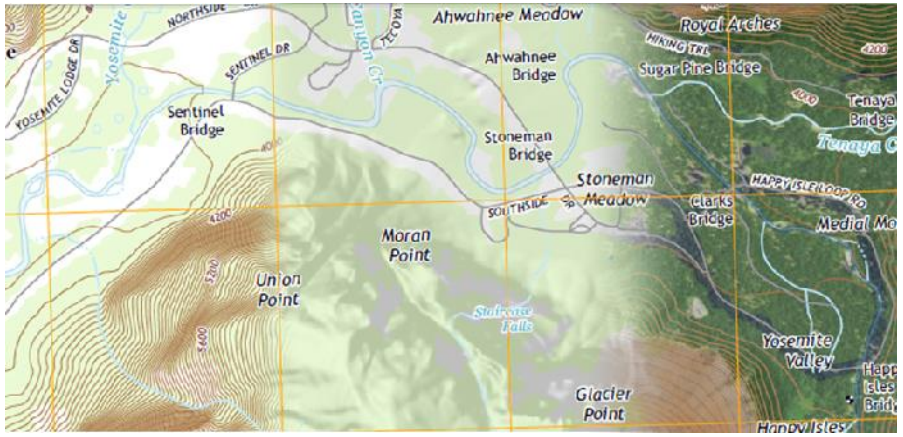
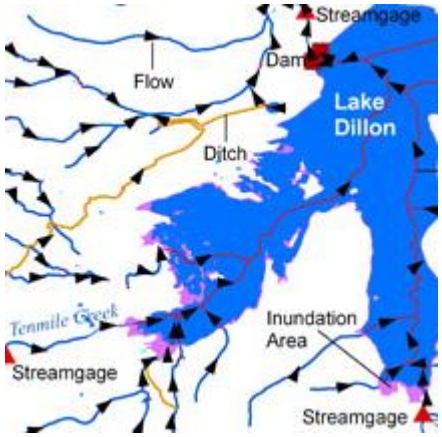
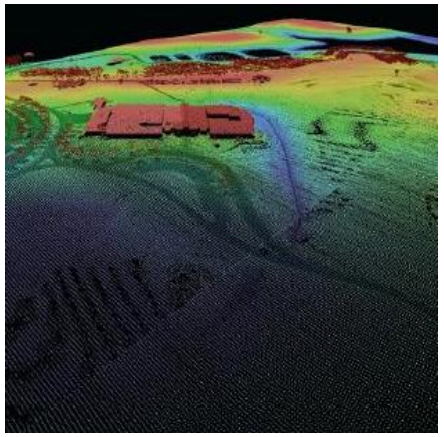
Preserving Line Sinuosity in Hydrographic Feature Simplification







Lawrence V. Stanislawski[1], Barbara P. Buttenfield[2], and Abdurraouf Okok[1]

[1] U.S. Geological Survey, Center of Excellence for Geospatial Information Science, Email: lstan@usgs.gov, jwendel@usgs.gov

[2] University of Colorado-Boulder, Email: babs@colorado.ed

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Problem Statement

- Problem: Simplification and other generalization operations can impact data and associated investigations regarding stream geomorphic conditions, particularly at smaller scales. Limits usability of generalized data.
- Problem: Cartographic production requires multiple simplification tolerance values that are tailored to landscape conditions.

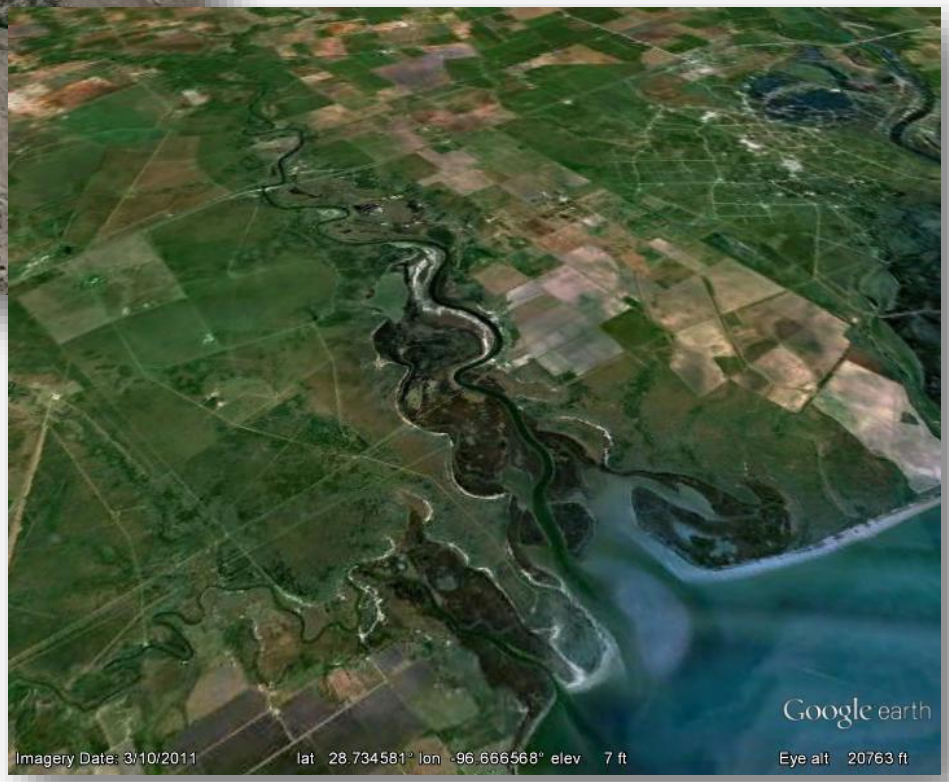
Objectives

- Explore methods to simplify linear stream features in a manner that more accurately retains the geometric variability (along with positional accuracy of the data) than traditional methods
  - Identify a rule or rules to estimate an appropriate amount of sinuosity to remove during simplification to smaller scales
  - Test automated methods to implement the rules
  - Methods should provide a good compromise between operational (display speed, legibility, etc.) and analytic usefulness.

Stream sinuosity varies in different landscapes

Rough terrain

Flat terrain



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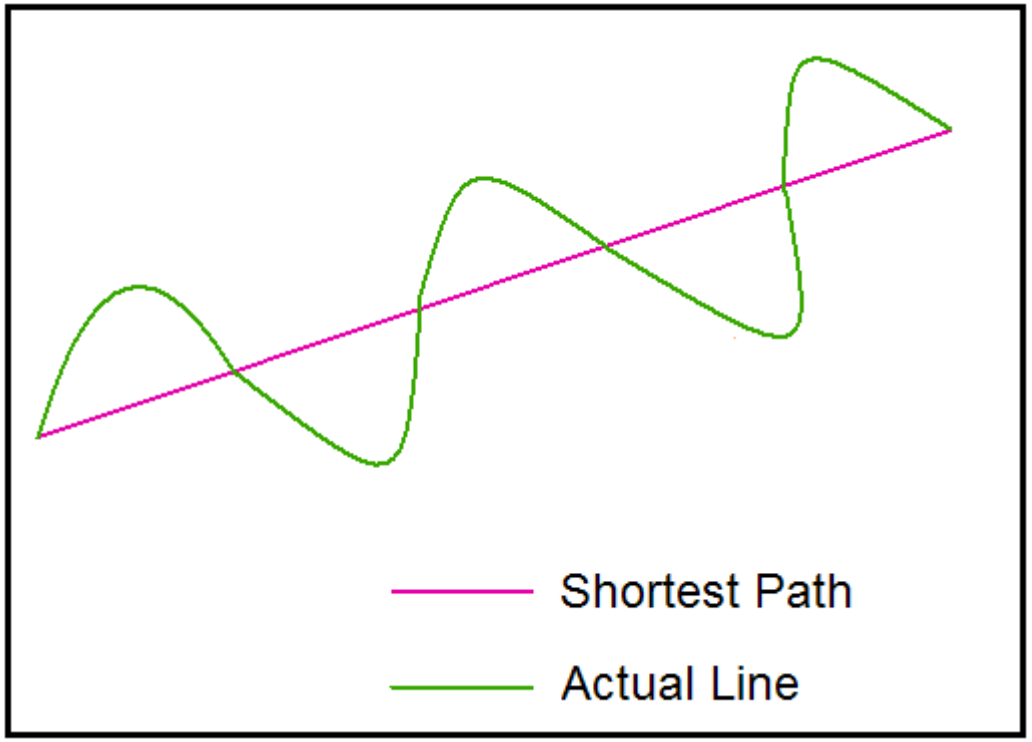
Sinuosity

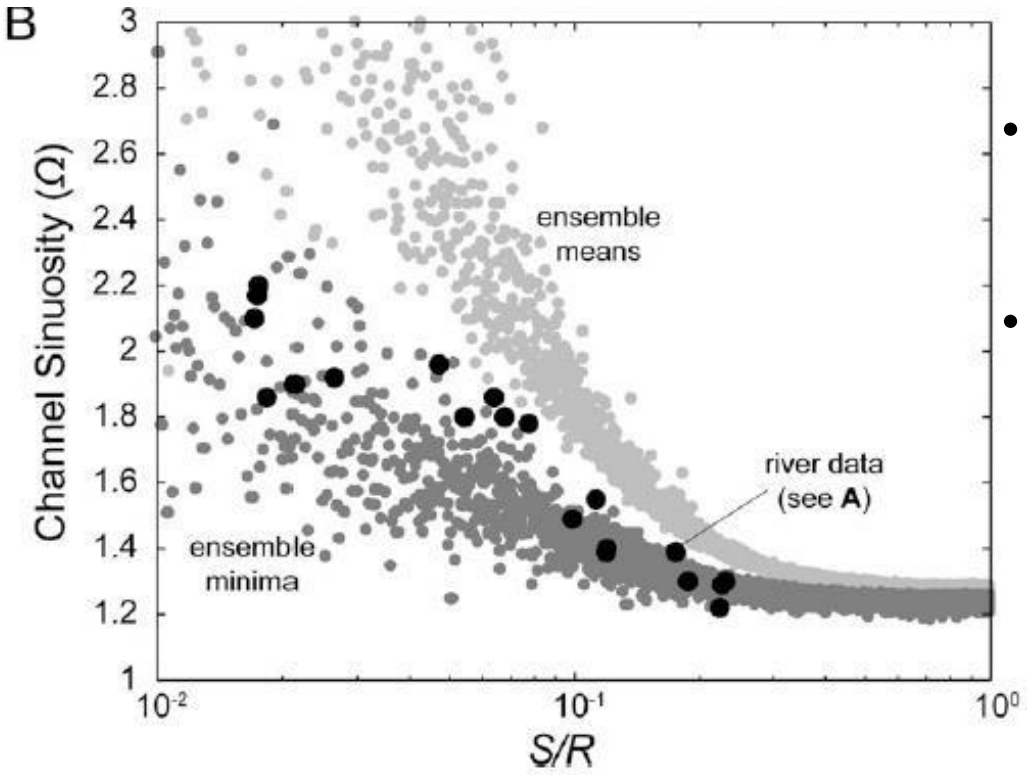
Sinuosity is defined as the length of a line (feature) divided by the distance between its endpoints.

Straight line sinuosity = 1;
else
sinuosity > 1

Residual sinuosity is sinuosity - 1



How and why is stream sinuosity related to geomorphic conditions?



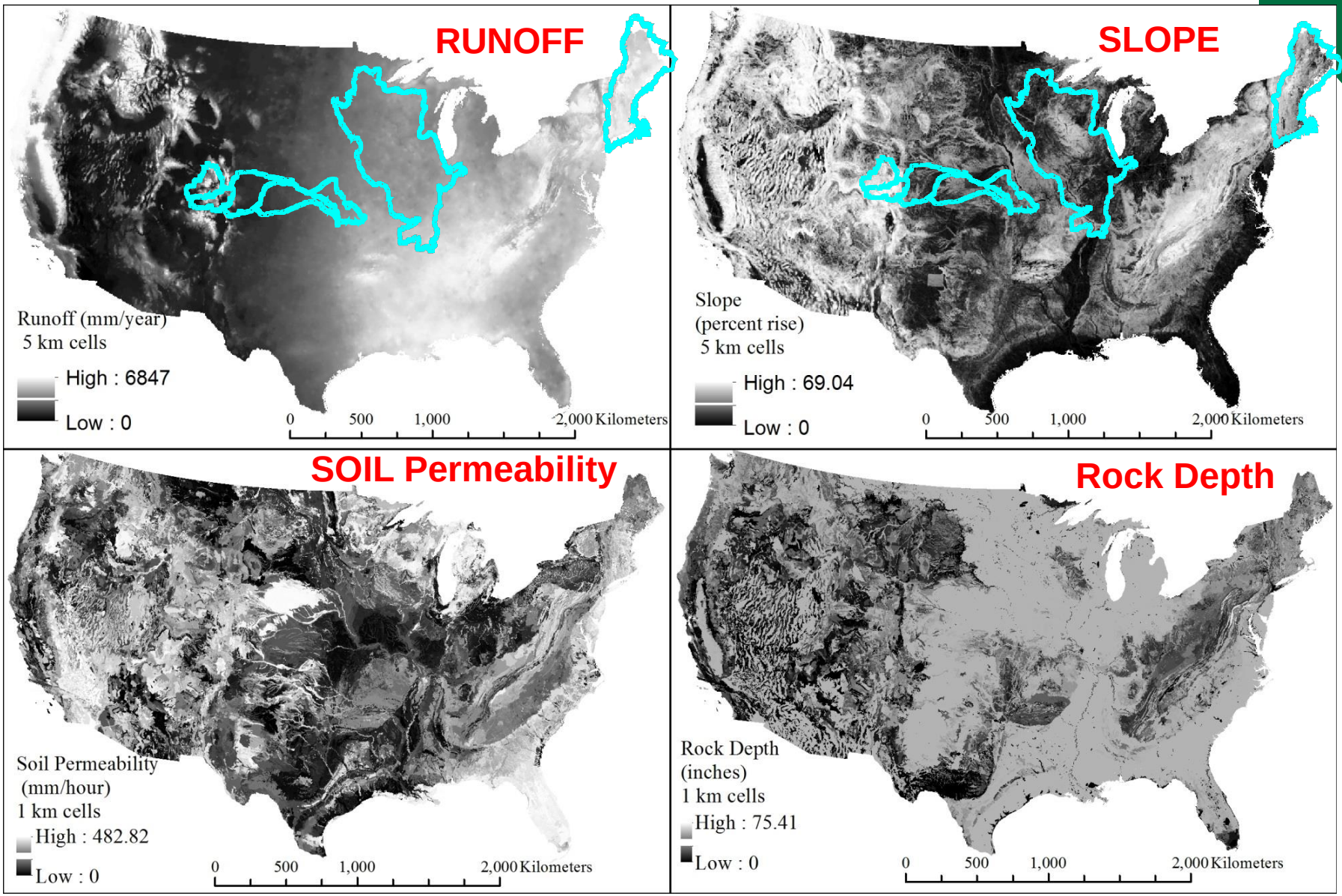
- **Within local conditions, channel stability, shape, and sinuosity are influenced by sediment load.**
- **Over the course of the river channel, critical thresholds in sediment load and slope alter a channel's pattern, which cause variations in channel sinuosity**

Schumm (1973)

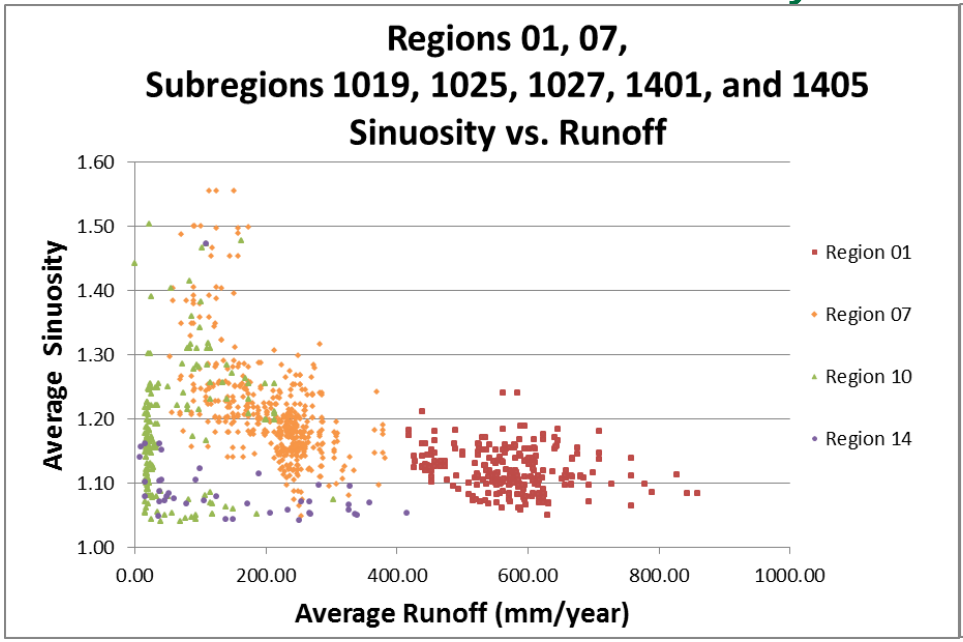
As shown above, Lazarus and Constantine (2013) propose generic theory for channel sinuosity whereby sinuosity is related to landscape slope relative to flow resistance (topographic roughness and vegetation).

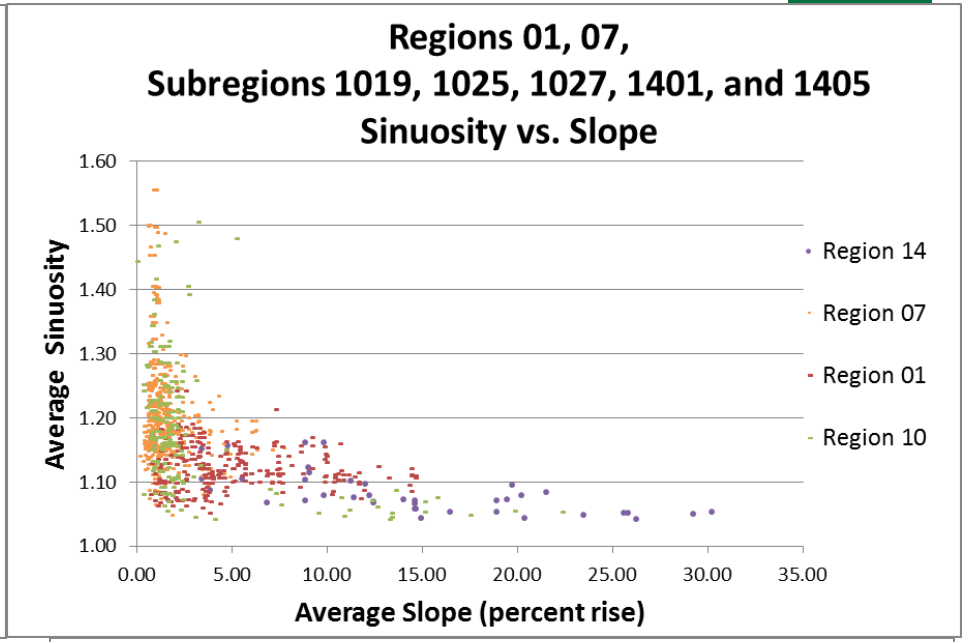
- Lazarus E D, and Constantine J A, 2013, Generic theory for channel sinuosity, Proceedings National Academy of Sciences 110(21): 8447-8452.
- Schumm S A, 1973, Geomorphic thresholds and complex response of drainage systems. Fluvial Geomorphology 6:69-85.

Stream Geomorphology Conditions (zonal mean for each density partition)



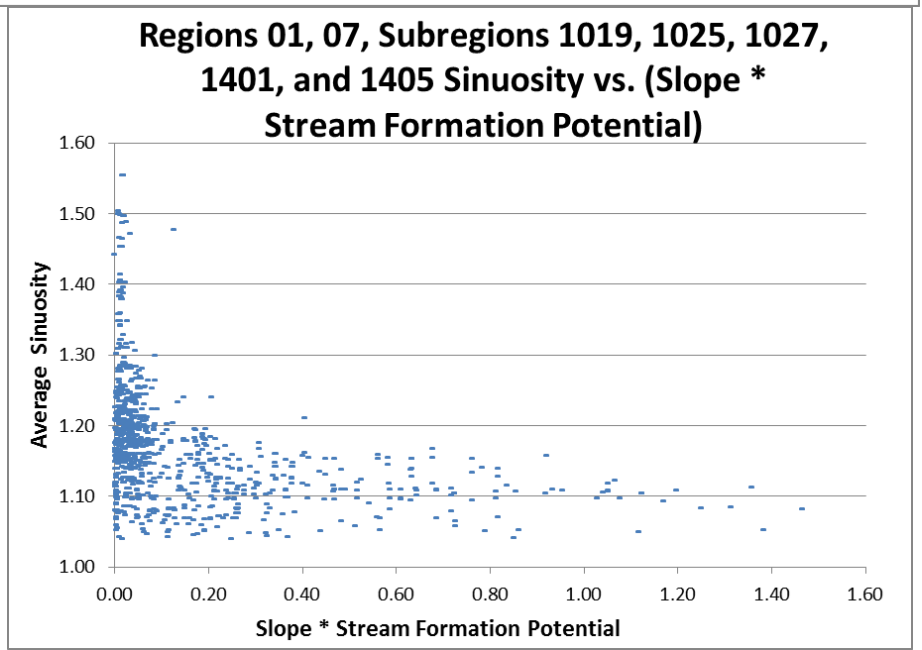
Results: Synoptic review of sinuosity and geomorphology characteristics for a study area





Dry 14-purple, 10-green; Humid 010-reddish, 07-orange.

We see a similar relation as described by Lazarus and Constantine (2013).



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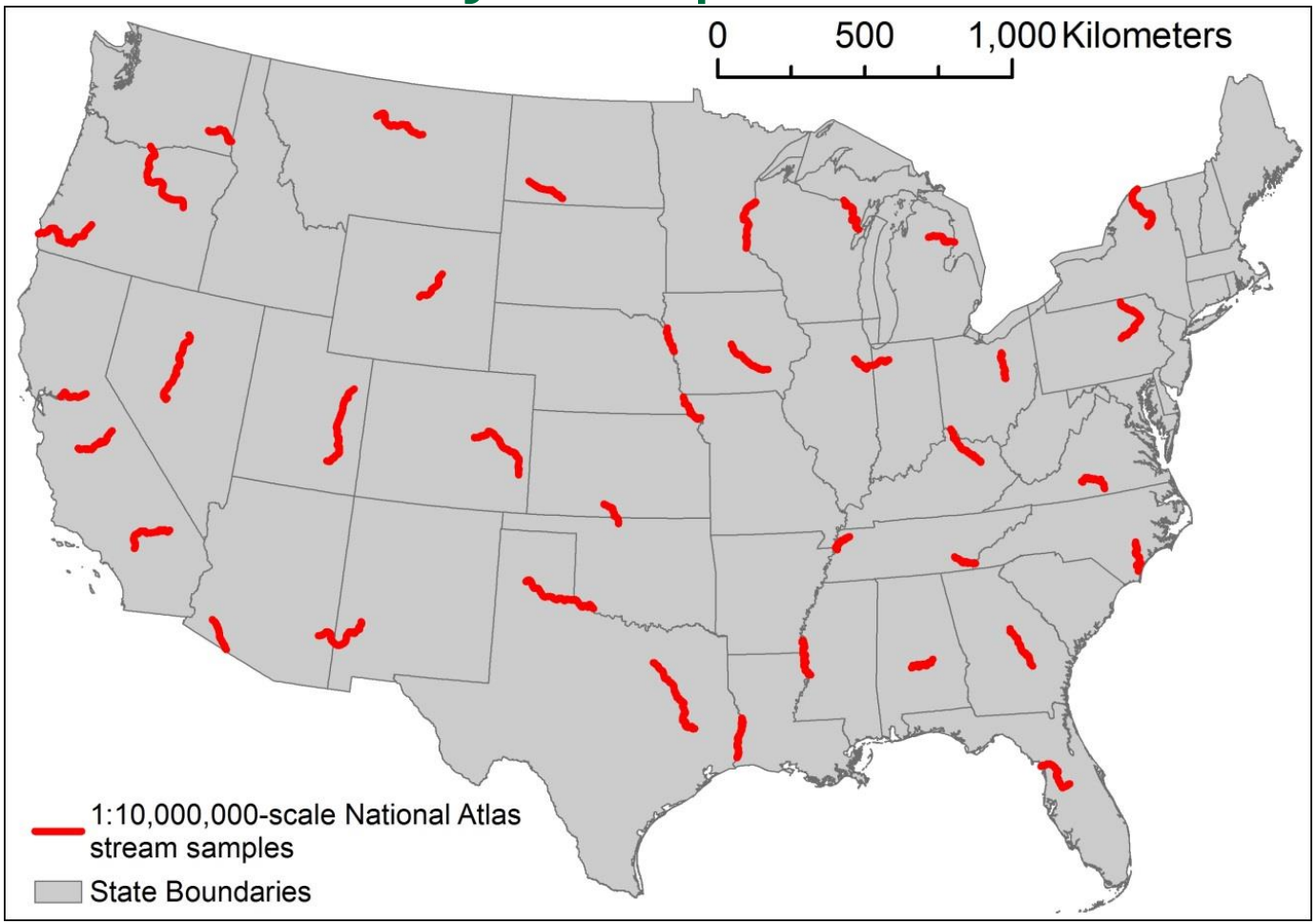
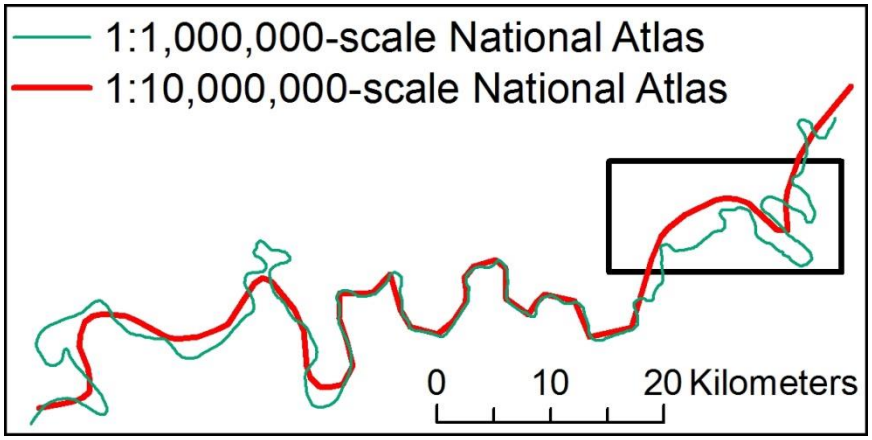
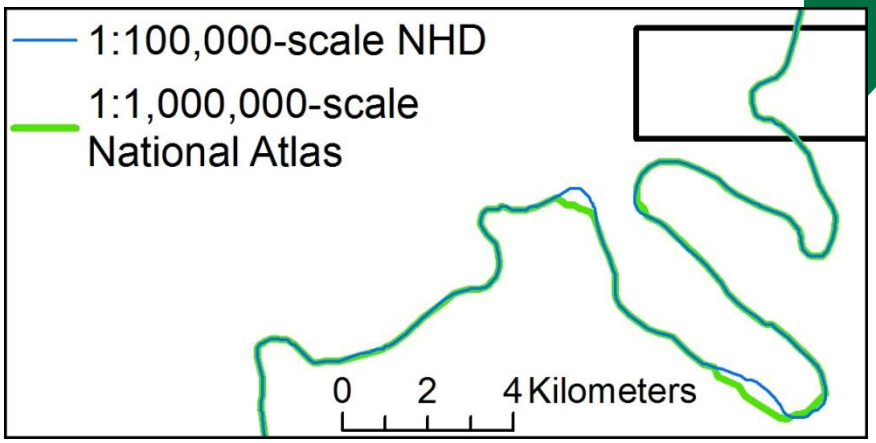
Methods: Study Sample

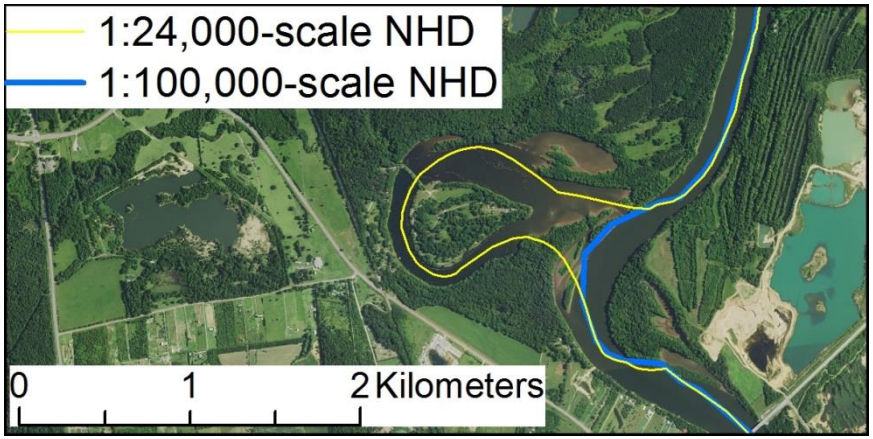


38 sections of linear stream features sampled from four scales (152 samples):
1:24,000-scale (24K) and 1:100,000-scale (100K) NHD,
1:1,000,000-scale (1M) and 1:10,000,000-scale (10M) National Atlas

Methods: Study Sample





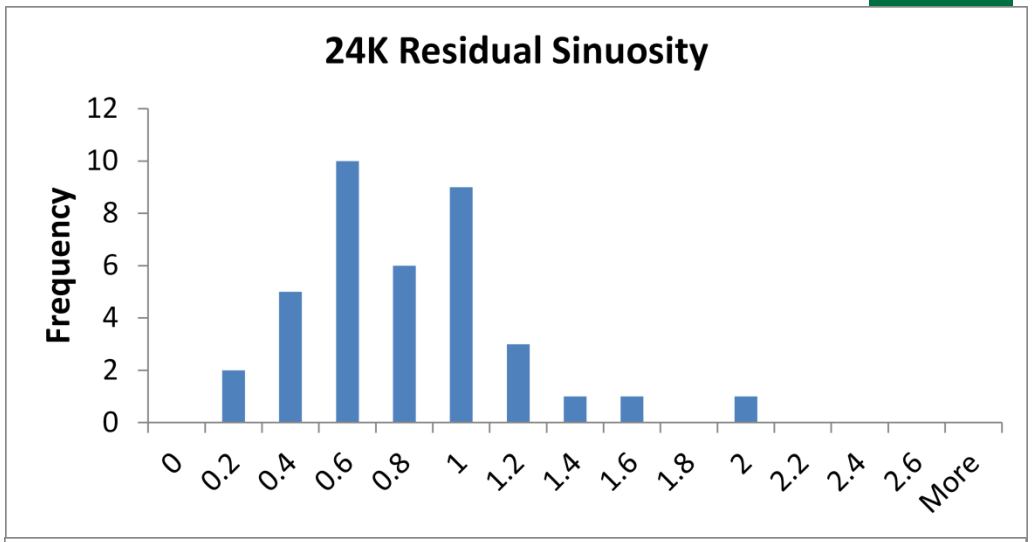


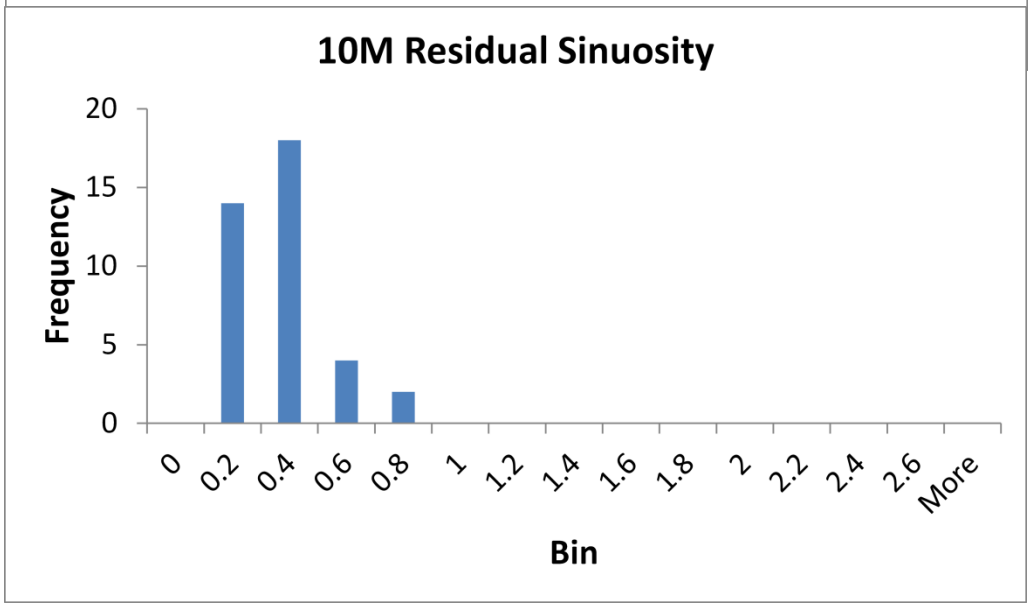
Section of Alabama River sample at four benchmark scales.

Residual sinuosity of stream lines from four scales of hydrographic data

	Residual Sinuosity			
	24K	100K	1M	10M
Average	0.71	0.69	0.64	0.28
Min	0.09	0.08	0.05	0.04
Max	1.84	1.80	1.43	0.67
Range	1.75	1.72	1.38	0.63

Variation in sinuosity is inversely related with generalization





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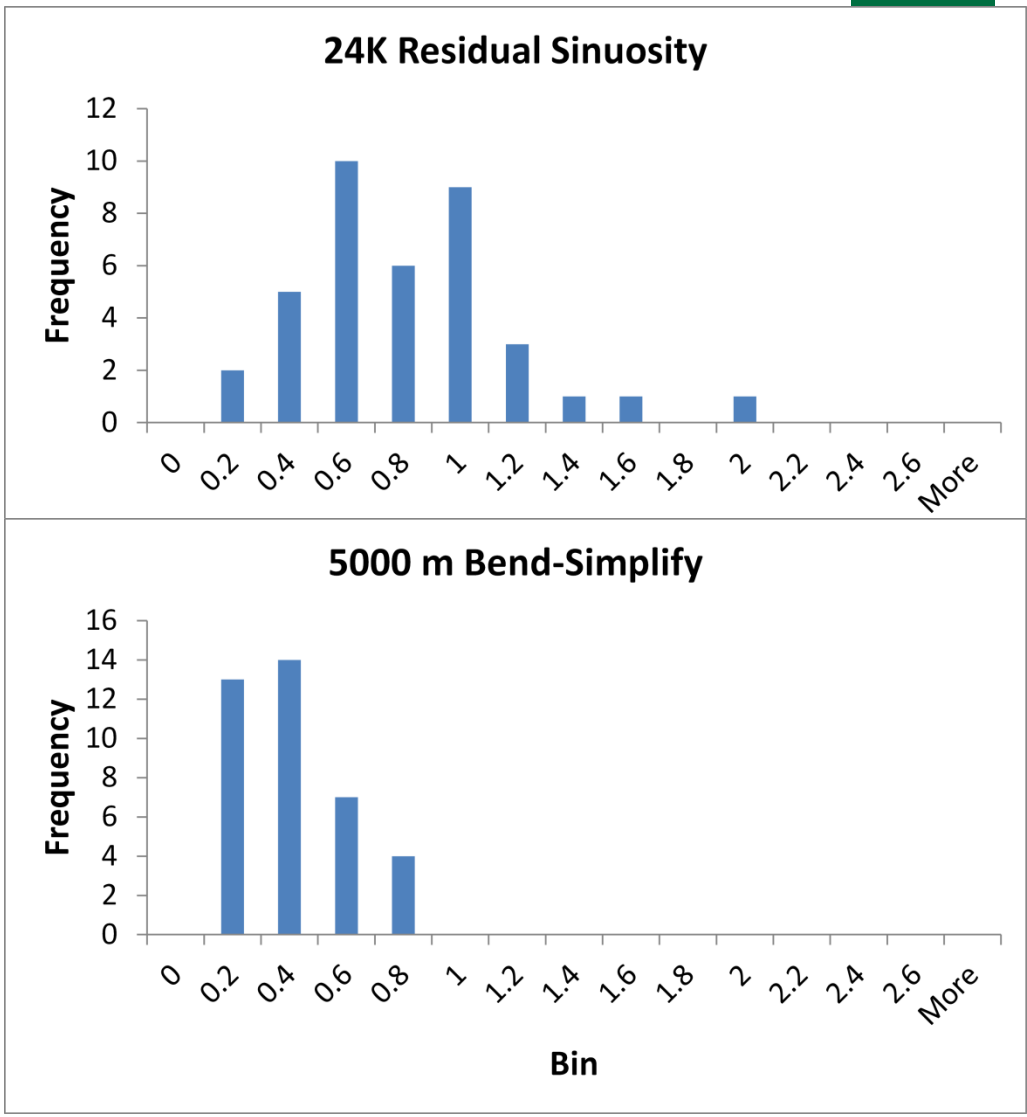
Residual sinuosity of stream lines from 24K and Bend-Simplified using 50, 500, and 5000 meter tolerance

		Residual Sinuosity from Bend-Simplify		
	24K	50 m	500 m	5000 m
Average	0.71	0.71	0.60	0.30
Min	0.09	0.09	0.07	0.03
Max	1.84	1.83	1.47	0.68
Range	1.75	1.75	1.40	0.65

Variation in sinuosity is inversely related with level of simplification



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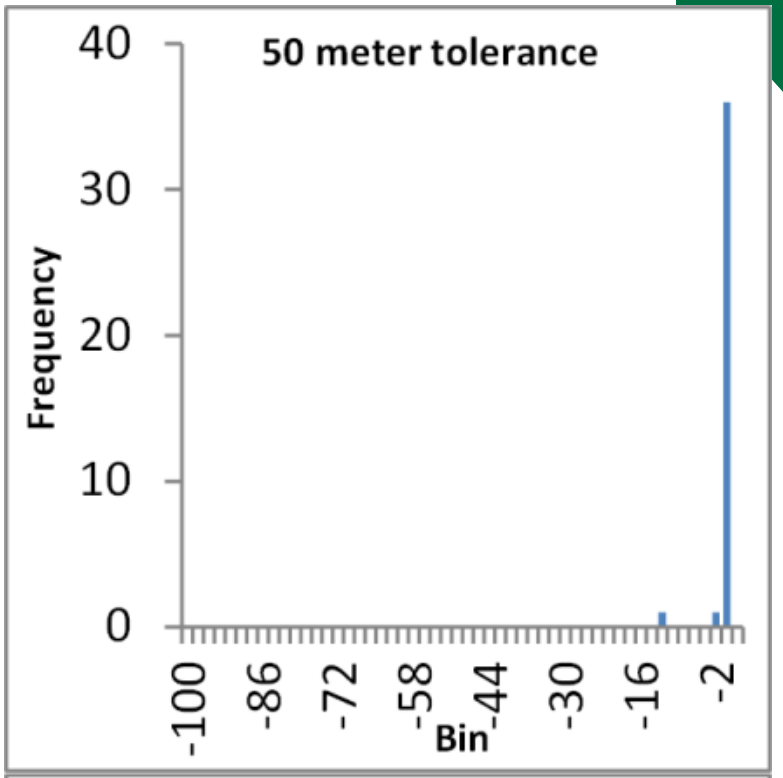
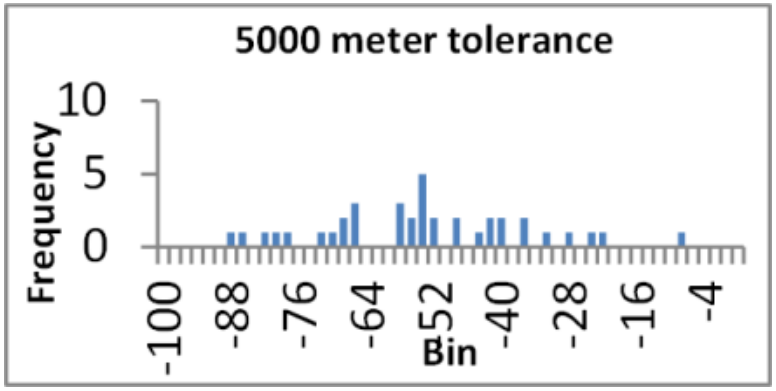
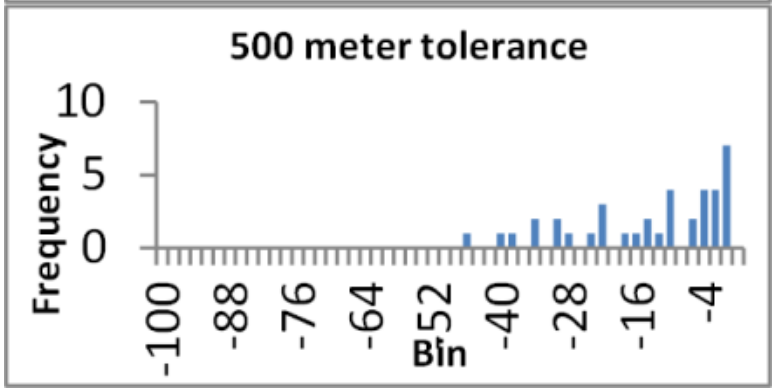
Percent reduction in residual sinuosity from simplification of 24K lines with Bend-Simplify operator with 50, 500, and 5000 meter tolerance

Percent reduction of 24K residual sinuosity from Bend-Simplify operator using tolerance of			
Meters	50	500	5000
Average	-0.821	-14.802	-54.825
Median	-0.316	-10.982	-55.211
Min	-13.730	-47.190	-89.162
Max	-0.002	-0.621	-8.988
Range	13.729	46.569	80.174







Simplification constrained to preserve sinuosity

- Adjust simplification tolerance for each feature to constrain the reduction in residual sinuosity to the minimum
  - 100K scale: 0.0015 to 0.0020 percent reduction (50 m tol)
  - 1M scale: 0.60 to 0.65 percent reduction (500 m tol)
  - 10M scale: 8.95 to 9.00 percent reduction (5000 m tol)
- Iteratively adjust Bend-Simplify tolerance until residual sinuosity is reduced within limits.
  - **Bend-Simplify**: eliminates bends having a diameter that is less than the tolerance

Wang, Z. and Muller, J.C. (1998). Line generalization based on analysis of shape characteristics. Cartography and Geographic Information Science 25, 3-15.

Wang, Z. 1996. "Manual versus Automated Line Generalization", GIS/LIS '96 Proceedings, p.94-106.

Simplification constrained to preserve sinuosity: results

100K scale: 0.0015 to 0.0020 percent reduction
1M scale: 0.60 to 0.65 percent reduction
10M scale: 8.95 to 9.00 percent reduction

	100K Tolerance (meters)	100K to 24K Residual Sinuosity Difference (percent)	1M Tolerance (meters)	1M to 24K Residual Sinuosity Difference (percent)	10M Tolerance (meters)	10M to 24K Residual Sinuosity Difference (percent)
Average	15.3	-0.0026	118.1	-0.64	850.3	-9.39
Standard Deviation	14.5	0.0016	108.6	0.05	935.2	0.59
Minimum	3.4	-0.0085	18.0	-0.92	39.7	-11.71
Maximum	50.0	-0.0015	445.0	-0.60	3915.0	-8.97
Range of residual sinuosity		1.75		1.74		1.60
Benchmark range (res. sin.)		1.72		1.38		0.63

- Retained most of variation in sinuosity in the simplified features.
- Reduction of sinuosity is near target constraints. Therefore, it is possible to estimate original sinuosity values from resulting features and constraint values.

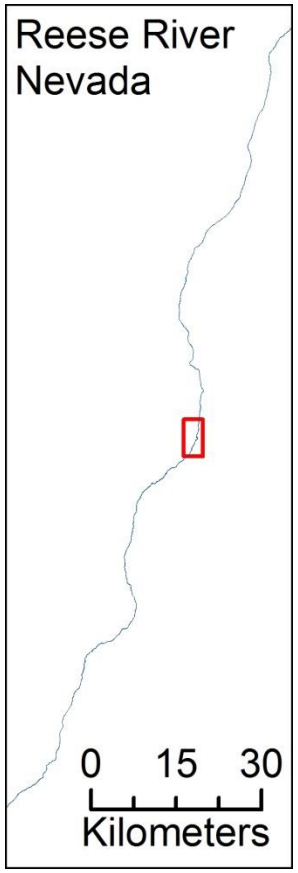
+ Simplification constrained to preserve sinuosity: vertices per kilometer

		Vertices per Kilometer					
		24K Simplified to			Benchmark Data		
	Source 24K	100K	1M	10M	100K	1M	10M
Average	29.8	29.4	20.7	12.0	8.7	6.1	0.4
Standard Deviation	22.9	22.8	15.4	10.6	3.5	1.6	0.1
Minimum	5.1	4.4	3.2	1.8	1.3	2.1	0.3
Maximum	84.8	84.6	56.1	40.3	14.8	10.2	0.7

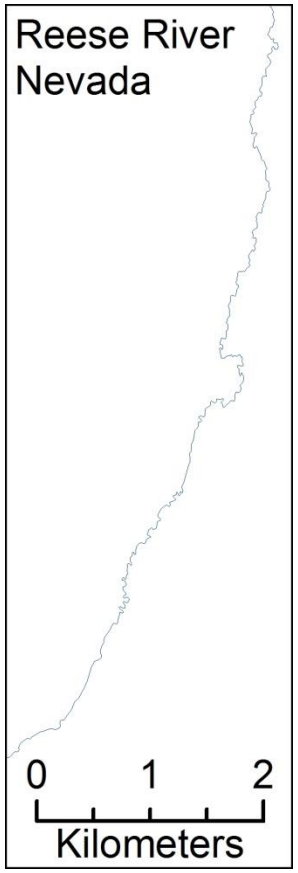
Little reduction of feature vertices is achieved.

Range of conditions and tolerance results

2M-scale

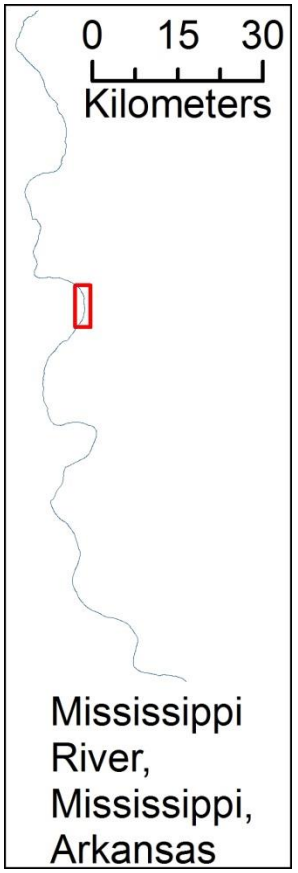


100K-scale

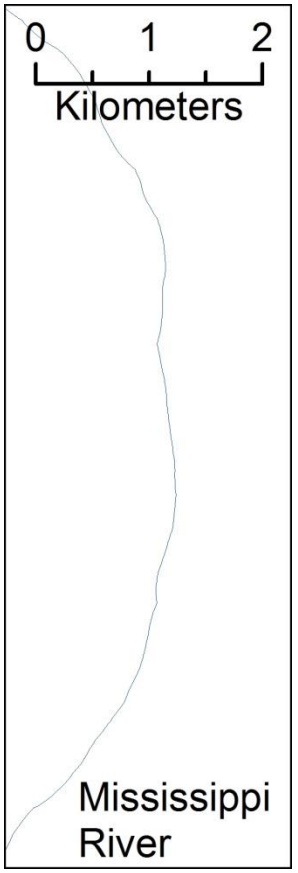


- 1.42 sinuosity
- High frequency small bends
- Arid, rugged slopes
- 90 percent stream type
- Tolerance to achieve target constraints: 3.7 to 40 meters

2M-scale



100K-scale



- 1.37 sinuosity
- No small bends, meandering pattern
- Humid, flat terrain
- Artificial path type in polygonal stream
- Tolerance to achieve target constraints: 10 to 3900 meters

+ Summary

- Sinuosity and other hydrographic line feature characteristics are related to geomorphic conditions and are useful for hydrologic investigations and modeling.
- Traditional generalization and simplification techniques can substantially reduce the magnitude and variation of sinuosity values, and thereby limit usefulness of the data.
- Proposed method adjusts simplification tolerance to achieve a relatively constant reduction of sinuosity and maintain more variation in sinuosity values than traditional simplification methods.
- Further testing is needed to find optimal constraints that are a good compromise between legibility, positional accuracy, and shape integrity.

+ Future Work

Develop and test automated simplification approach:

- Parameters: scale denominator
- Constraints:
  - Positional accuracy (1/50th inch, NMAS)
  - Legibility (0.414 mm, screen pixel diagonal)
  - Percentile reduction of sinuosity determined from simplification with legibility constraint.
- Possible algorithm
  1. Bend-Simplify data with legibility tolerance
  2. Identify target percentile reduction of sinuosity for a dataset, and build a constraint interval centered on the percentile reduction.
  3. Iteratively simplify each feature, allowing tolerance to expand until target sinuosity reduction is achieved.
     - Do not allow bend to be removed if it violates positional accuracy constraint
- Implement distributed processing techniques for enhanced processing speed.

THANK YOU!

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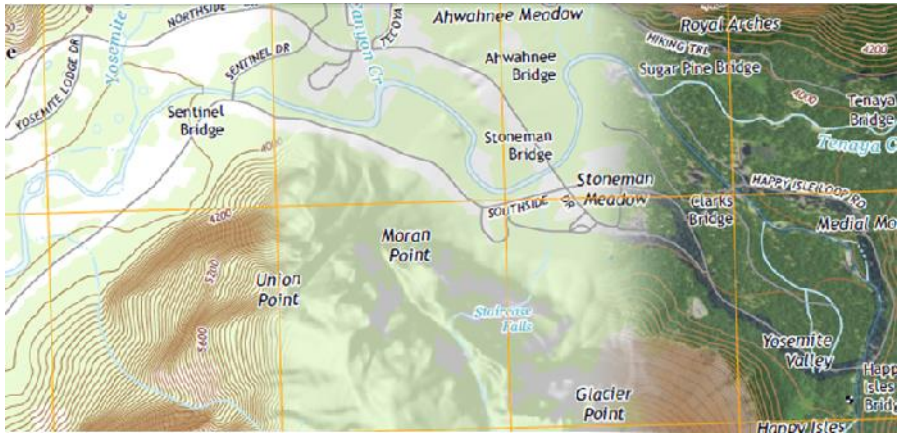

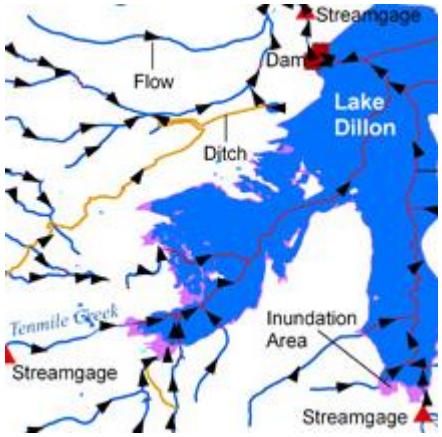

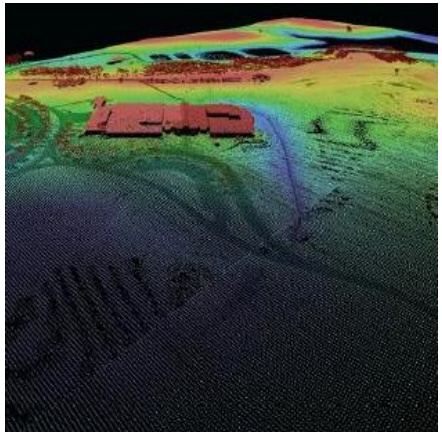

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[1] U.S. Geological Survey, Center of Excellence for Geospatial Information Science, Email: lstan@usgs.gov, jwendel@usgs.gov

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