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Assessment of interpolation methods for refining SRTM and DEM

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Abstract. *Shuttle Radar Topographic Mission (SRTM) DEM is widely used in analyzing topography of developing countries because it is freely available. But due to its coarse resolution (3 arc-second or 90m), the SRTM is sometimes not appropriate for use in hydrologic analysis and deriving stream networks. The purpose of this study was to evaluate the potential and performance of seven interpolation techniques as a means of refining the resolution to 30m. IDW with exponents of 0.5, 1, and 2, regularized and tension Spline, Kriging, and Natural Neighbor interpolation were tested using ArcGIS 9.1 Spatial Analyst. The obtained elevation, slope, aspect, sink, and stream networks from the interpolated 30m DEM were compared quantitatively with those derived from the original 30m SRTM DEM. The Renasco River area of New Mexico was selected for the analysis area because it has a range of topographic features from flat lands and hills, to mountains.*

The interpolation techniques were not significantly different in deriving elevation, total flow length, and delineating watersheds. However, all methods produced shallower slopes than the original 30m SRTM DEM and had a smoothed surface with fewer sinks. Interpolated DEMs had easterly bias in the aspect which was not found in the original. The IDW interpolation showed lattice artifacts in slope and aspect grids. Kriging did not have significant weaknesses, but spline interpolation showed the best performance in defining slope and stream networks.

Keywords. Interpolation, SRTM, Spline, IDW, Natural Neighbor, Kriging, Cubic Convolution, elevation, slope, sink,

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Introduction

Interpolation techniques may be divided into two branches, deterministic and geostatistical. The deterministic techniques assign values to locations based on the surrounding measured values and on specified mathematical formulas (Lam, 1983). IDW (Inverse Distance Weighted), Spline, and Natural Neighbor methods are deterministic methods. Geostatistical techniques, such as Kriging, are based on statistical models that include autocorrelation, the statistical relationship among the measured points (Lam, 1983).

IDW interpolation is an 'exact' interpolator since the resulting surface passes through the data points. However, IDW does not represent the general curvature of the surface with the potential for peaks or valleys different from the sample points. Spline interpolation defines a piece-wise surface between points using a minimum-curvature spline technique, with a cubic function fitting a flexible surface exactly through the input points. Thus a spline surface will generate peaks and valleys not explicitly included in the known sample data. Kriging weights the elevation of surrounding known points to estimate values for a new location, but the weights are based not only on the distance between the known points and the estimation location, but also on the overall spatial arrangement among the known points. So, the spatial autocorrelation must be quantified to use this technique. Natural Neighbor interpolates a surface from points using a natural neighbor technique and generally works well with clustered scatter points. Because of simplicity in its concept and calculation, it can be used to handle large input points efficiently.

Shuttle Radar Topographic Mission (SRTM) elevation data (DEM) is widely used in developing countries to analyze topography because it is global in scope and freely available. But due to its resolution (3-arc second, approximately 90m), the SRTM data is sometimes not appropriate for use in hydrologic analysis and for deriving stream networks. The purpose of this study was to evaluate the potential and performance of commonly used interpolation techniques as a means of refining SRTM resolution to 30m.

Method

The source 3-arcsec SRTM data (WGS84) was projected to 30m UTM grid using cubic convolution, and this “resampled” data set was used as the basis of comparison for the 30m grids created using a variety of point-based interpolations from the source data. Inverse distance weighting (IDW), regularized and tension splines, Kriging, and Natural Neighbor interpolation were evaluated using ArcGIS 9.1 Spatial Analyst. The derived elevation, slope, aspect, sink, and stream networks from the interpolated 30m DEMs were compared quantitatively with those derived from the resampled 30m SRTM DEM. The flow chart for the methodology of this study is represented in Figure 1. A study area of 2,520km^2 in New Mexico (Figure 2) was selected because it consists of a wide range of topographic features such as flat lands, hills, and mountains. The 90m SRTM for the area was obtained from the National Map Seamless Server (http://seamless.usgs.gov).

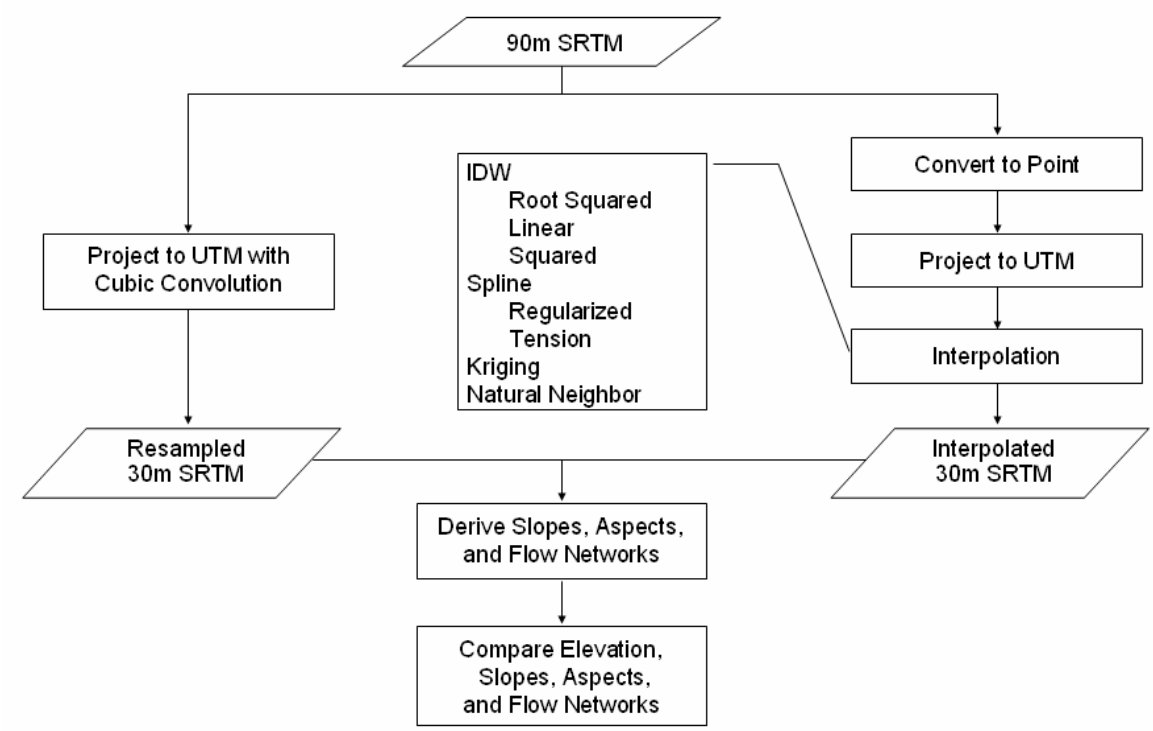

Figure 1. Flow chart of procedure

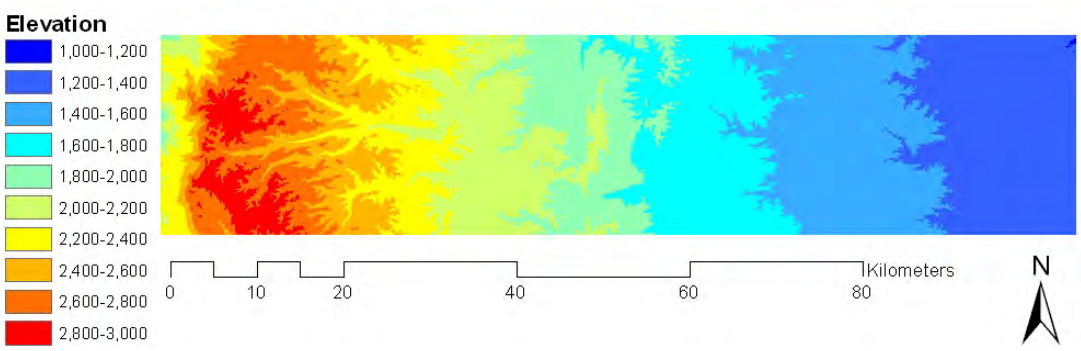

Figure 2. Topography of the study area

Results

Elevation

Using the interpolation methods, 7 different DEMs with a 30m resolution were created. They produced very similar elevation-cumulative area curves (Figure 3), and the regularized spline provided the closest mean and standard deviation to those of the “resampled” data (Table 1). In the cell by cell comparison (Figure 4), the IDW had greater differences than did the other methods except for the natural neighbor which was the largest (Table 1). As seen in Figure 4, all the interpolation methods had big differences in the mountain areas but little in flat areas.

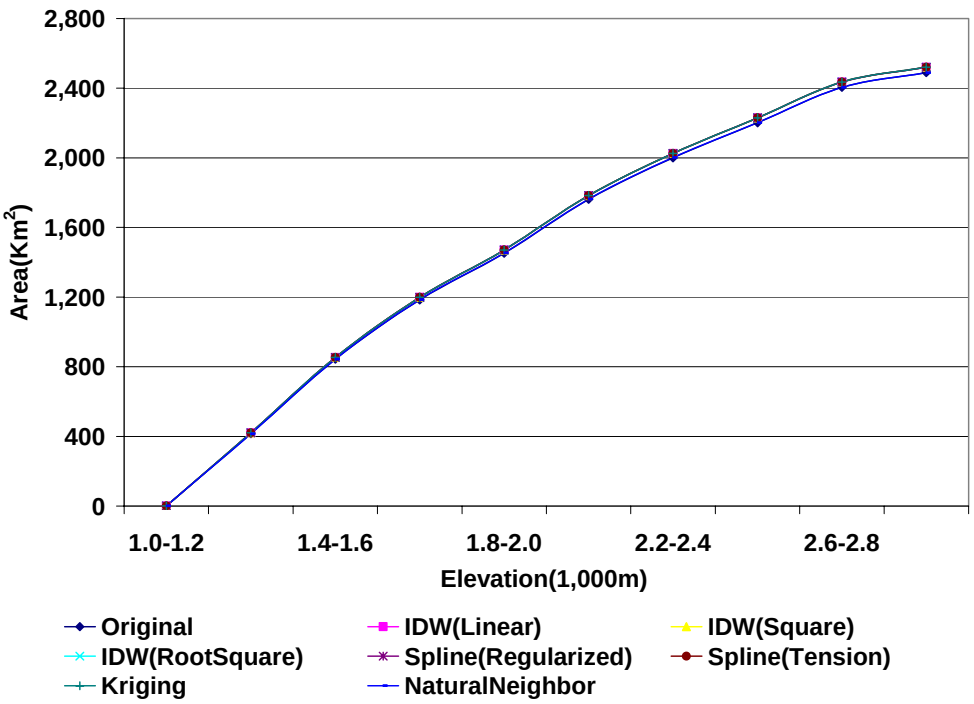

Figure 3. Topography of the study area

Table 1. Statistics of the elevations and their differences with the resampled DEM

Method	Option	Elevation				Differences of the Elevations			
		Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.
Resampled		2,955.3	1,187.0	1,912.0	475.9	-	-	-	-
IDW	0.5	2,945.5	1,190.3	1,942.6	437.0	51.05	-62.86	0.009	5.41
	1	2,947.8	1,189.7	1,942.6	437.1	42.31	-55.36	0.009	4.40
	2	2,952.5	1,187.8	1,942.6	437.1	27.63	-41.47	0.009	2.82
Spline	Reg.	2,955.4	1,183.7	1,911.8	475.7	39.43	-31.22	0.014	0.80
	Ten.	2,955.4	1,187.3	1,942.6	437.2	31.22	-29.53	0.013	0.72
Kriging		2,953.9	1,187.7	1,942.6	437.2	28.63	-30.45	0.013	1.03
Natural		2,952.5	1,187.9	1,941.3	437.2	736.53	-118.43	0.179	8.54

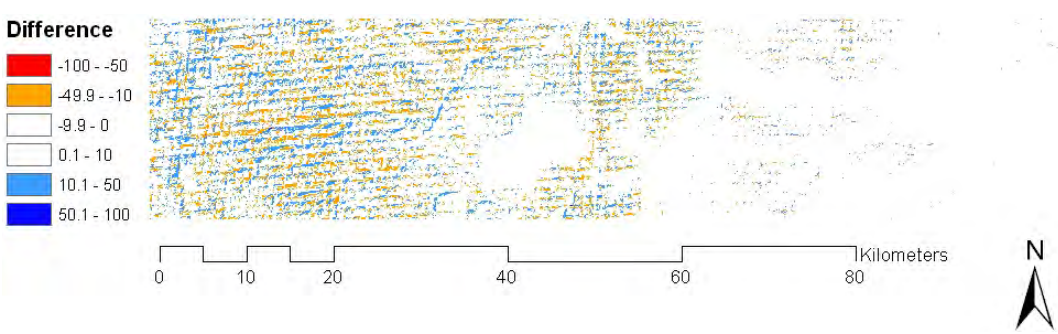

Figure 4. Elevation differences between the resampled grid and tension spline

Slope

From the interpolated DEMs, slope grids that have a 30m cell size were derived. All the interpolation methods produced shallower slopes than did the resampled DEM, and the IDW most underestimated slopes (Figure 5). The spline method produced the closest mean and standard deviation to those of the resampled grid (Table 2).

In the cell by cell comparison the IDW and natural neighbor methods again had the largest differences (Table 2). The IDW also produced lattice pattern as calculation artifacts (Figure 6).

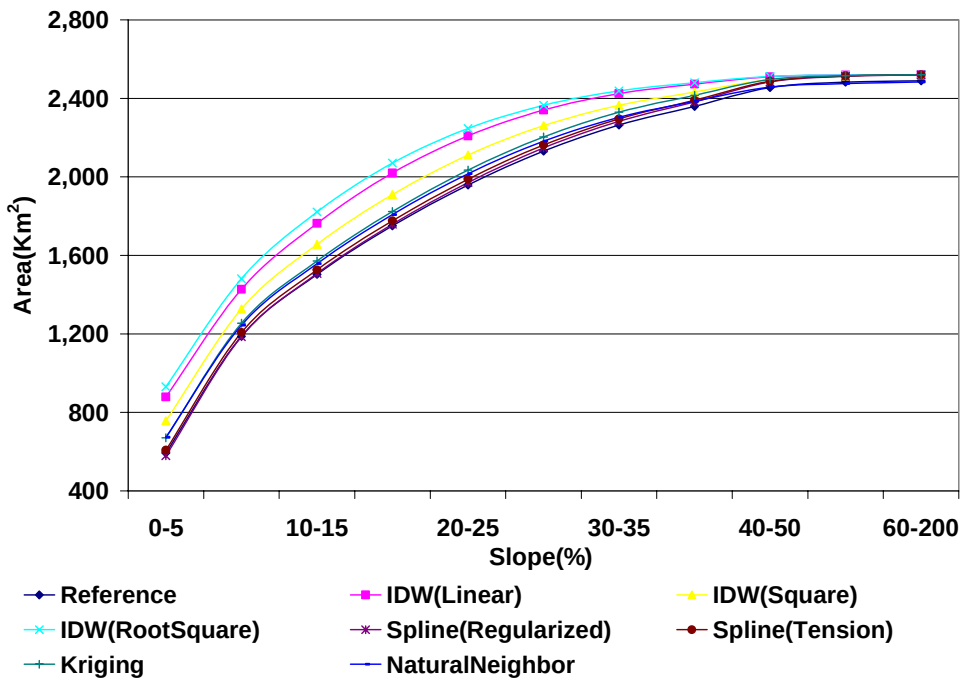

Figure 5. Slope-accumulated area curve

Table 2. Statistics of the slopes and their differences with the resampled DEM

Method	Option	Slope				Differences of the Slopes			
		Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.
Resampled		124.68	0.00	15.16	12.60	-	-	-	-
IDW	0.5	85.09	0.00	11.16	10.00	77.32	-43.01	3.95	5.74
	1	87.00	0.00	11.76	10.37	59.83	-50.88	3.33	4.79
	2	116.12	0.00	13.30	11.64	48.20	-59.43	1.79	4.02
Spline	Reg.	127.87	0.01	15.39	12.72	33.83	-111.55	-0.23	1.41
	Ten.	123.44	0.01	15.09	12.55	33.11	-91.45	0.03	1.20
Kriging		112.01	0.00	14.33	12.05	36.95	-77.81	0.76	1.42
Natural		1,324.66	0.00	15.27	26.67	49.19	-1,318.42	0.47	18.65

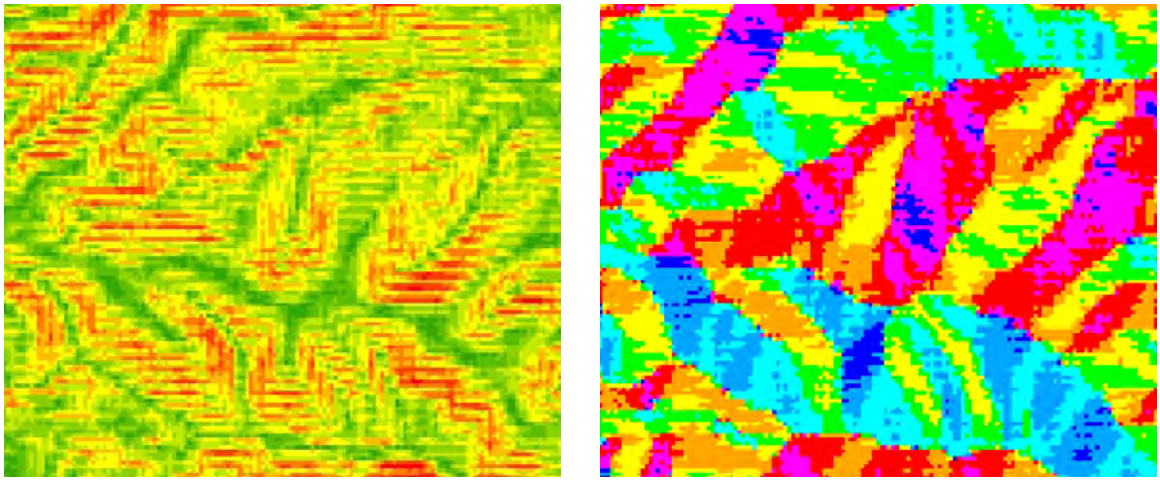

Figure 6. Lattice pattern in slope (left) and aspect (right) of the IDW-interpolated DEM.

Aspect

From the interpolated DEMs, aspect grids that have a 30m cell size were derived. All the interpolation methods produced similar distributions of aspect (Figure 7). It can be noticed that the eastern bias of the aspect that exists in the resampled DEM was preserved through the interpolation. Like the case of slope, the IDW also produced lattice artifacts in aspect (Figure 6).

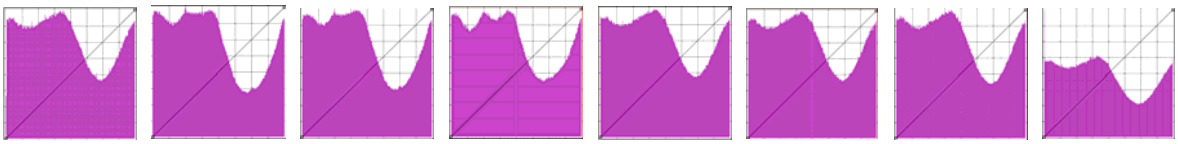

Figure 7. Distributions of aspects

Sinks

The sinks were extracted from the interpolated DEM, and the cell by cell comparisons were done with those of the resampled. For the comparison, the numbers of cells correctly and wrongly classified as sinks were counted and are listed in Table 3.

As seen in Table 3, the IDW methods produced the greatest number of wrongly classified cells and most underestimated the number of sink cells. However, the spline methods created the smallest number of wrongly classified cells. Distributions of the sinks are represented in Figure 8.

Table 3. Percentage of cells correctly and wrongly classified as sinks in the interpolated

Method	Option	Sink – Sink	Sink – Not (A) ***	Not – Sink (B)	Not - Not	Wrong (A) + (B)
IDW	0.5	1.34	2.65	0.91	95.10	3.56
	1	2.39	1.60	2.01	94.01	3.61
	2	0.86	3.13	0.67	95.34	3.80
Spline	Reg.	3.65	0.33	0.57	95.45	0.90
	Ten.	3.53	0.46	0.35	95.67	0.81
Kriging		2.96	1.03	0.34	95.68	1.37
Natural		2.93	1.07	0.43	95.58	1.50

*** The number of cells classified as sinks in the resampled DEM but not in the interpolated.

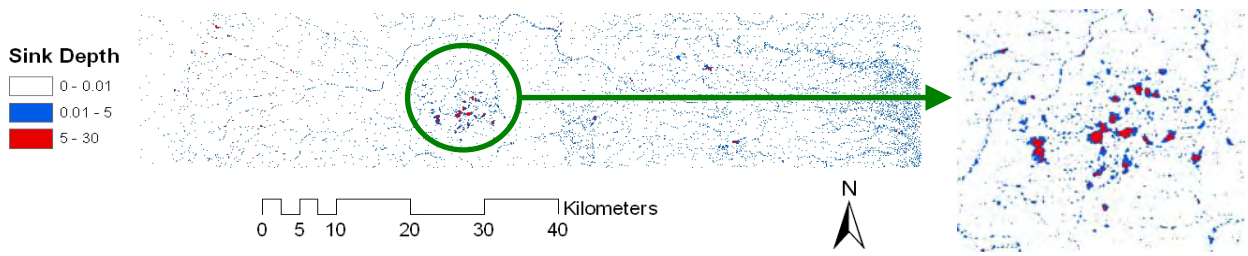

Figure 8. Sink distributions of the interpolated DEM with tension spline

Flow Networks

For comparing flow networks, the resampled and interpolated DEMs were filled, and flow direction and accumulation grids were extracted. For the sake of simplicity of analysis, threshold area for stream initiation was set to 90km^2.

The euclidean distances between the stream line derived from the resampled DEM and those derived from the interpolated DEMs were calculated to compare the stream networks quantitatively (Table 4). The IDW methods created the longest average and maximum distances. Thus, the IDW interpolated DEM produced poor quality results in deriving the stream networks (Figure 9). In contrast, the spline methods provided the relatively small average distances and high overlap percentages.

Table 4. Percentage of cells correctly and wrongly classified as sinks in the interpolated

Method	Option	Basin Area (Km^2)	Average Distance (m)	Maximum Distance (m)	Overlap Percentage
Resampled		1,098.60	-	-	-
IDW	0.5	1,105.00	33.53	984.07	30.34
	1	1,104.60	26.91	810.56	36.58
	2	1,105.70	23.79	984.07	46.35
Spline	Reg.	1,103.80	6.12	212.13	77.79
	Ten.	1,104.10	6.61	212.13	77.89
Kriging		1,105.10	7.15	150.00	74.94
Natural		1,127.50	10.08	127.28	66.48

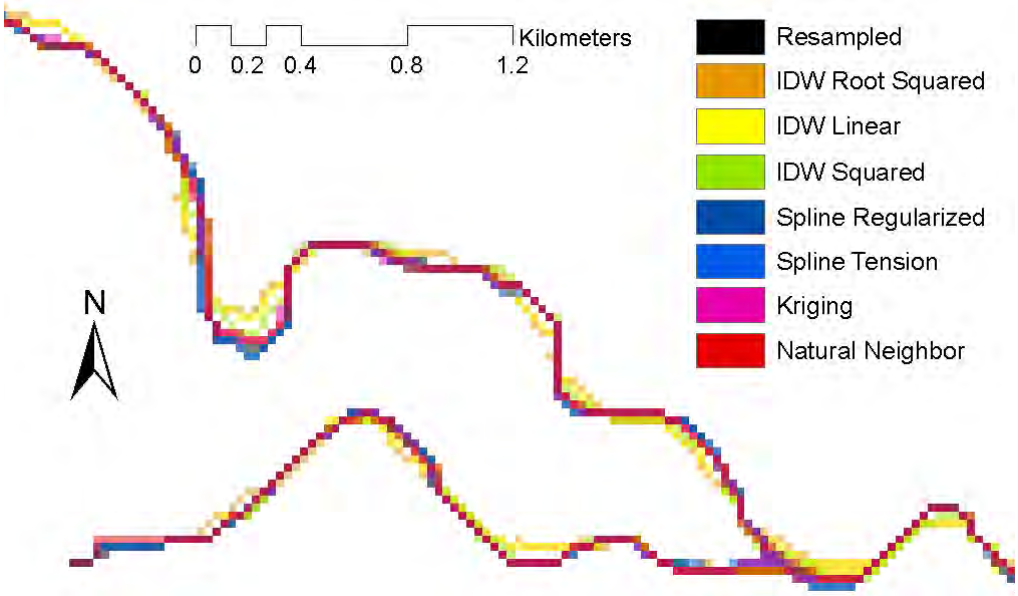

Figure 9. Comparison of the stream networks

Conclusions

The IDW and natural neighbor interpolation were inferior in deriving slopes, sinks, and flow networks. IDW created lattice artifacts in the slopes which may lead to poor results in hydrologic modeling because many hydrologic mechanisms are greatly affected by slope. Spline methods were superior in deriving stream networks and other elevation derivatives. The kriging method had results comparable to spline interpolation, but is more complex to implement and shows no distinct advantage. Direct projection of the SRTM source decimal degree data to a 30m grid using cubic convolution is comparable to the spline interpolation in the properties of the resulting elevation grid. However, direct projection is much simpler to implement so there is no reason from this study to justify a more complicated interpolation procedure. Finally, comparison of flow networks from 30m and 90m grids (the nominal SRTM resolution) with high resolution imagery shows that the 30m grid gives better representation of the surface with improved matching of the stream network, thus is recommended.

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