Revisiting watershed drainage density: New considerations for hydrologic prediction

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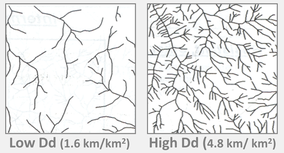
- There is a strong theoretical basis for drainage density (Dd) as a landscape level predictor of flow, but its application has been met with mixed success.
- Dd, traditionally represented as a single average value, can also be represented as a probability distribution function (PDF) of a range of values, reflecting Dd heterogeneity within a watershed.
- In single watersheds and within nested systems, PDFs and L-moment statistics describing their shapes explain flow behavior better than average Dd.
- In some landscapes, PDF metrics can greatly improve our process-based understanding of how drainage density influences peak and low flows.

1 – Why Drainage Density (Dd)?

- Directly applicable to flow routing
- Measurable at a landscape scale and in ungaged basins
- Reflects interaction between geology & climate
- Represents underlying geology (lithology, structure, age and history)
- Theoretically related to key hydrologic properties

Dd = Stream Length (km) / Basin Area (km^2)

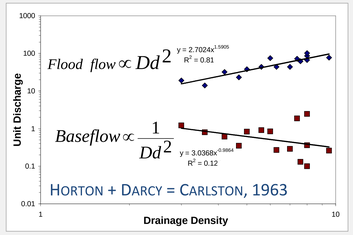
(inverse of spacing btwn streams)



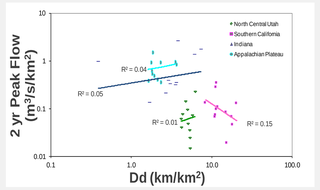
Low Dd (1.6 km/km²)

High Dd (4.8 km/ km²)

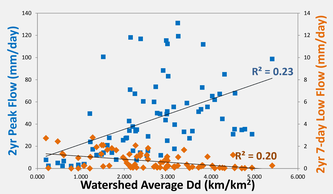
In theory…



But it didn't work so well in other places…including our study area in Oregon



Data from Patton and Baker, 1976 ; as discussed by Dingman, 1984.

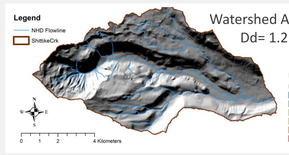


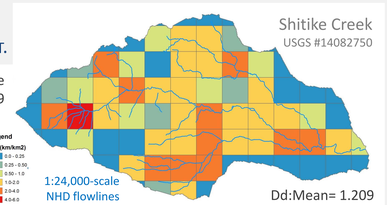
This study, 80 watersheds in Oregon (see site figure, Panel 4, for USGS gage locations)

2 – Probability Distribution Functions & Statistics

How to represent heterogeneity within a watershed?

A. Overlay a grid on NHD flowlines and calculate Dd for each 1 km^2 unit.





Grid method captures average watershed behavior and provides additional information about distribution of Dd within the watershed.

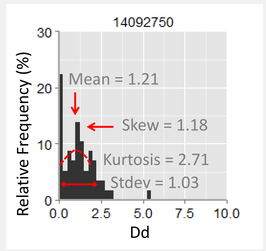
Is this sensitive to grid size?

2km grid under-estimates Dd, especially in elongate basins; 0.5km grid doesn't improve estimates and is computationally heavy.

B. Rank all units by area weighted Dd and aggregate

For Shitike Creek example, the initial 75 units (including edges) are ranked by area weighted Dd and progressively summed to create 58 1km² units, accurately accounting for edge cells without over-or under-weighting.

C. Generate PDFs and descriptive statistics



PDF for Shitike Creek is positively skewed to lower Dd values and mesokurtic (normal).

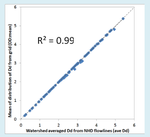
Normal distributions & standard descriptive (L-moment) statistics

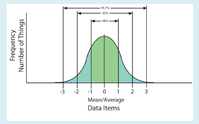
1st moment **Mean** equivalent to traditional watershed ave Dd

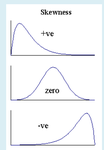
2nd moment **Standard deviation** variation

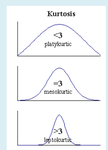
3rd moment **Skewness** asymmetry

4th moment **Kurtosis** shape of peak, weight of tails

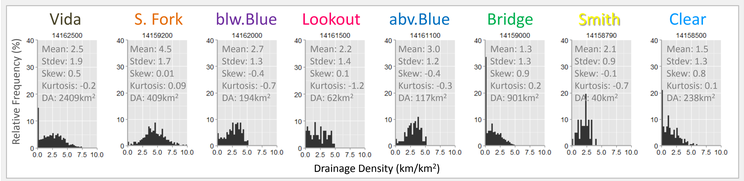




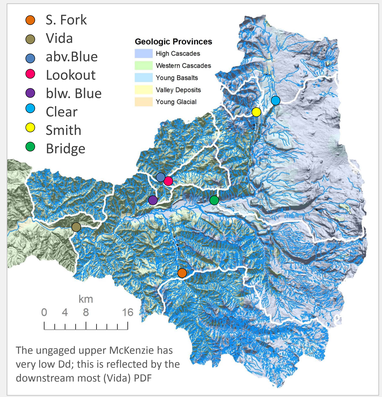




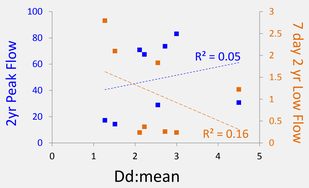
3 – A Unique Example: The McKenzie River

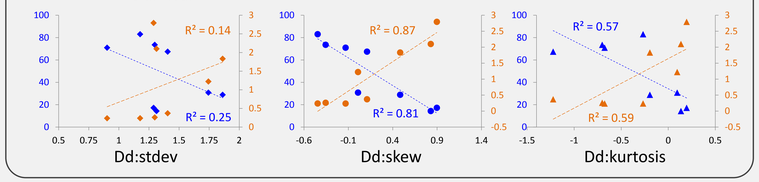


The Upper McKenzie River is a landscape of strong geologic contrasts. Sourced from the young volcanic High Cascades, the upper streams are groundwater dominated and rarely flood. Joined downstream by flashy tributaries running through the older, steep and highly-dissected Western Cascades, the larger watersheds are a hybrid of the two distinct geologic and hydrologic regimes.



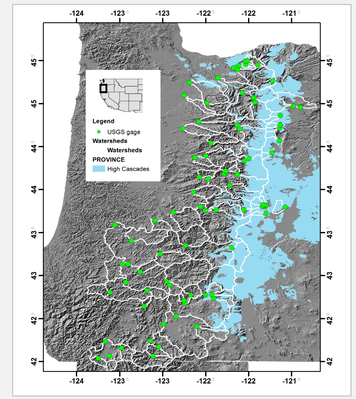
The ungaged upper McKenzie has very low Dd; this is reflected by the downstream most (Vida) PDF





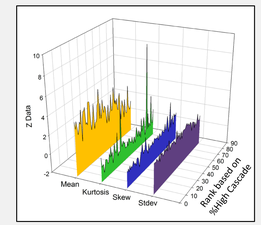
4 – Scaling up to a regional view

Landscape level variation in standard descriptive statistics



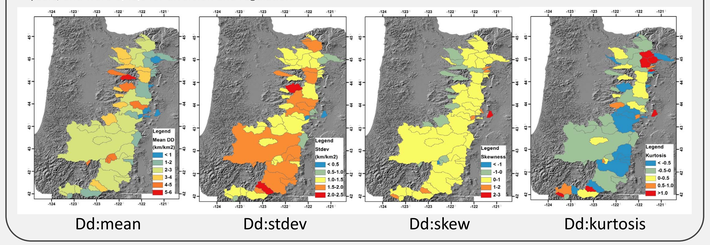
80 watersheds along the length of the Oregon Cascades, with varying proportions of High Cascade geology, a proxy for low Dd. Watersheds on the drier, east side of the Cascade crest are limited by gage availability. Gage records range from 30 to 100 years, and were QAQC for diversion and regulation.

Summary Statistics for 80 Study Watersheds



To get a sense of how these statistics play out across the landscape, we rank them by High Cascade geology. High Cascade dominated watersheds have lower Dd:mean and are also positively skewed.

% HC	mean	stdev	skew	kurtosis
0	3.15	1.33	0.04	0.06
21	3.07	1.37	0.08	-0.24
46	2.64	1.50	0.22	-0.38
75	2.04	1.36	0.52	-0.07
100	1.18	0.93	0.88	0.81



5 – Predicting Peak and Low Flows

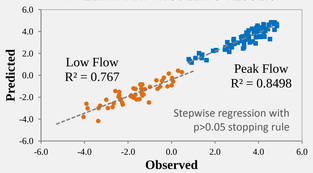
Cross correlation of L-moment statistics from PDFs

	mean	stdev	skew	kurtosis	area (km^2)
mean	1				
stdev	0.60	1			
skew	-0.75	-0.37	1		
kurtosis	-0.16	-0.27	0.63	1	
area (km^2)	0.08	0.33	0.00	-0.11	1

PDFs help us understand how Dd works with respect to flow, but do not necessarily improve models where landscape properties (slope, relief) and climate (precip, snow) are incorporated

Preliminary Modeling Results

Low
Dd:range
Dd:mean
Dd:skew
Precip
Slope
logMaxEl



Peak
Dd:mean
Elev:mean
Precip
Slope