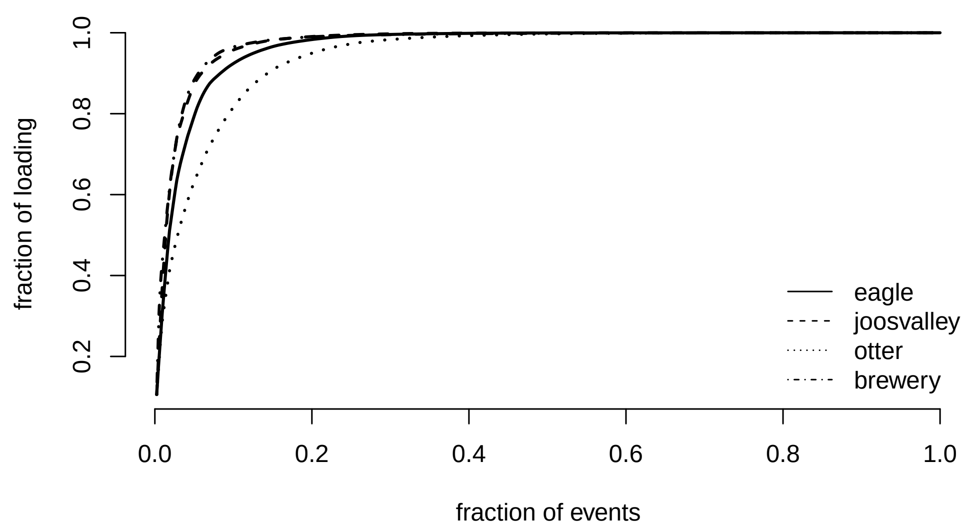


FIGURE 2 – Cumulative storm loadings at the three creeks.

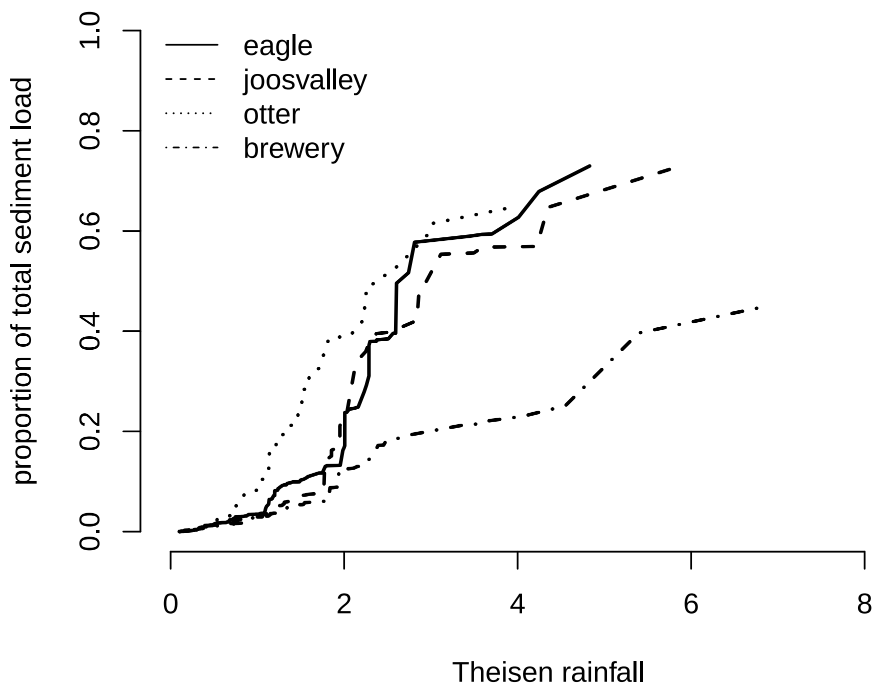


FIGURE 3 – Proportion of the total sediment load contributed by rainfall events up to the size shown. Snowmelt-driven events are excluded.

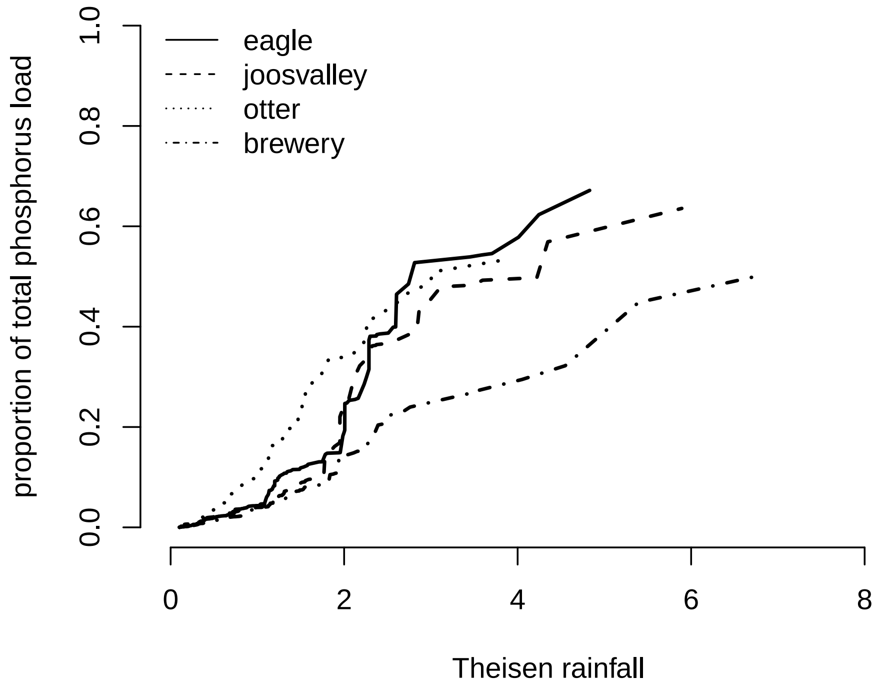


FIGURE 4 – Proportion of the total phosphorus load contributed by rainfall events up to the size shown. Snowmelt-driven events are excluded.

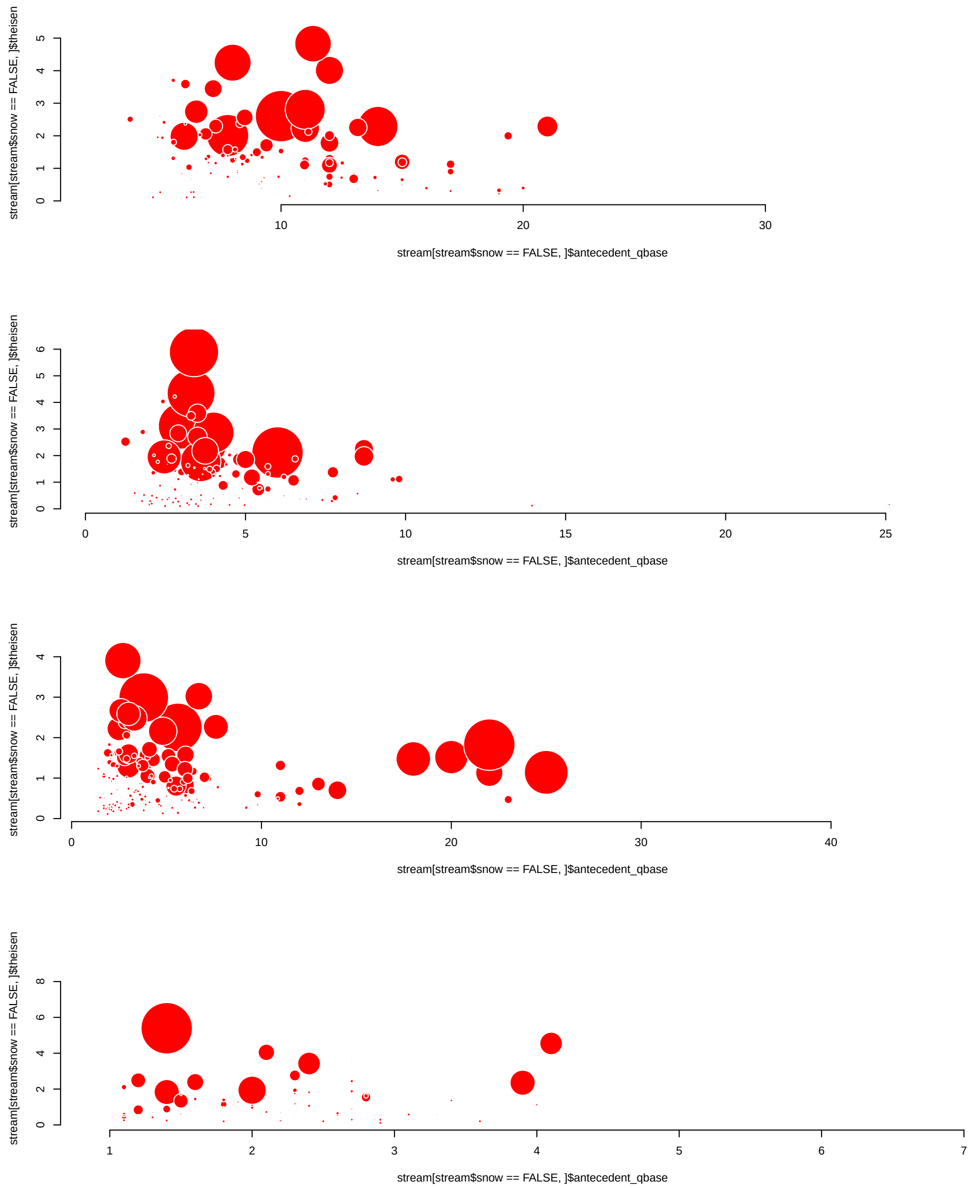


FIGURE 5 – Antecedent base flow is the horizontal axis; theisen rainfall is the vertical axis. Each dot represents one event. The size of the dot shows the total sediment load contributed by that event.