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Geo 480
2/8/15

Exploring a Northwest Stream Network with LiDAR

Abstract

Each stream restoration project is different in some aspect of the desired outcome. How do you measure the success of stream restoration projects that vary in scope, size, and goal? The analysis should measure the changes that occur in relation to the goals of the project. Certain characteristics of stream morphology, such as slope and elevation, are of importance to calculations and analysis. Accurate stream morphology is dependent on the base information, a Digital Terrain Model (DTM), Digital Elevation Model (DEM), Bare Earth model (BE), Digital Surface Model (DSM), or field collected data, the latter of which is costly for large stream projects. The overarching goal of this exploration is the creation of a model capable of analyzing the success of a stream restoration project as well as stream health in general. The micro-exploration phase of the analysis and the focus of this paper are determining the suitability of stream networks produced with Environmental System Research Institute (ESRI) ArcGIS software and utilizing light detection and ranging (LiDAR) data. The stream project for this analysis is the "Fivemile-Bell Landscape Management Project" in the Siuslaw National Forest.

Introduction

Stream restoration projects are an effort to repair anthropogenic damage normally relating to land use, water use projects, or pollution. Due to the variance in need, each stream restoration project is different in some aspect of the desired outcome. How to measure the success of stream restoration projects that often vary in scope, size, and goal is a complex undertaking? The analysis should measure the changes that occur in relation to the goals of the project. Certain characteristics of stream morphology, such as slope and elevation, are of importance to calculations and analysis. Accurate stream morphology is dependent on the base information, a Digital Terrain Model (DTM), Digital Elevation Model (DEM), Bare Earth model (BE), Digital Surface Model (DSM), or field collected data, the latter of which is costly for large stream projects. LiDAR DTMs have the ability to improve base map information such as slope and drainage density and the remotely sensed data is a cost effective method of surveying a large study area (Vianello, Cavalli, and Tarolli, 2009, 97).

The stream project for this analysis is the "Fivemile-Bell Landscape Management Project" in the Siuslaw National Forest. With the goals of the project (See Goals and Location below) as the guiding force for the design of the analysis, data collection for the analysis began with acquiring Lidar Data. The LiDAR data for the analysis is from the Oregon Department of Geology and Mineral industries (DOGAMI) via the FTP site at Oregon State University (OSU).

Goals, Location, and Partners

The project is in Douglas County, Oregon and includes land in Township 20 South, Range 11 West. Sections 1-5, 8-12, 14-17, 22, and 23; W.M. (See Figure 1 below). The management districts for the project location are Central Coast Ranger District/Oregon Dunes National Recreation Area (Fivemile-Bell). The partners in the project are Ecotrust, Siuslaw Soil and Water Conservation District, Siuslaw Institute, Siuslaw Watershed Council, and the Siuslaw National

Forest. According to the Suislaw National Forest website for the Fivemile-Bell Landscape Management Project, the project goals are as follows (Siuslaw).

Two overarching goals guide the project:

- *To enhance the health of* ***streams and associated aquatic ecosystems****, focusing on threatened Coho salmon habitat.*

  Actions to achieve the goal:
  - *recapture natural stream meander*
  - *increase aquatic habitat diversity*
  - *remove barriers to aquatic species*
  - *reduce impacts from invasive plants*
  - *reestablish native plant species*
  - *speed the development of conifers and hardwoods in riparian areas*
  - *reduce impacts of the valley bottom road on fish habitat*

- *To speed the development of* **late-successional and old-growth forest habitats** *to benefit a variety of species, such as the northern spotted owl and marbled murrelet.*

  Actions to achieve the goal:
  - *improve habitat diversity in young stands*
  - *improve nesting or resting habitat in mature forest*
  - *maintain existing meadows*
  - *reduce the impacts from invasive plants*
  - *modify the transportation system (e.g., repairing, decommissioning, or closing roads)*

Measuring the existing length of the stream and the roads will establish a baseline for decommissioning of roads and increasing meander that will increase the overall length of the stream. Maintaining existing meadows is also an action that may be measured based on existing area. The overarching goal of this exploration is the creation of a model capable of analyzing the success of a stream restoration project as well as stream health in general. The micro-exploration phase of the analysis and the focus of this paper is determining the suitability of stream networks produced with Environmental System Research Institute (ESRI) ArcGIS software and utilizing light detection and ranging (LiDAR) data.

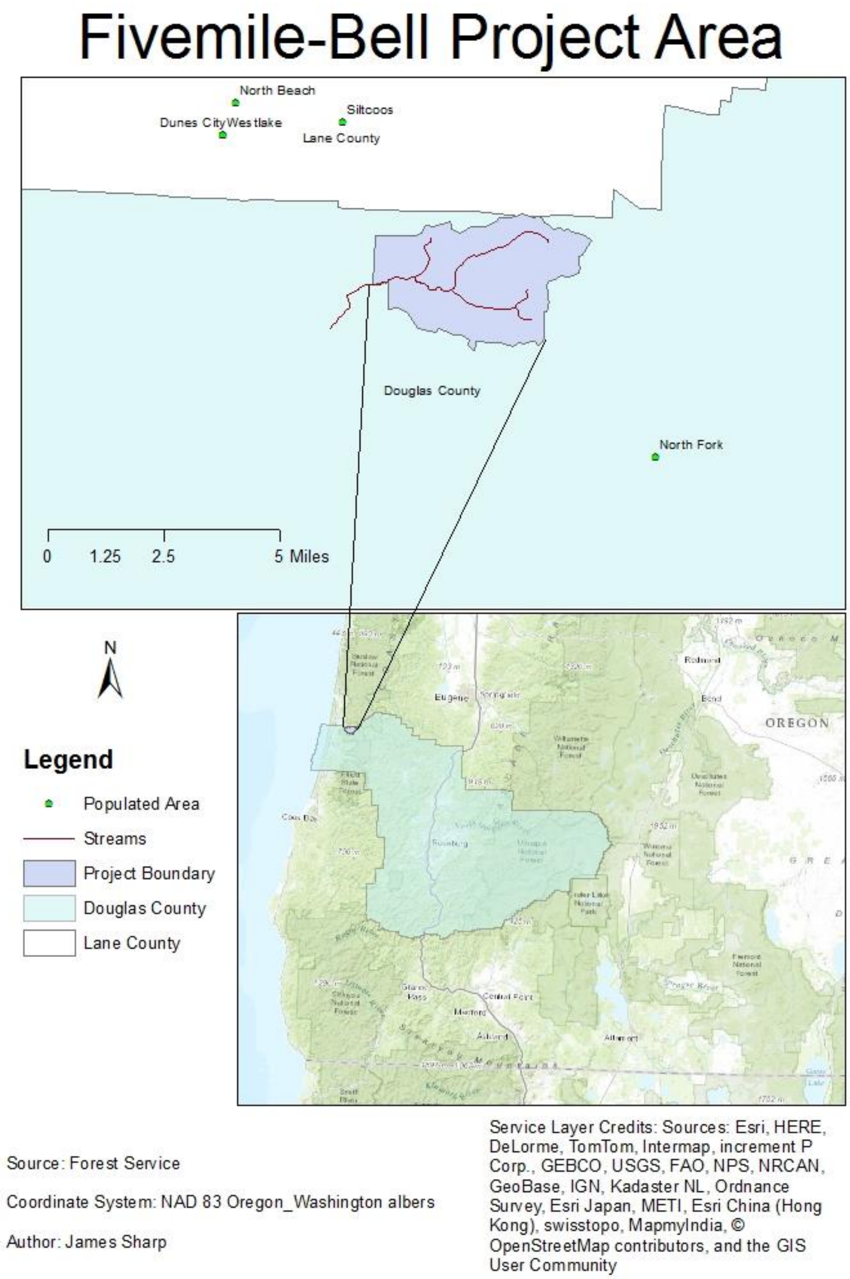
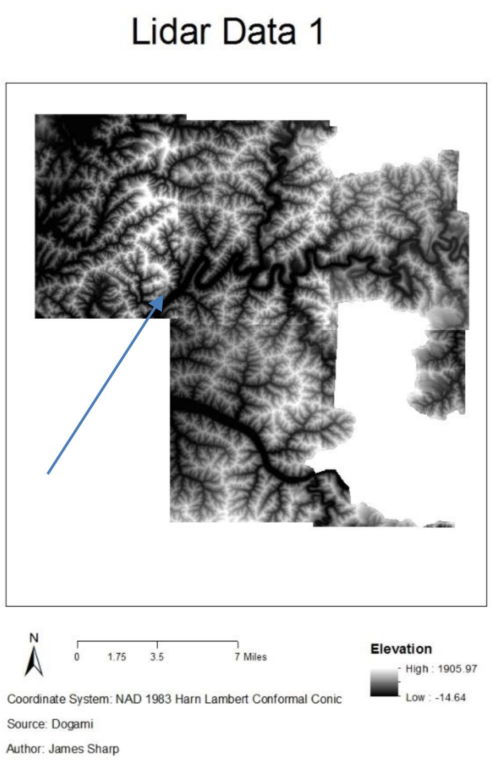


Figure 1: *Map of Project Area*

Methods

The first step of the process of determining the study area of the project was contacting the Forest Service for information on the project area. LiDAR data based on the location given in Township, Section, and Range, including sufficient LiDAR data to cover several watersheds near the study area, was acquired from the Oregon Department of Geology and Mineral industries (DOGAMI) via the FTP site at Oregon State University (OSU). The data has a 3-foot resolution and the creator of the data is Watershed Sciences of Corvallis, Oregon. The extent of the LiDAR data is needed to establish several watersheds that do not have ongoing restoration projects so they may be used as a comparison to the Fivemile-Bell Project in the form of a control group to assure changes and improvements to the stream health is the result of the project and not naturally occurring changes.

In order to acquire sufficient data entailed the use of multiple Bare Earth files from the site. To create a homogenous DTM the multiple LiDAR files were converted to a single mosaic file (DEM) (See Figure 2 and 3 below). This mosaic is an area of some concern due to the possibility of edge error in the individual rasters. There is also some uncertainty in the LiDAR data as the vender advises signal scatter may exist over water bodies and vegetation limits the ground returns giving less than perfect bare earth models. The DEM file was converted to a hillshade file (hillsh2, See Figure 4 below) to examine the bare earth characteristics of the location (See Figure 5 below). After creating the model to overlay the stream network on, the actual process of creating the stream network began. This process is performed on the entire data set so the streams for the other watersheds are consistent with the streams in the Fivemile-Bell Project.



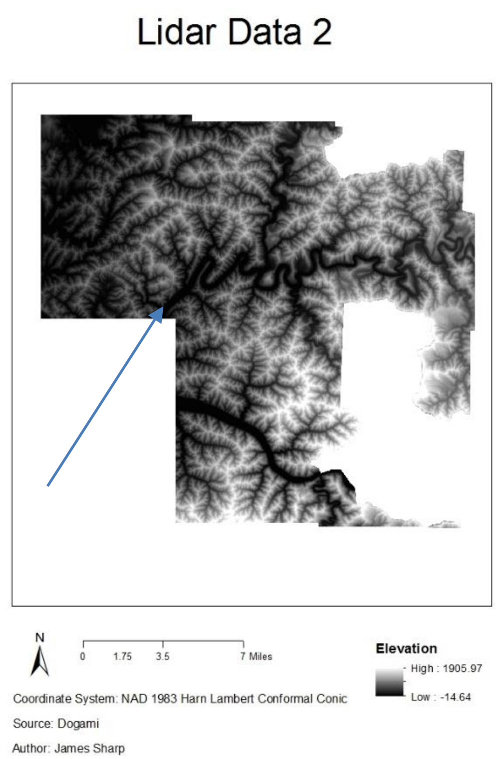


Figure 2 and 3 *LiDAR before and after Mosaic process.*
The LiDAR image on the left is the multiple files before the mosaic process that creates the image on the right, the DEM. The arrow shows the location of a "seam" that is between two original LiDAR files and on the right after the mosaic the "seam" is no longer visible.

ESRI software has a suite of tools for the creation of stream networks and watersheds in the Hydrology section of the Spatial Analyst Tools. The main steps involved in the process are Fill, Flow Direction, Flow Accumulation, Snap Pour Point, Watershed, and Streams to Feature. The explanation of each of these processes is given below as the process is performed. The first step is the Fill process that "fills" the sinks, or depressions, in the terrain until water flows across the digital landscape. This paper shall examine this process in detail after explaining several more aspects of the hydrology process in ESRI. Filling the terrain allows virtual water to find the direction of flow in ESRI's Flow Direction process. The target cell will flow to the nearest adjacent cell lower than the target cell (See Figure 6 below).

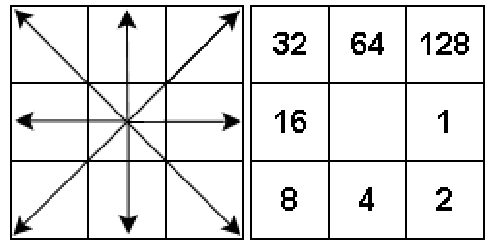
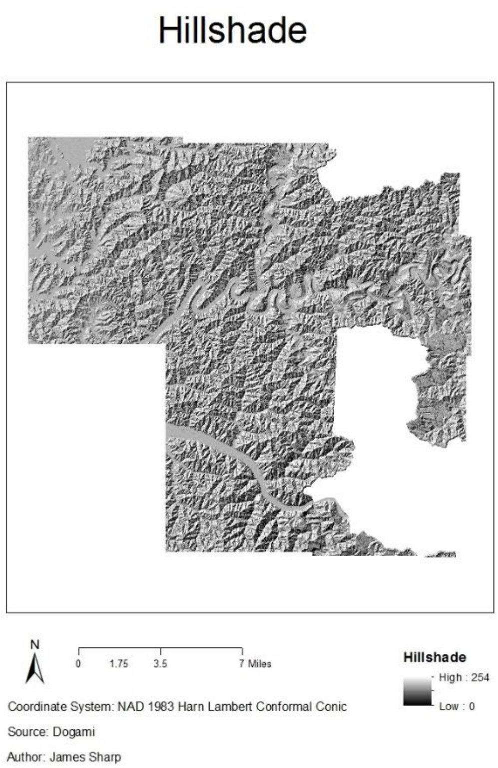


Figure 6: *Example of "Flow Direction" in ESRI ArcMap (UW).*



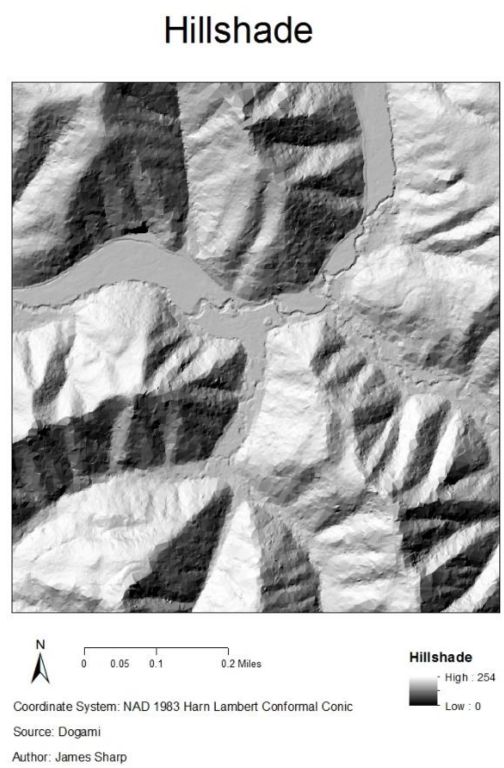


Figure 4 and 5 *Hillshade Image*

The image on the left is a hillshade of the entire study area and the image on the right is a "zoomed in" hillshade depicting the bottom of the valley floor and the stream meandering through the valley.

After performing the flow direction process, the Flow Accumulation determines the accumulated flow of the stream as it moves down the network. The streams were created for the entire study area. In order to create the watershed a point must be set at the outlet or downstream terminus of the watershed. This was something of a guess, as the original point of the watershed used by the Forest Service in the original analysis is not available. After creating the watershed, comparison of the watershed and the Forest Service boundary visually indicated an acceptable immolation with the exception of the western boundary that is “squared,” and does not align with the watershed (See Figure 6 below).

Buffering of 250 meters was applied to the watershed to reduce edge error. The next process of the analysis involved creating clip files utilizing the watershed buffer of 250 meters as the clip boundary. This included creating clips for the stream network, the hillshade, DEM, aspect, slope, and sinks filled. The entire stream network for the watershed area is shown below in Figure 7.

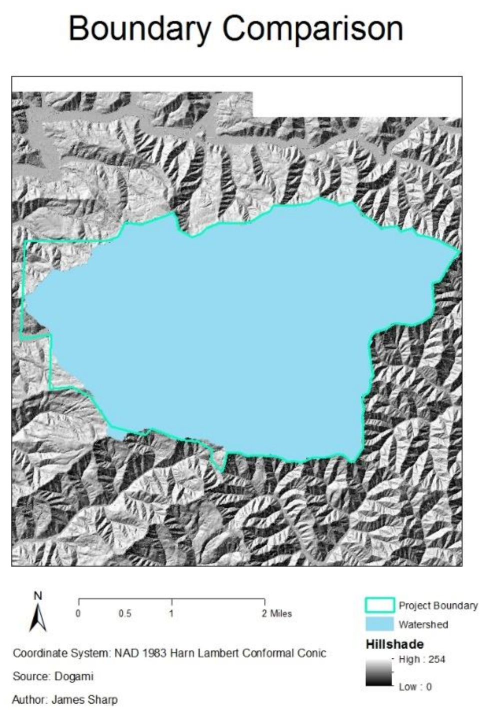


Figure 6: *Comparison of watershed boundary and Forest Service Project boundary.*

The streams were reclassified to remove the smaller, possibly ephemeral, streams. The cutoff for visible cells was set to 500,000 to remove any cells with less than 500,000 accumulated cells (see Figure 8 below).

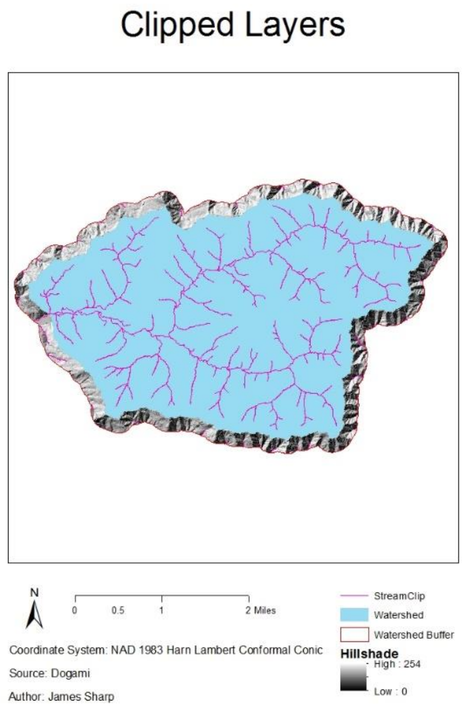


Figure 7: *Image representing the stream network and watershed.*

The process of determining the amount of the fills requires use of the Raster Calculator in ESRI ArcMap. Subtracting the DEMfill raster from the DEM raster gives the sink filled depth as a negative number indicating the amount of virtual water added to reach the flow point. This information is utilized to determine areas that may not have reliable data based on the magnitude of the fil. Slope of the streambed and other calculations depend on accurate elevations at the flowline of the stream. Determining an accurate length of the stream network requires the stream creation in ESRI ArcMap actually follows the stream meander. The Raster Calculator results for the fills is shown below in Figure 9.

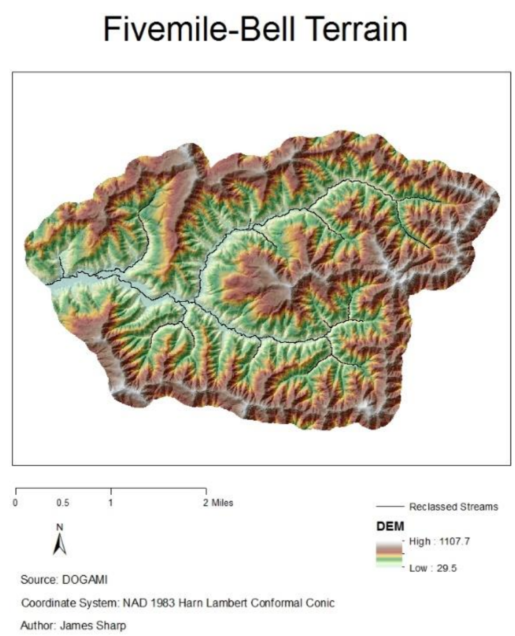


Figure 8: *Reclassified streams overlain onto the terrain model.*

The next phase of the process was the creation of routes along the stream networks. These routes are utilized to create what ESRI terms "construction points" in ArcMap. The construction points were placed every 20 feet along the route of the stream. Extracting multiple values to points allowed the information for the slope, aspect, sinks filled, and other data to be attributed to each of the construction points. Joins allow other data to be attached to the extracted values for additional analysis as needed.

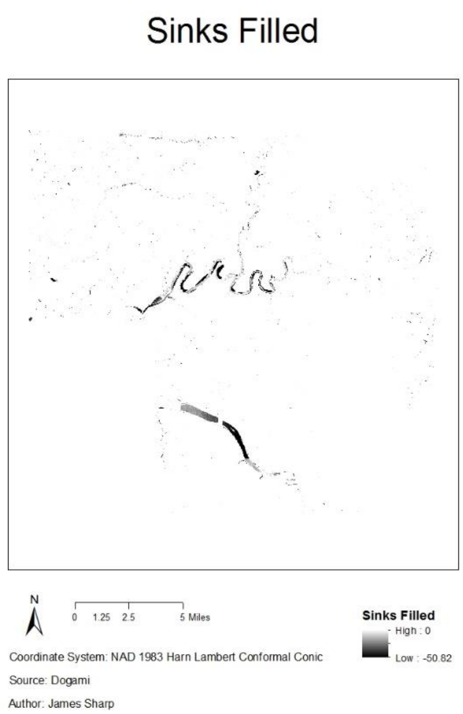
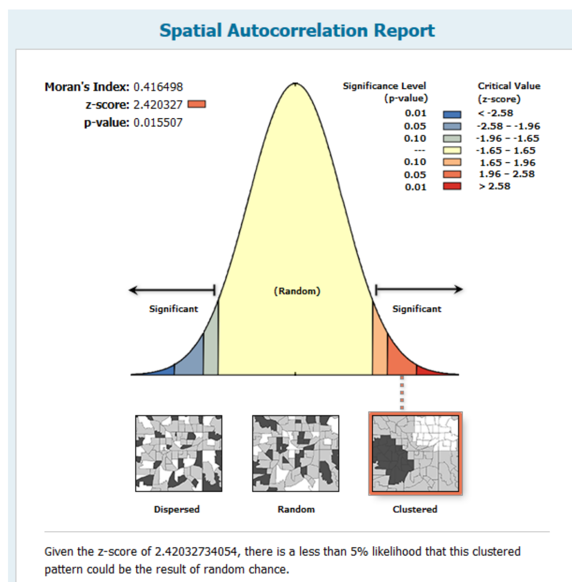


Figure 9: *The sinks filled are the result of subtracting the DEMfill from the DEM. Due to the negative values the more fill is for the least value.*

Once all of the data was attributed to the construction points exploratory analysis began.

Results

To determine the extent of autocorrelation among the multi-join construction point file a Global Moran's I was utilized. The sinksfldCli attribute and an "inverse distance squared" setting were utilized for the analysis. The results are shown below in Figure 10.



Global Moran's I Summary	
Moran's Index:	0.416498
Expected Index:	-0.000369
Variance:	0.029665
z-score:	2.420327
p-value:	0.015507
Dataset Information	
Input Feature Class:	Join_Multi
Input Field:	SINKFLDCLI
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	20.0020 Feet
Weights Matrix File:	None
Selection Set:	False

Figure 10: *Autocorrelation results for the multi-join construction point file.*

The results of the Moran's I indicate the data has a level of clustering. The data has less than a 5 percent chance of the clustering being the result of random chance. Although the p-value is greater than 0.01, the 0.0155 value is of importance to the clustering of the data.

The next process of analysis on the data is a least squares evaluation. For this examination, the dependent variable is the *sinkfldCli* and the explanatory variables are the *slope_Clip*, and *aspectClip.* The results for the Ordinary Least Squares (OLS) are shown below in Tables 1 and 2.

Table 1: *Diagnostics of the Ordinary Least Squares analysis.*

OLS Diagnostics

Input Features:	Join_Multi	Dependent Variable:	SINKFLDCLI
Number of Observations:	2711	Akaike's Information Criterion (AICc) [d]:	9170.720688
Multiple R-Squared [d]:	0.066031	Adjusted R-Squared [d]:	0.065342
Joint F-Statistic [e]:	95.727388	Prob(>F), (2,2708) degrees of freedom:	0.000000*
Joint Wald Statistic [e]:	186.255431	Prob(>chi-squared), (2) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	7.665594	Prob(>chi-squared), (2) degrees of freedom:	0.021649*
Jarque-Bera Statistic [g]:	3881.717500	Prob(>chi-squared), (2) degrees of freedom:	0.000000*

Notes on Interpretation

* An asterisk next to a number indicates a statistically significant p-value (p < 0.01).

Table 2: *Results of the Ordinary Least Squares analysis.*

Summary of OLS Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	-0.609310	0.062045	-9.820402	0.000000*	0.060930	-10.000184	0.000000*	--------
SLOPE_CLIP	-0.035553	0.002583	-13.766259	0.000000*	0.002614	-13.602376	0.000000*	1.009063
ASPECTCLIP	0.000021	0.000252	0.083697	0.933287	0.000253	0.083347	0.933565	1.009063

Several of the statistics have significant p-values and according to the analysis information. Although the Koenker p-value is greater than 0.01 (0.0216) the Robust_Pr shows the intercept and *slope_clip* coefficients to have significant value, both indicate a significant zero value. The Probability (b) also indicates a coefficient that is statistically significant. Due to the recommendation of the Ordinary Least Squares analysis a Global Moran's I analysis was performed on the residuals. A histogram of the residuals is shown below in Figure 11.

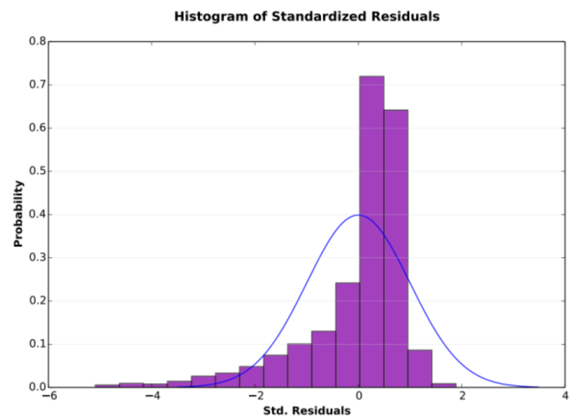
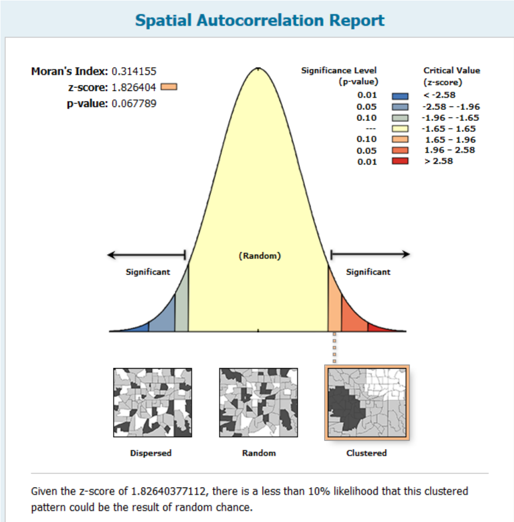


Figure 11: *The histogram indicates a slightly skewed, but nearly normal, distribution of the residuals of the Ordinary Least Squares analysis.*

The Moran's I for the residuals indicates clustering of the data, but with slightly lower results than the Global Moran's analysis on the multi-join construction point file. The results of the analysis are shown below in Figure 12.



Global Moran's I Summary

Moran's Index:	0.314155
Expected Index:	-0.000369
Variance:	0.029656
z-score:	1.826404
p-value:	0.067789

Dataset Information

Input Feature Class:	Least2
Input Field:	RESIDUAL
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	20.0020 Feet
Weights Matrix File:	None
Selection Set:	False

Figure 12: Global Moran's I spatial Autocorrelation results.

Discussion

Visually examining the results of the Ordinary Least Squares analysis indicated the "cold" spots (values in the blue spectra) are the greater fills (negative numbers).The clustering of blue in Figure 13 below is a visual indicator of potential high fill areas.

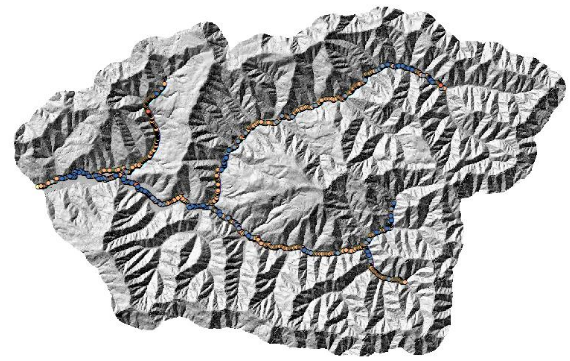


Figure 13: Image of watershed and stream area with construction points along stream. The blue areas indicate "cold" spots that represent high fill cells.

Zooming in on the image allows the examination of the cluster, which indicates the terrain does not match the stream network in many areas. Figure 14 indicates this in the hillshade model and figure 15 shows the same location with an aerial map image. Examination of both images indicates the stream does not match the terrain and the blue clustering is located in the area where the stream deviates from the terrain.

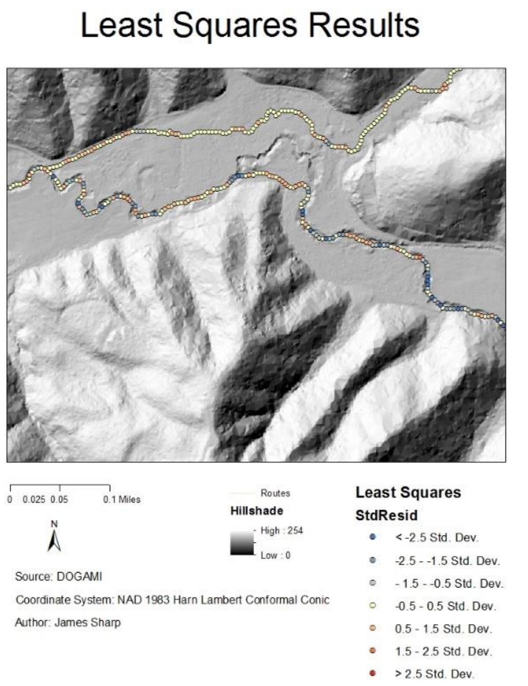


Figure 13: Construction points along stream.

The aerial map indicates presence of water when zoomed in to higher magnification as shown in Figure 15 below. It is of course possible the stream is in the process of creating an oxbow at this location. Verification of all results and speculations require field "truthing" of the site.

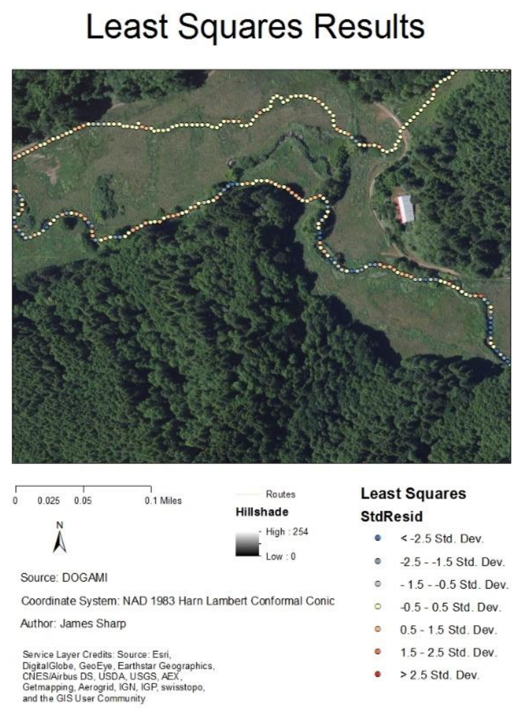


Figure14: Image of construction points overlain on an aerial map.

Further examination of several clusters of blue gave similar results. In several areas, the tree canopy made visual examination of the stream impossible with the aerial. Areas without tree canopy normally water was visible in the aerial near the area of the blue (high fill areas).

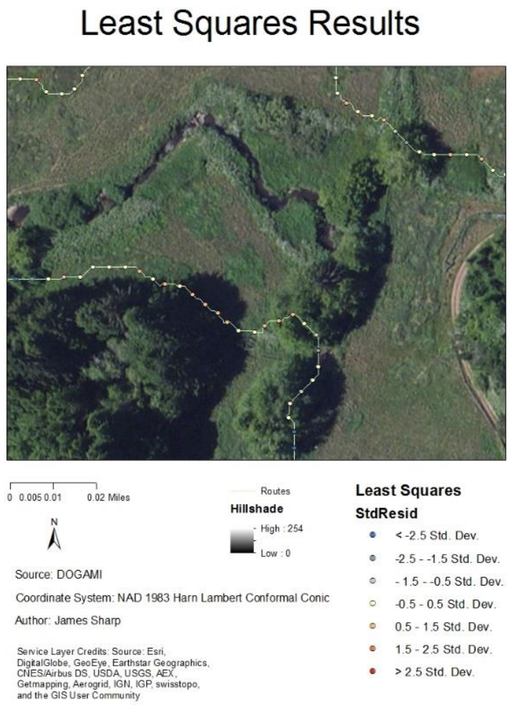


Figure 15: Image showing the stream path not following the creek.

Vianello, Cavalli, and Tarolli discuss LiDAR and the application as a method of stream analysis in the paper "LiDAR-derived slopes for headwater channel network analysis (). The authors describe accurate results when comparing LiDAR derived slopes to field derived slopes but do indicate some over calculation of slope in alluvial channels 2 to 5 meters wide when using a 1 meter resolution (3.28 feet verses 3 feet) DTM. Although these results were acquired in somewhat steeper terrain the indications, at least preliminarily, are the ESRI Software has either mis-calculated the stream or the LiDAR data has discrepancies which are creating the high fills which intern correlate to deviation from the stream bed.

Conclusions

Certain characteristics of stream morphology, such as slope and elevation, are of importance to calculations and analysis. Accurate stream morphology is dependent on the base information, whether the source is field data, or remotely sensed data such as LiDAR. The process of filling sinks is an area of uncertainty in any hydrologic network, especially if LiDAR data is utilized. The data set used to perform the creation of the hydrologic network does have a disclaimer stating returns may be lacking in areas of high vegetation or water bodies. Before continuing with the stream study, further examination of the LiDAR data, and the methodology, and a field examination of the problem area on site need to occur. The current data would allow the pinpointing of areas that should be checked prior to the field excursion, which increases efficiency. The overarching goal of this exploration is the creation of a model capable of analyzing the success of a stream restoration project as well as stream health in general. The initial indication is the present configuration has the potential, with verification of input data, of creating a model to examine multiple stream characteristics simultaneously or in conjunction to determine impacts and changes to the stream networks. The micro-exploration phase of the analysis and the focus of this paper are determining the suitability of stream networks produced with Environmental System Research Institute (ESRI) ArcGIS software and utilizing light detection and ranging (LiDAR) data. The initial indication is the data will need to be adjusted with field data before being beneficial in the study of a stream project that has the goal of lengthening streams with the addition of meanders. The methodology appears to be sufficient for the examination of the road network as the initial indication is water may influence results as much or more than canopy cover. More research on the process, as well as field data collection to verify the legitimacy of the LiDAR in target areas is needed. Where the ESRI generated stream follows the existing are also areas that should have data collected to verify the model. Field data collection needs to be performed to test the model in areas that are not significant according to the model.

References

The project details may be found at the following link.
http://www.fs.usda.gov/detail/siuslaw/landmanagement/resourcemanagement/?cid=stelprdb5383646

Fivemile-Bell, 2014, United States Forest Service, Retrieved from
http://www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c5/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gDfxMDT8MwRydLA1cj72BTUwMTAwgAykeaxRtBeY4WBv4eHmF-YT4GMHkidBvgAI6EdIeDXIvfdrAJuM3388jPTdUvyA2NMMgyUQQAyrgQmg!!/dl3/d3/L2dJQSEvUUt3QS9ZQnZ3LzZfS000MjZOMDcxT1RVODBJN0o2MTJQRDMwODQ!/?project=32496
Siuslaw Nation Forest, 2014, retrieved from
http://www.fs.usda.gov/detail/siuslaw/landmanagement/resourcemanagement/?cid=stelprdb5383646

UW, 2014, UW Hydro Computing Workshop, retrieved from
http://www.hydro.washington.edu/~nijssen/computing_workshops/GIS_workshop_exercise/GIS_Computing_Workshop_Homework.pdf

Vianello, A., Cavalli, M., & Tarolli, P. (n.d.). LiDAR-derived slopes for headwater channel network analysis. *CATENA,* 97-106.

Research Question: How do you measure the success of a stream restoration project?

Layer Name	Date created	Original scale/resolution	PCS	GCS (datum)	Creator	Useful Attributes	Data Quality Issues	Method of creation	Relevance to analysis
Be43123g7a	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123g7b	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123f8	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123f7d	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123f7c	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123f7b	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be43123f7a	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit	LiDAR	Base for stream analysis

			Conic				returns		
Be43123g1	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Be4313g8	2009-05-28	3 foot	NAD 1983 Harn Lambert Conformal Conic	NAD 1983 Harn	Watershed Sciences	Elevation	Vegetation and water limit returns	LiDAR	Base for stream analysis
Project_Boundary	2010-05-03	10,000?	NAD 1983 Oregon_Washington Albers	NAD 1983	Jeff Jackson	Project area	None	vector	Project area
Dist_Coho_2005	2/16/2006	1:100,000	OGICdefaultAG82	NAD83	Streamnet	End feet	Cartoon	vector	Habitat of Coho
Orcnty24.dhp	3/17/2008	1:24,000	OR statewide	NAD83					Show location

James Sharp Workflow Diagram