PREDICTING GEOMORPHIC STABILITY in LOW-ORDER STREAMS of the WESTERN LAKE SUPERIOR BASIN

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Abstract:

Width:depth ratios, entrenchment ratios, gradients, and median substrate particle sizes (D_{50}s) were measured in 32 second- and third-order stream reaches in the western Lake Superior basin in 1997-1998. More than 700 measurements of suspended sediment (SS) concentration during snowmelt, baseflow, and precipitation events were taken in these reaches during 1997- 1999. In-stream and riparian habitat quality were also assessed, as was land use and land cover in each stream's watershed. The stability of each stream reach was re-evaluated in 2010-2012 and geomorphic assessments were repeated. Streams were considered unstable if the Rosgen geomorphic stream type had changed or if the width:depth ratio had more than doubled. The effects of stability on SS outputs were analyzed via linear regression. Logistic regression was used to determine stability over the course of the study. Stability after 12 to 14 years was best predicted by stream geomorphology, suspended sediment and bedload outputs, and the presence of wood in the riparian zone and streambed. Suspended sediment outputs could be predicted by stability over 12 to 14 years, geomorphology, discharge, wood availability, and by agricultural and road densities within the streams' watersheds.

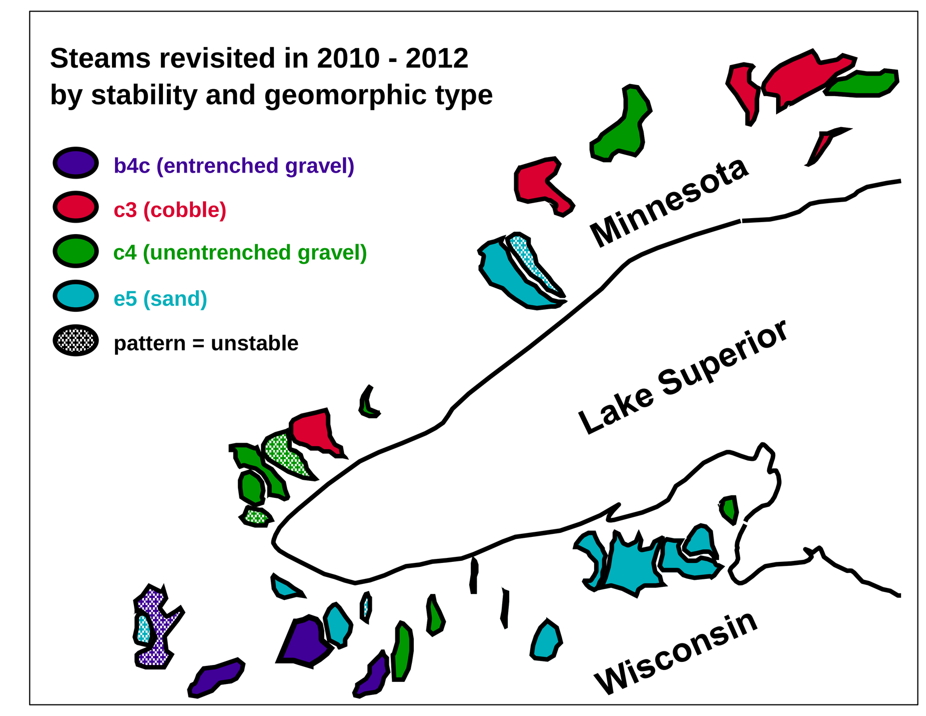
Research Questions:

Why are some streams stable or unstable over time ?

How can we partition out natural variations due to geology, soils, morphology?

What are the best predictors of future stability/instability?

Hindsight: if we had known which streams were stable and unstable back in 1997 – 1999, could we have used that information to predict sediment outputs?



Defining Stability:

Streams were defined as "unstable" after 12 – 14 years if either the geomorphic type had changed or if the width:depth ratio had more than doubled.

Dealing with Natural Variation:

Alluvial streams may be more prone to erosion/morphological change than rock-constrained streams even when n pristine condition. We considered factors contributing to instability for all 32 streams combined as well as dividing streams by geomorphology to assess what conditions contribute to stability and instability within a given stream type.

Results:

When all sites were evaluated as a group, the significant factors in determining stability after 12 – 14 years included (arrows indicate positive or negative correlation with likelihood of stream reach being stable, chi sq. $p < 0.001$):

suspended sediment export
bedload export 250 – 2000 μm; coarse to medium sands
number of road/stream intersections/watershed area, #/ha
total road density in watershed
fraction riparian shrub cover
count of woody debris in streambed

Rosgen type c3
unentrenched,
high width:depth ratio (>12)
D_{50} = cobble

All c3 sties were stable; large fractions of rock/bedrock in stream bottom and banks prevented natural forces over ~12 years (incl. flood) from significantly altering morphology.

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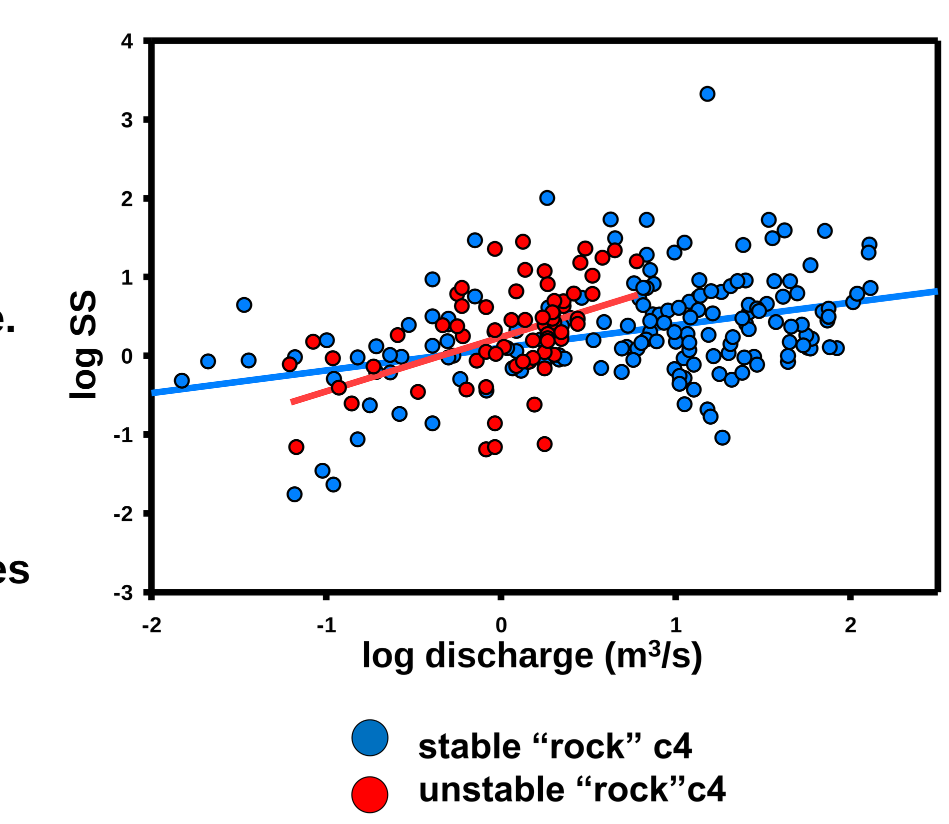
Rosgen type c4
unentrenched,
high width:depth ratio (>12)
D_{50} = gravel

Needed to segregate c4 sites w/ > 20% and < 20% sand in stream substrate due to natural differences in fine sediment availability. All high sand sites were stable.

For the low sand ('rock') c4 sites, stability was best predicted by SS and riparian shrub cover, with unstable sites exporting more SS and having less riparian shrub cover, chi sq. $p < 0.001$.

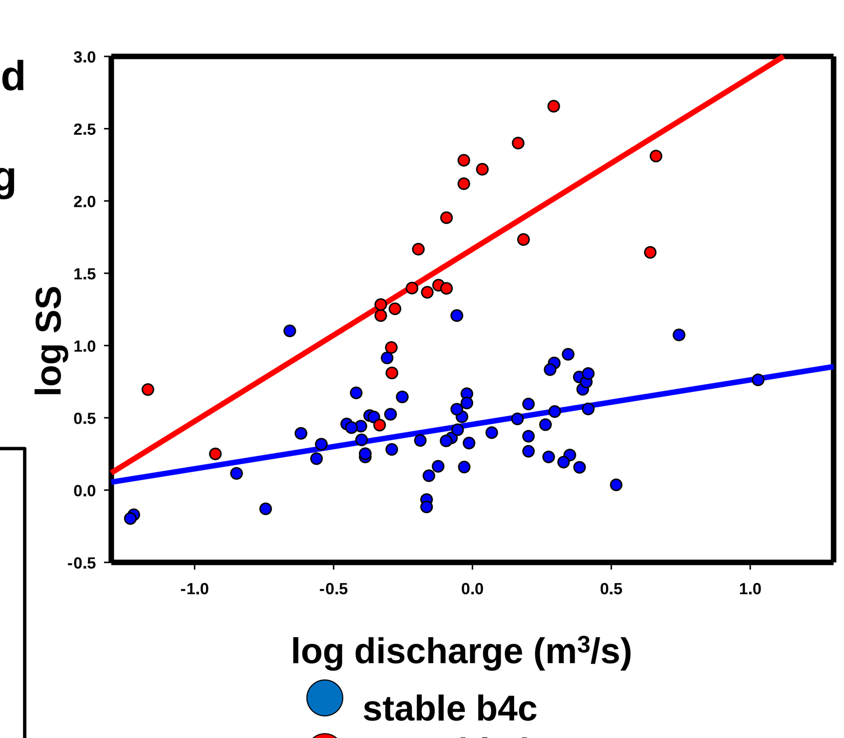


Hindsight – SS outputs in 1997 – 1999 could have been predicted by
(arrows indicate positive or negative correlation w/decreased SS, adj. $r^2 = 0.43$):

stability
fraction sand in streambed , category (< 20% sand = "rock" c4 site (less SS), > 20% sand = "sand" (more SS))
discharge
fraction riparian shrub cover
count of woody debris in streambed

Rosgen type b4c
moderately entrenched
high width:depth ratio
(>12)
D_{50} = gravel

Stability was best predicted by SS outputs, with the unstable b4c site exporting more SS along the range of observed discharges, chi sq. $p < 0.001$.

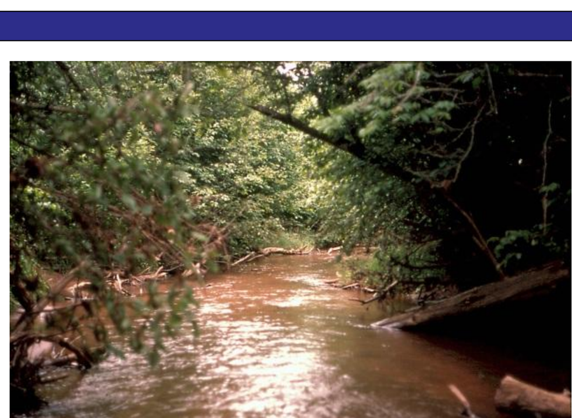


Hindsight - SS outputs in 1997 – 1999 could have been predicted by
(arrows indicate positive or negative correlation w/decreased SS, adj. $r^2 = 0.70$):

stability
discharge
number of road/stream intersections/watershed area, #/ha

Conclusions:

- "Changing geomorphic type" and "doubling width:depth ratio" were useful definitions of stream instability
- Best predictors of geomorphic stability over 12+ years were suspended sediment concentrations and the availability of wood in the stream and riparian zone
- Unstable streams exported more SS than stable streams of the same geomorphic and substrate type.



Rosgen type e5
unentrenched
low width:depth ratio (<12)
D_{50} = sand

Stability was best predicted by SS outputs and woody debris in the streambed, with unstable sites exporting more SS and having less woody debris, chi sq. $p < 0.001$.

Hindsight - SS outputs in 1997 – 1999 could have been predicted by (arrows indicate positive or negative correlation w/decreased SS, adj. $r^2 = 0.55$):

stability
discharge
count of woody debris in streambed
total road density in watershed
fraction watershed land area in agriculture