LiDAR Stream Detrending:

A Comparison of Elevation Sampling Methods

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Intro:

Whether you're studying stream geomorphology, historic stream channels and meandering scars, flood plains and flood inundation, or cartography, stream detrending is a valuable geoprocessing workflow. This study is heavily inspired by the breathtaking work of cartographer Dan Coe. His work focuses on using LiDAR data to depict geomorphology, such as his more well-known work depicting Willamette River stream channels as seen in **Figure 1**.

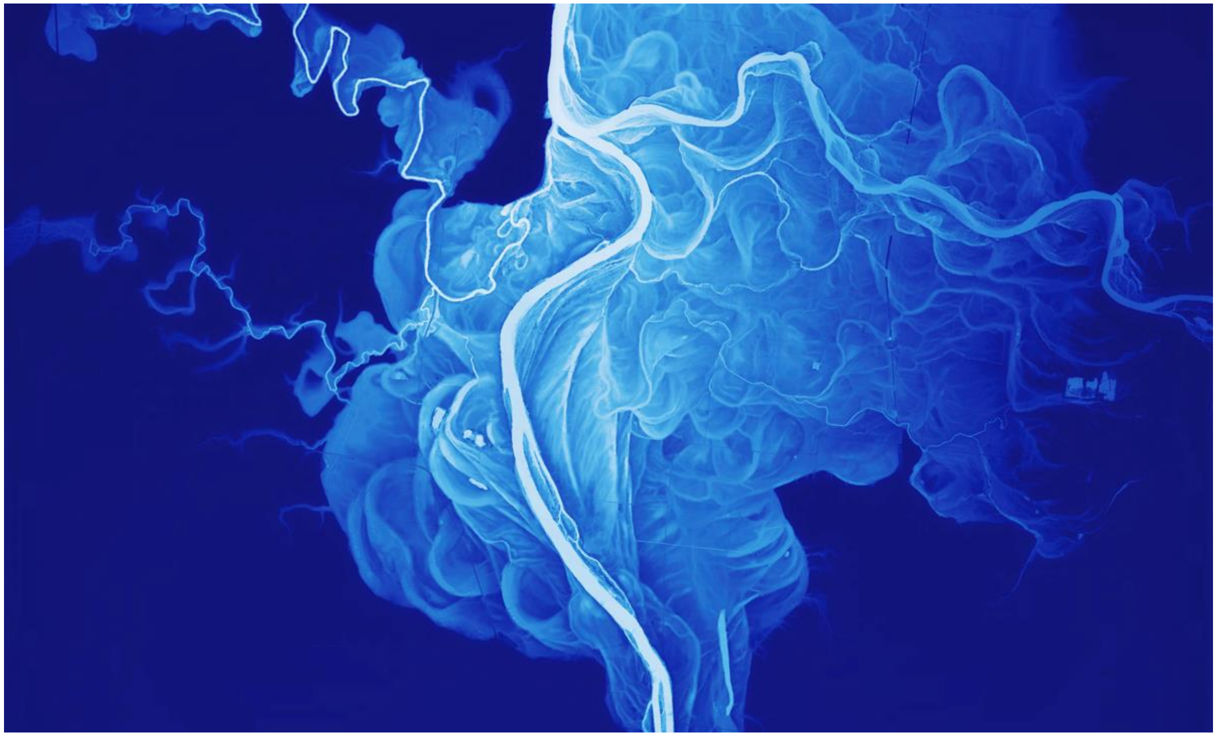

Figure 1: Dan Coe - Willamette River Channels

I set out to understand and replicate Dan Coe's techniques for performing stream detrending and was lucky enough to find a couple PowerPoint presentations from public talks where he had discussed his methods. One presentation generally breaks down the methods of stream detrending using tools in ArcMap (Coe, 2013) and the other presentation has more of an emphasis on manipulating imagery in Adobe Photoshop (Coe, 2011). Throughout the process I also referred to several Esri Help Documentation articles as well as class materials provided by James White to develop my understanding of the topic.

Data: My first step was to select a study site. I chose to focus on an area along the Willamette River that had a wide floodplain as well as an area that was contained well within one or two LiDAR quads. The area adjacent to Peoria, OR seemed to be a good fit. For this study I acquired two main datasets. I used two quads (Greenberry and Peoria, along the Willamette River) of LiDAR data from the Oregon Department of Geology and Mineral Industries (DOGAMI) as well as a dataset containing LiDAR data supplemented with single-beam SONAR bathymetry along a stretch of the Willamette River. A hand drawn polygon of the floodplain in the study area was also used as a clipping feature.

Methods: The basic idea behind stream detrending is that you are 'flattening' the down-valley slope along a stream channel. Down-valley slope is a natural characteristic of a stream channel whereby the elevation downstream is generally lower than the elevation upstream.

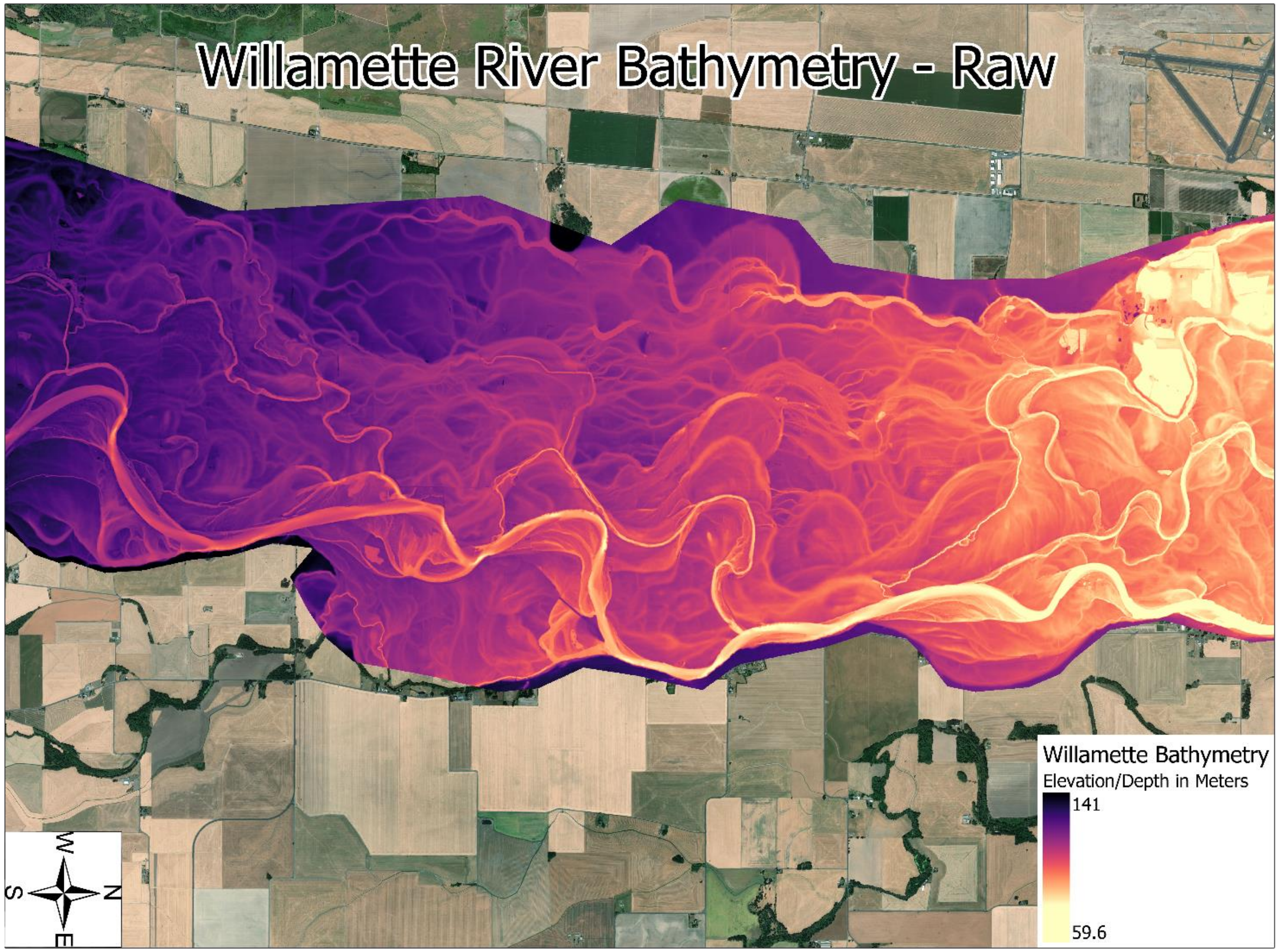

Figure 2: Raw Bathymetry-Supplemented LiDAR

Figure 2 above shows the raw bathymetry-supplemented LiDAR in the study area. You can clearly see the linear trend of darker, high values on the left (upstream) and lighter, low values on the right (downstream). While this image alone is pretty stunning, there is a lot of detail and depth lost in the floodplain because the range of values hasn't been detrended. The raw LiDAR dataset (**Figure 3**) is similar, but the range of values is considerably higher (since traditional LiDAR doesn't penetrate water well, the bathymetry-supplemented dataset inherently has lower lows).

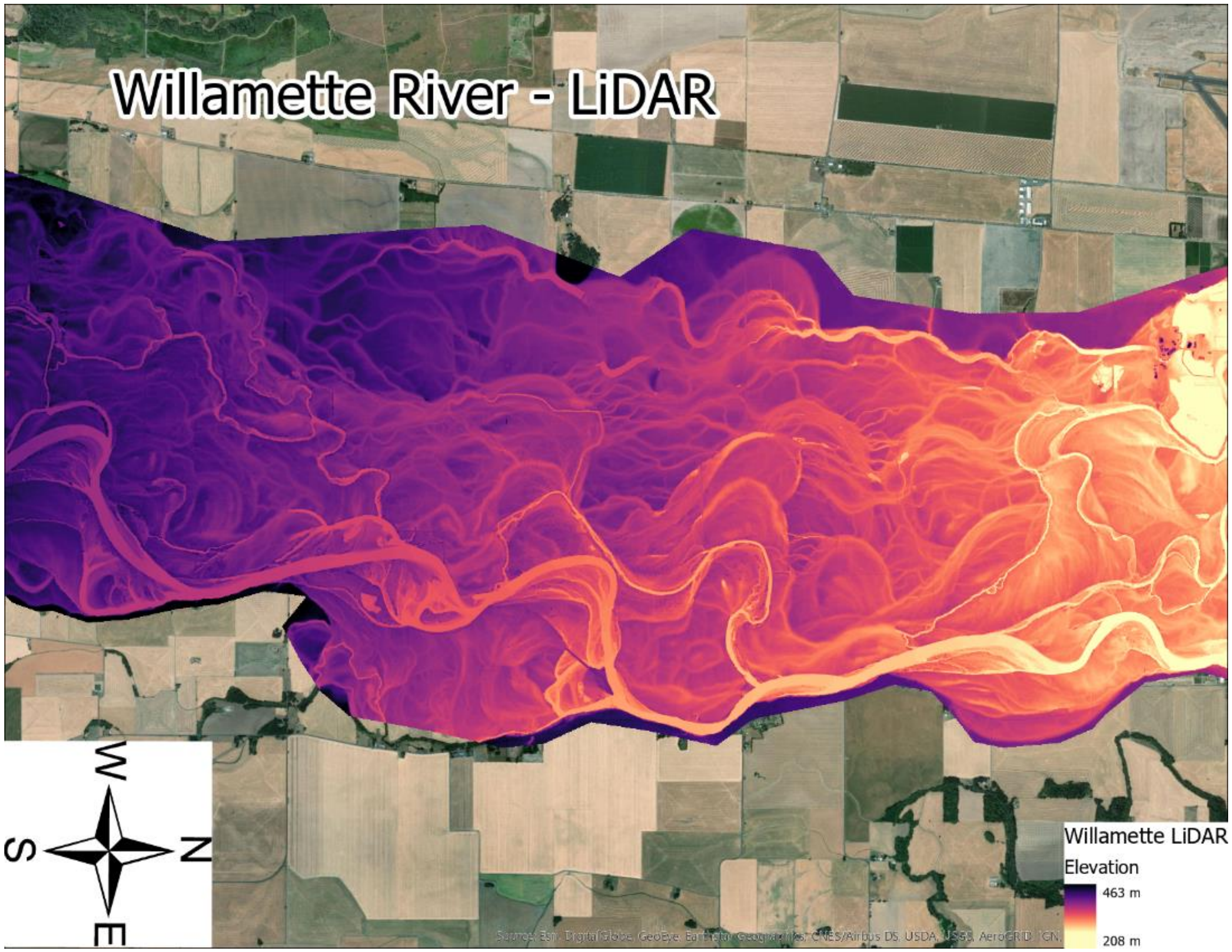

Figure 3: Raw LiDAR

In order to detrend elevation data along a stream channel, you first have to sample elevations perpendicular to the stream itself. From those elevation samples, you can interpolate a triangulated irregular network (TIN). That TIN is then converted and resampled into a raster with a cell size that matches the original elevation dataset. That resampled raster is then subtracted from the original elevation dataset to produce the final detrended result.

I discovered after I began this study that the end results varied somewhat significantly based on my elevation sampling methods, so I chose to experiment with three different sampling techniques. Dan Coe's presentation suggested creating an empty polyline feature and hand-drawing transects perpendicular to the stream spanning the width of the floodplain along the entire stream reach in your study area. He also suggests that this process could be automated (but doesn't explain how), so I experimented and developed a semi-automated method using the fishnet tool. Finally, I used a hybrid method that was the product of merging my manually drawn transects with those created by the fishnet tool. Before I decided on limiting my study area and limiting my analysis to those methods, I also tried detrending the entire bathymetry-supplemented LiDAR dataset by using the Generate Transects Along a Line script in ArcPro, but the results were sloppy and lacked the luster of the more deliberate methods.

Manually drawing transects was somewhat time consuming and challenging, because the goal is to keep the transects perpendicular to the stream channel without too much overlap. The fishnet tool allows you to draw a grid over a study area, specifying the number of and interval between rows and columns. The output of the fishnet tool can be set to produce polylines, and a little manual editing is needed to remove the outer bounding box of the grid and any vertical segments (we are only interested in the horizontal lines generated between rows, these should be mostly perpendicular to the stream channel). The hand-drawn floodplain polygon was then used as a clipping feature to clip the fishnet to the shape of the floodplain. The hybrid transects were created by using the Merge tool in ArcPro and merging together the manually drawn transects and the fishnet transects. **Figure 4** below shows the three transect methods side-by-side.

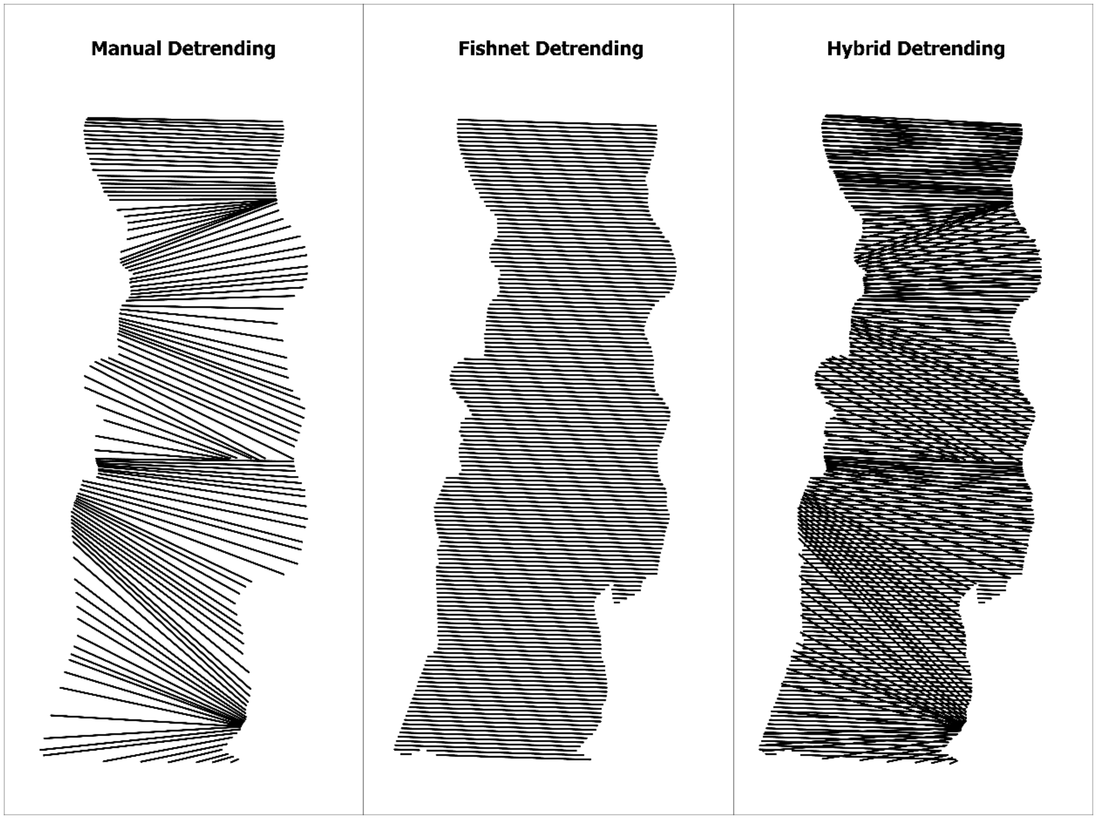

Figure 4:Transect Methods

The next step was to sample the elevations from the elevation raster using the Add Information from Surface tool in ArcPro. This tool takes each transect line and samples elevations along it's length and then calculates the mean and adds that value to the feature. Next, the Create TIN tool is used to interpolate a smooth elevation surface from the sampled elevations. The transects (now attributed with mean elevations) are input into the Create TIN tool and the mean elevation attribute is used as the field to interpolate a surface from. The result is then converted to raster (TIN to Raster tool in ArcPro) using default settings and then resampled (Resample tool in ArcPro) so the cell size matches the cell size of the original elevation raster. **Figure 5** below shows the resampled elevation surfaces for each sampling method (lighter is higher, darker is lower).

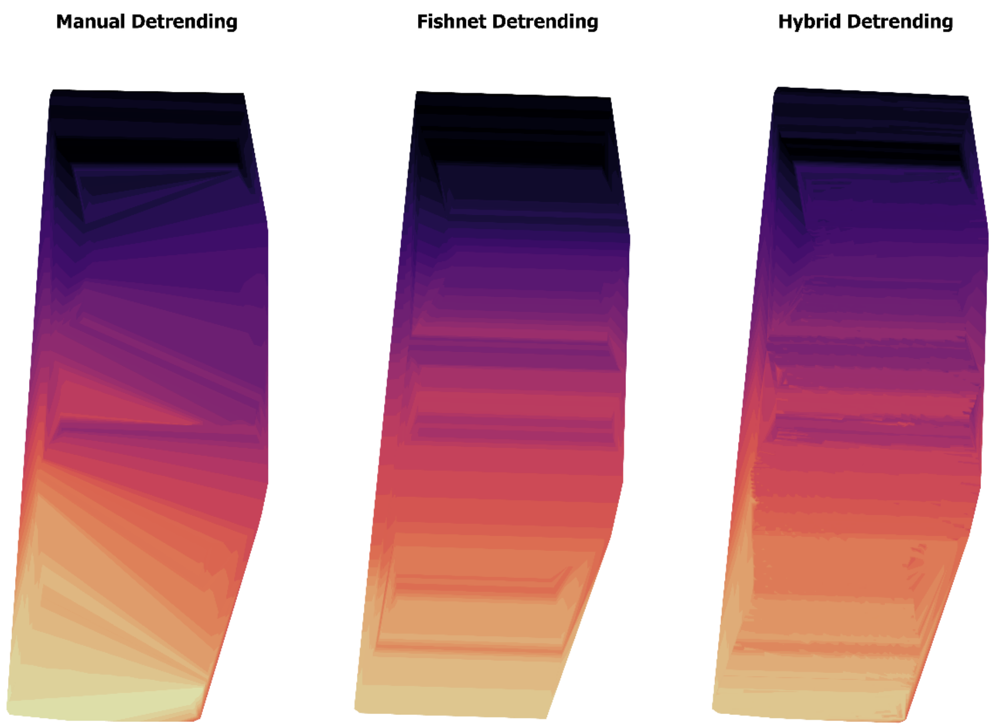

Figure 5: Sampled Elevation Surfaces

Finally, this elevation surface is subtracted from the original elevation raster to produce a raster that is detrended along the stream channel.

Results: The resulting images were detrended with varying degrees of smoothness. **Figure 6** below shows the results of manually drawing transects for sampling elevations in the bathymetry-supplemented LiDAR raster.

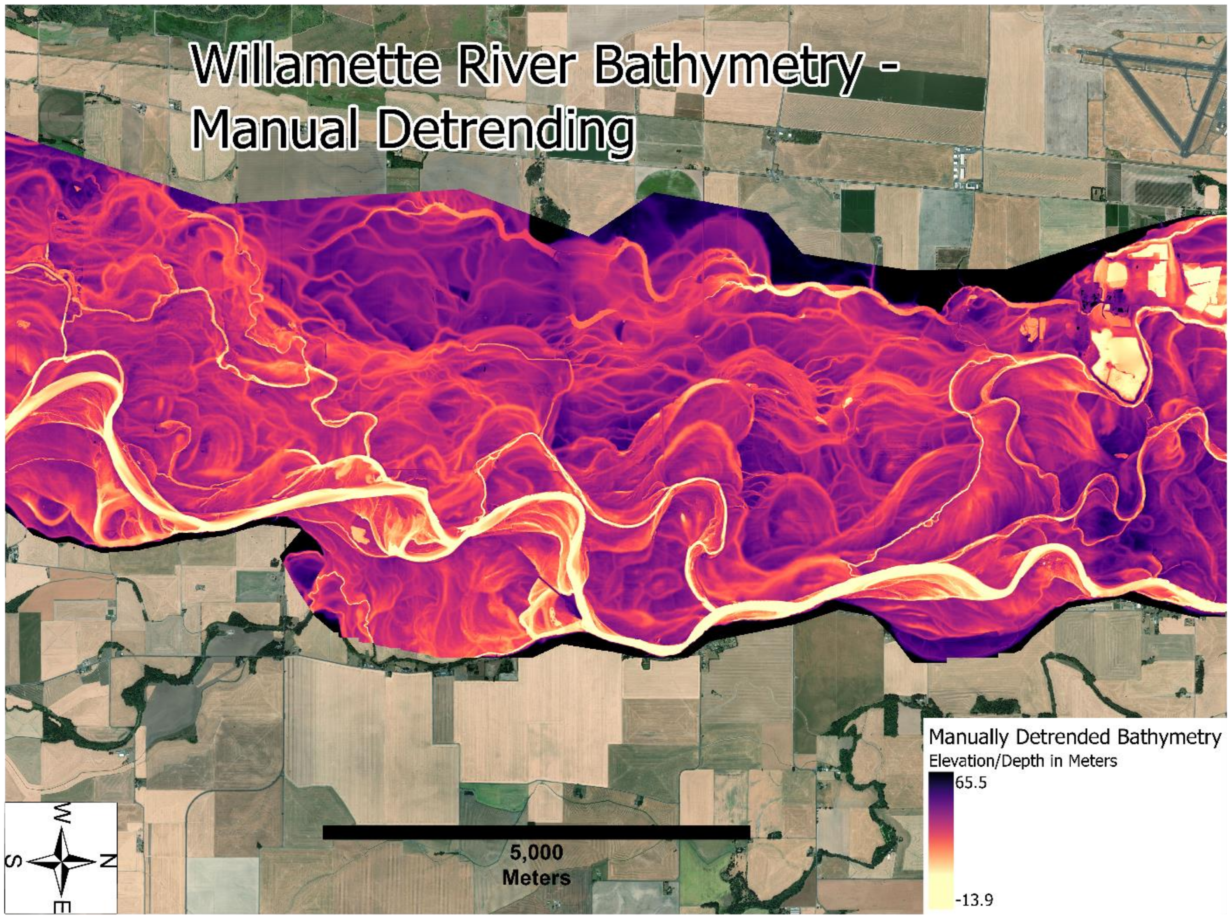

Figure 6: Manually Detrended Bathymetry

Figure 7 below shows the results of manually drawing transects for sampling elevations in the LiDAR raster.

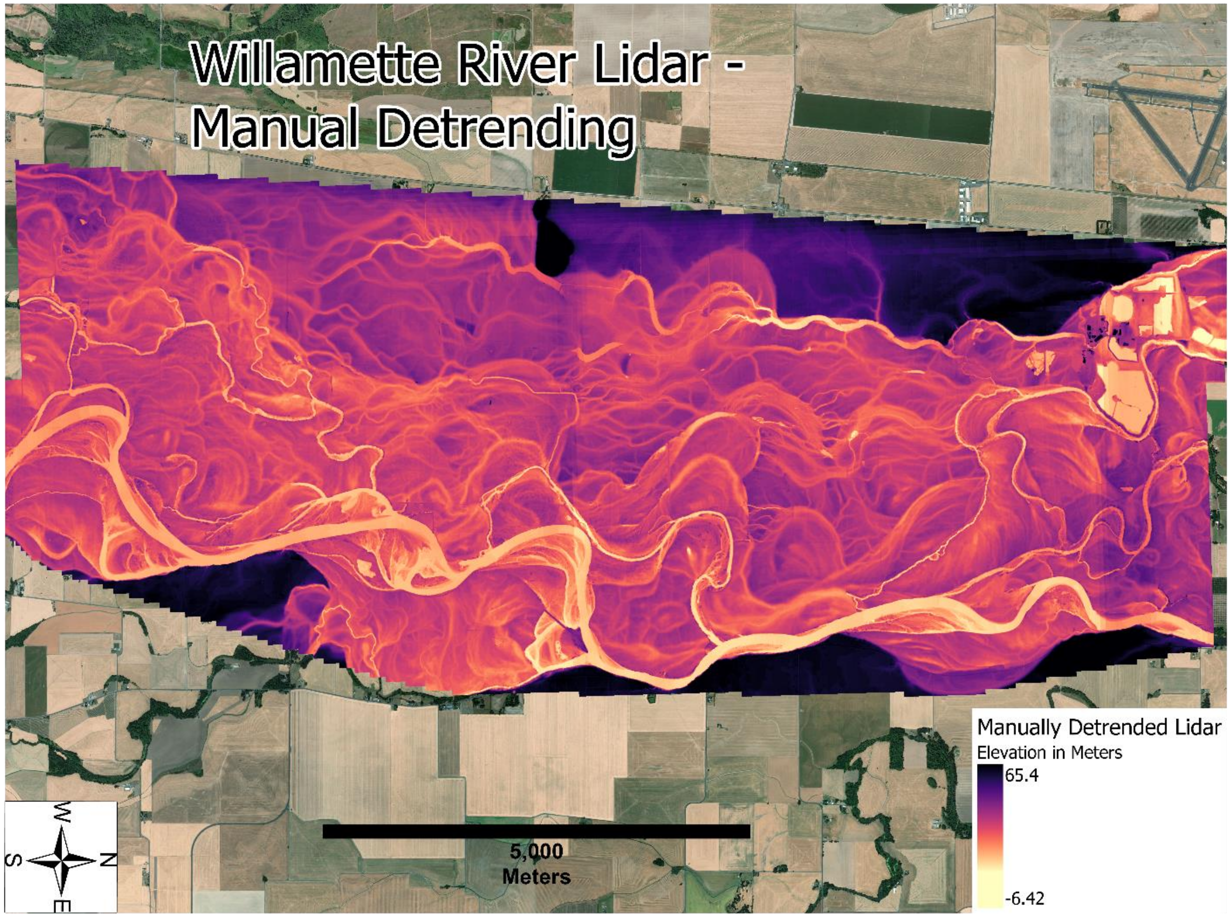

Figure 7: Manually Detrended LiDAR

Figure 8 below shows the results of using the fishnet tool to draw transects for sampling elevations in the bathymetry-supplemented LiDAR raster.

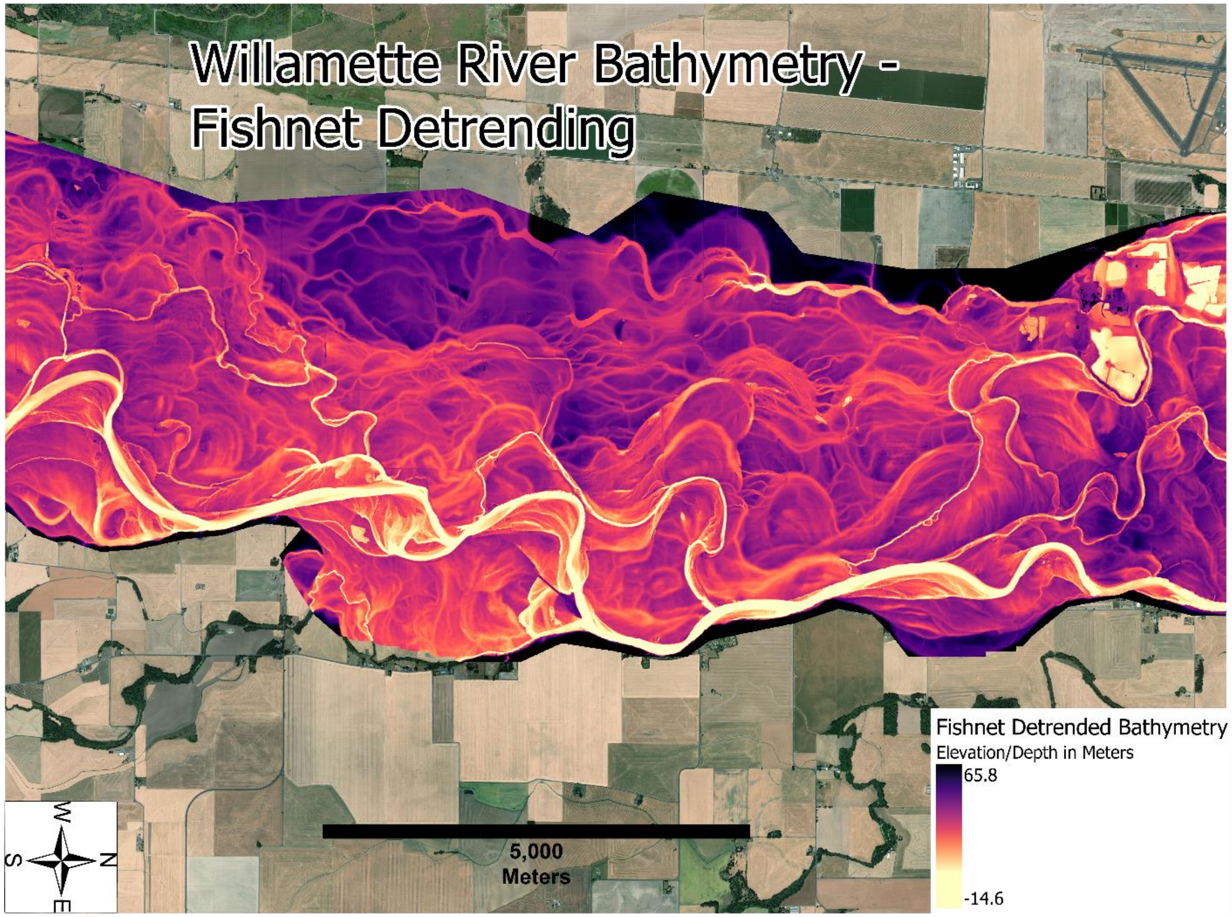

Figure 8: Fishnet Detrended Bathymetry

Figure 9 below shows the results of using the fishnet tool to draw transects for sampling elevations in the LiDAR raster.

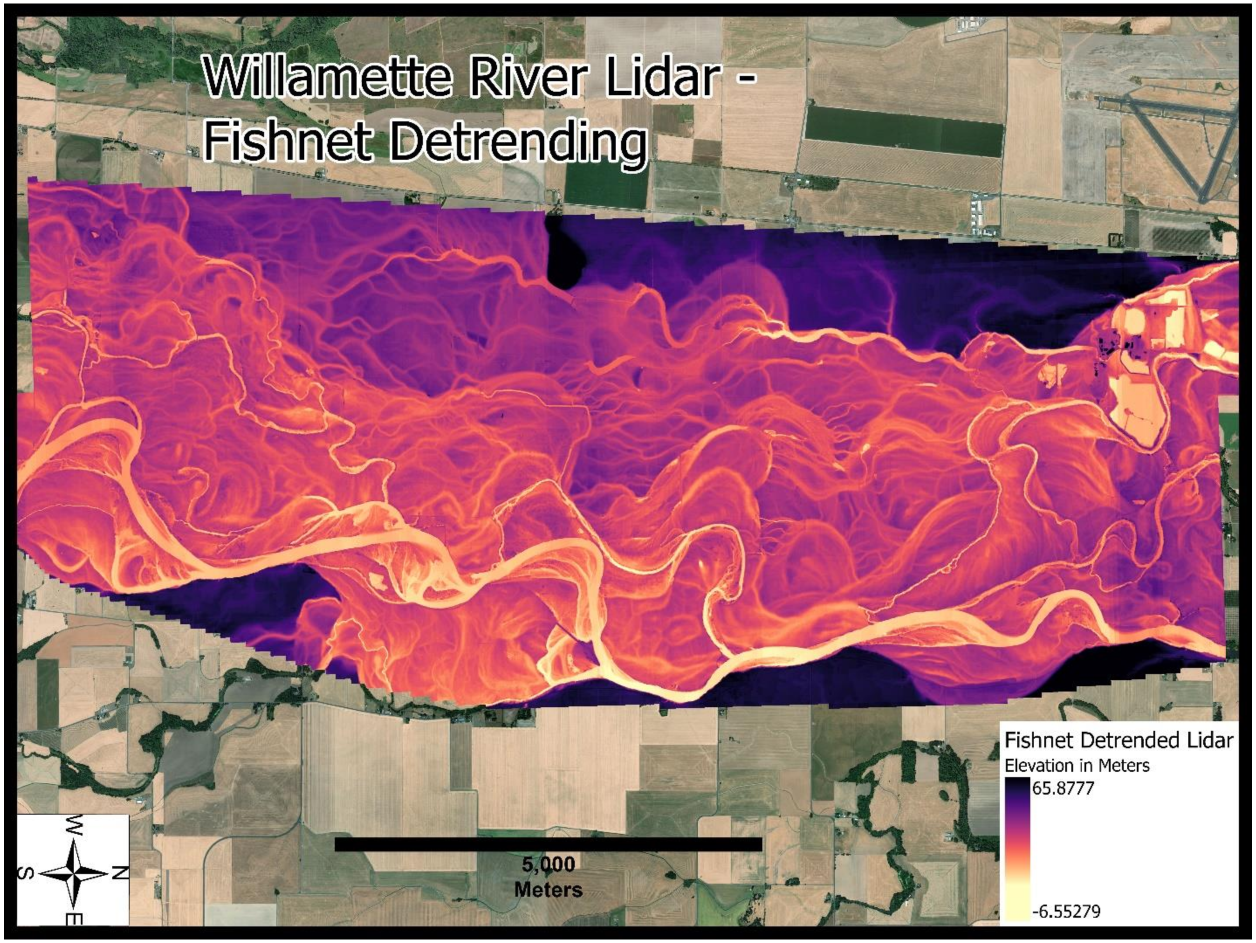

Figure 9: Fishnet Detrended LiDAR

Figure 10 below shows the results of using the hybrid transects for sampling elevations in the bathymetry-supplemented LiDAR raster.

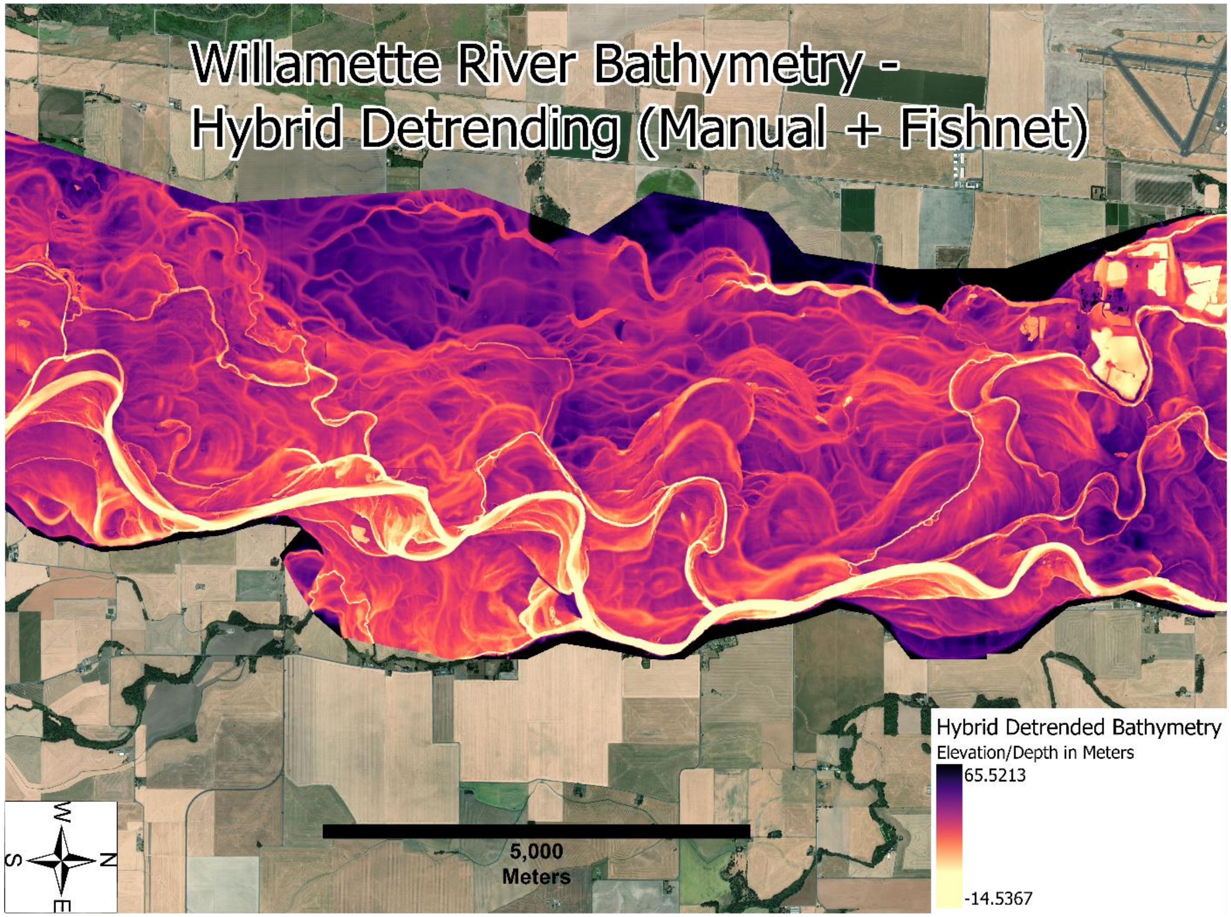

Figure 10: Hybrid Detrended Bathymetry

Figure 11 below shows the results of using the hybrid transects for sampling elevations in the LiDAR raster.

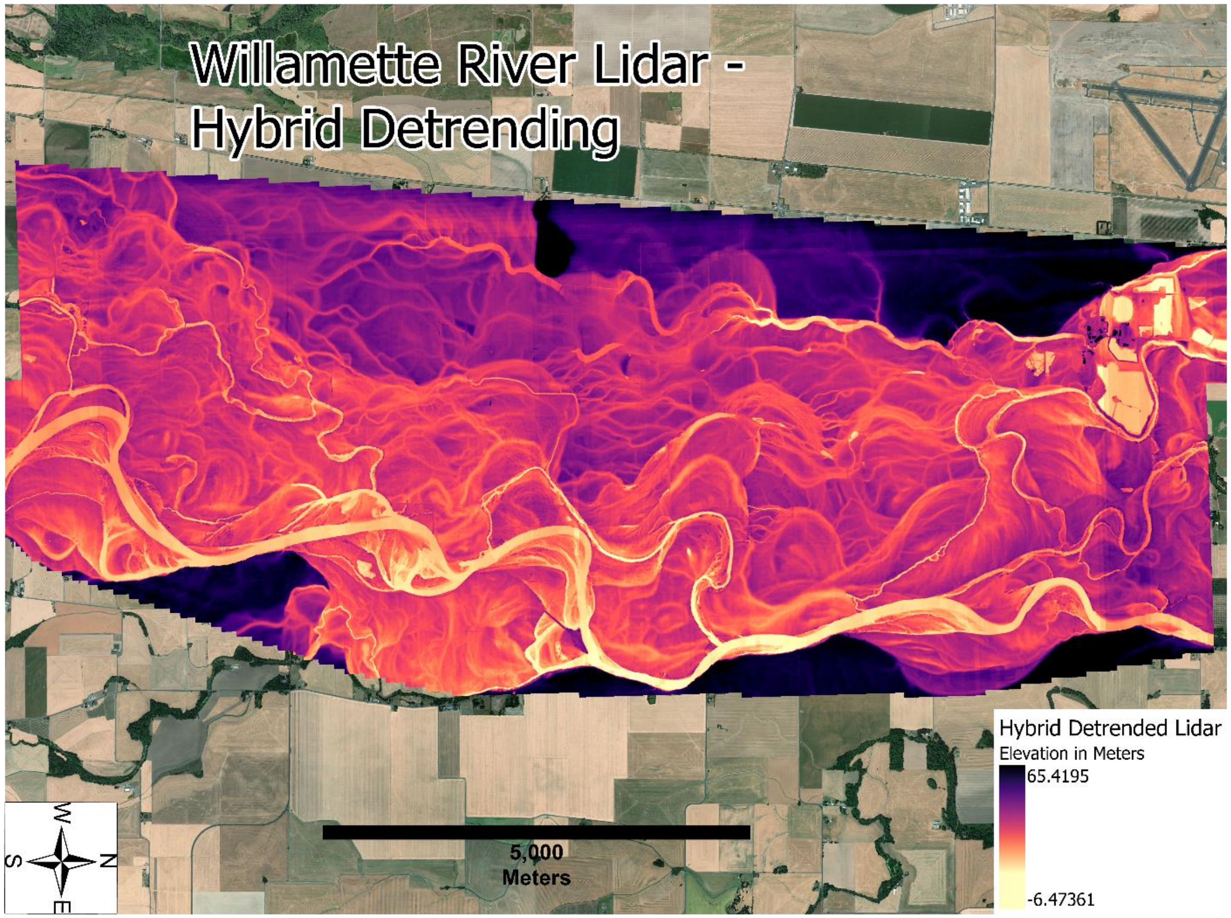

Figure 11: Hybrid Detrended LiDAR

Figure 12 below shows a visual comparison of the different results for the bathymetry-supplemented LiDAR raster.

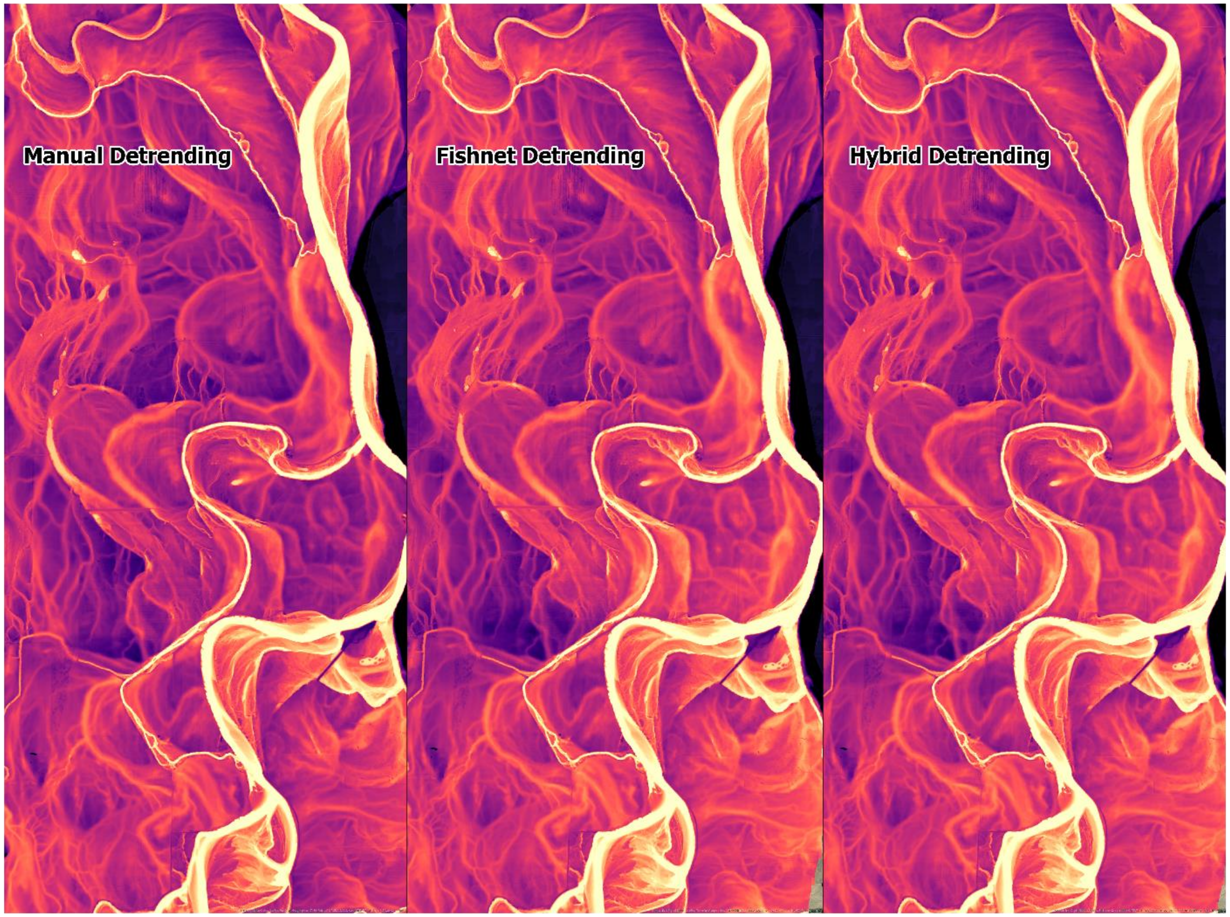

Figure 12: Results Comparison for Bathymetry

Figure 13 below shows a visual comparison of the different results for the LiDAR raster.

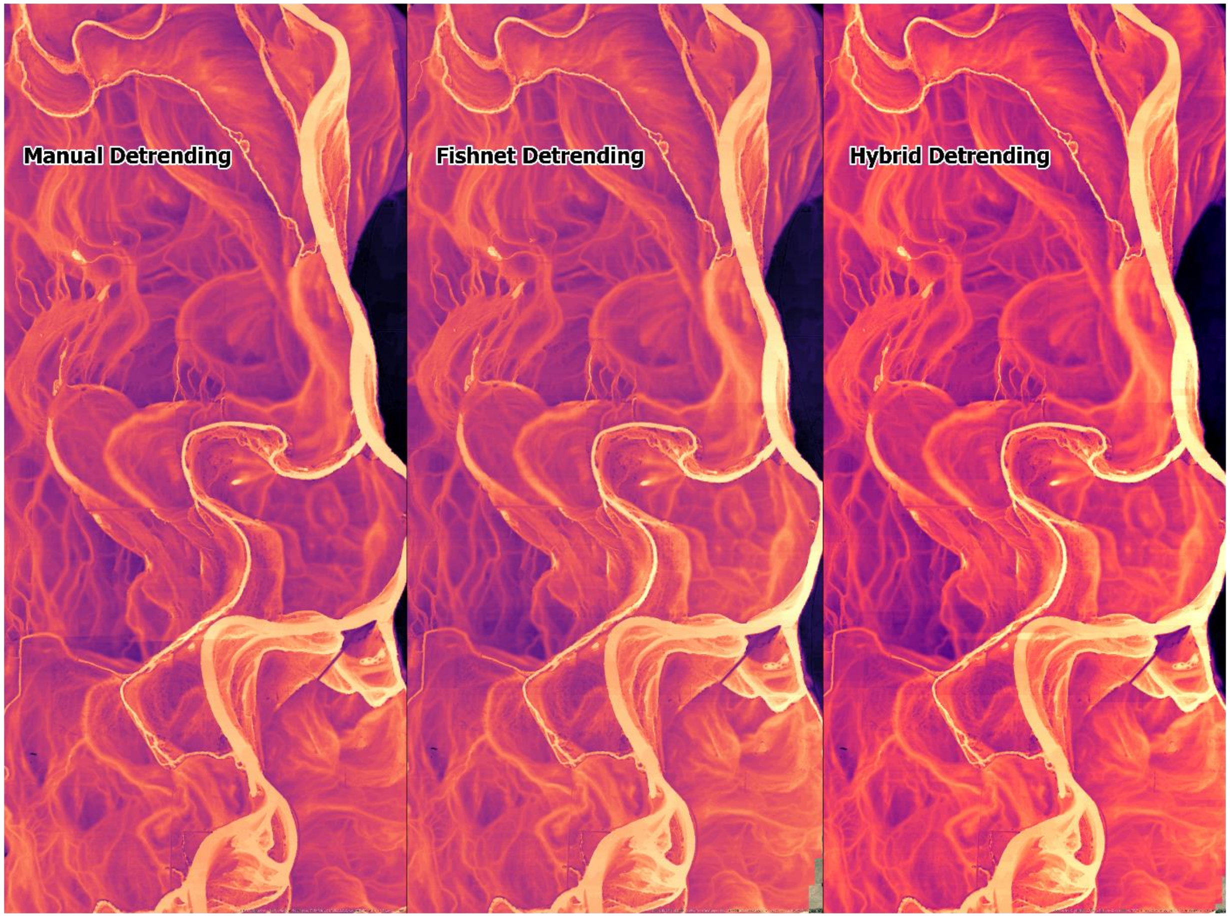

Figure 13: Results Comparison for LiDAR

Figure 14 below shows the absolute difference between the results from each elevation sampling method for the bathymetry-supplemented LiDAR raster.

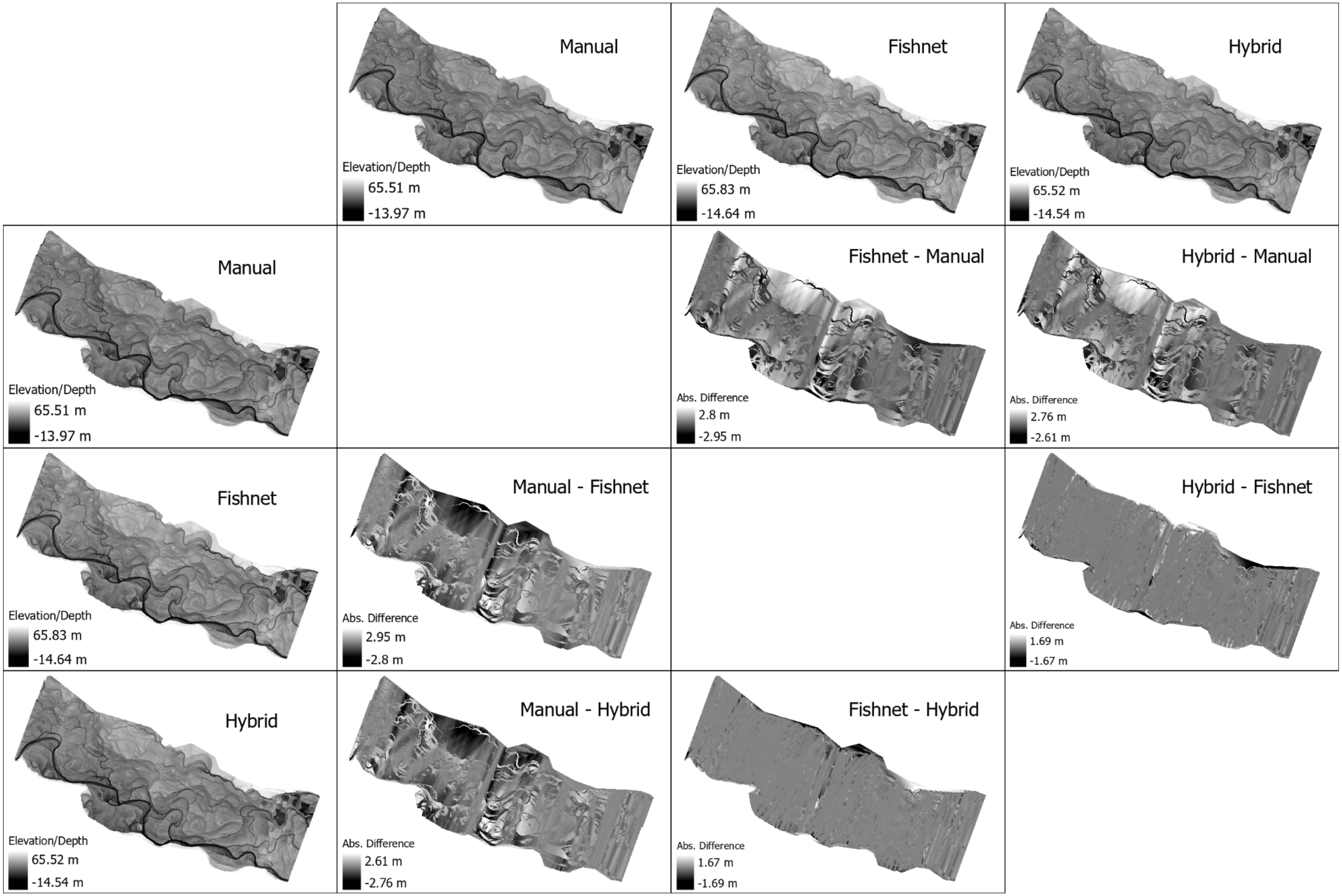

Figure 14: Absolute Difference Between Methods

Discussion:

Of the three methods, I believe the fishnet method produced the smoothest end results (**Figures 8 & 9)**. I believe this was due to the fact that the transects were drawn at very precise and relatively short intervals, whereas the manually drawn transects were generally unevenly spaced. The results of the manual method visually appear somewhat smooth (**Figures 6 & 7**), but closely comparing the results with the other two methods shows that the results are somewhat coarse, with steep gradations (**Figures 12 & 13)**. The results from the hybrid transects took most of the characteristics of the fishnet transects (because they are so evenly and tightly spaced) and the overlapping manually drawn transects practically just add noise to the results (**Figures 10 & 11**). I believe having a smoother surface such as the results of the fishnet method is ideal, though I found myself wondering if the results would be more impactful if there were a way to draw tight, evenly spaced transects along the centerline of the river that cover the floodplain without the transects overlapping. This is something that I would like to touch on in a later study.

The absolute difference between the results of each method were interesting to analyze. In **Figure** 14 I chose to show the differences between each method in a grid so they could be easily compared. You can see that overall, there is a difference between ≈ 3 and ≈ -3 meters between methods. The results from the hybrid method and the fishnet method have the least amount of difference, due to there being more areas of overlap. I was originally confused by the results because I was expecting the difference to be something like the max value from one dataset subtracted from the max value of the other dataset and the same thing with the minimum values. It eventually dawned on me that the results are spatial, so the lowest pixel value in one raster may not overlap with the lowest pixel value in another, so you get situations where one method guessed high for one cell and another method guessed low, resulting in greater variance. I didn't create a figure comparing the difference of the LiDAR results because I assumed they would show essentially identical patterns.

Moving forward, I would like to develop a detrending toolbox built in ArcGIS and share it so that people can perhaps automate the process in some way. I would also like to experiment with other elevation sampling methods, perhaps using contours? **Figure 15** below shows my final photoshopped image.

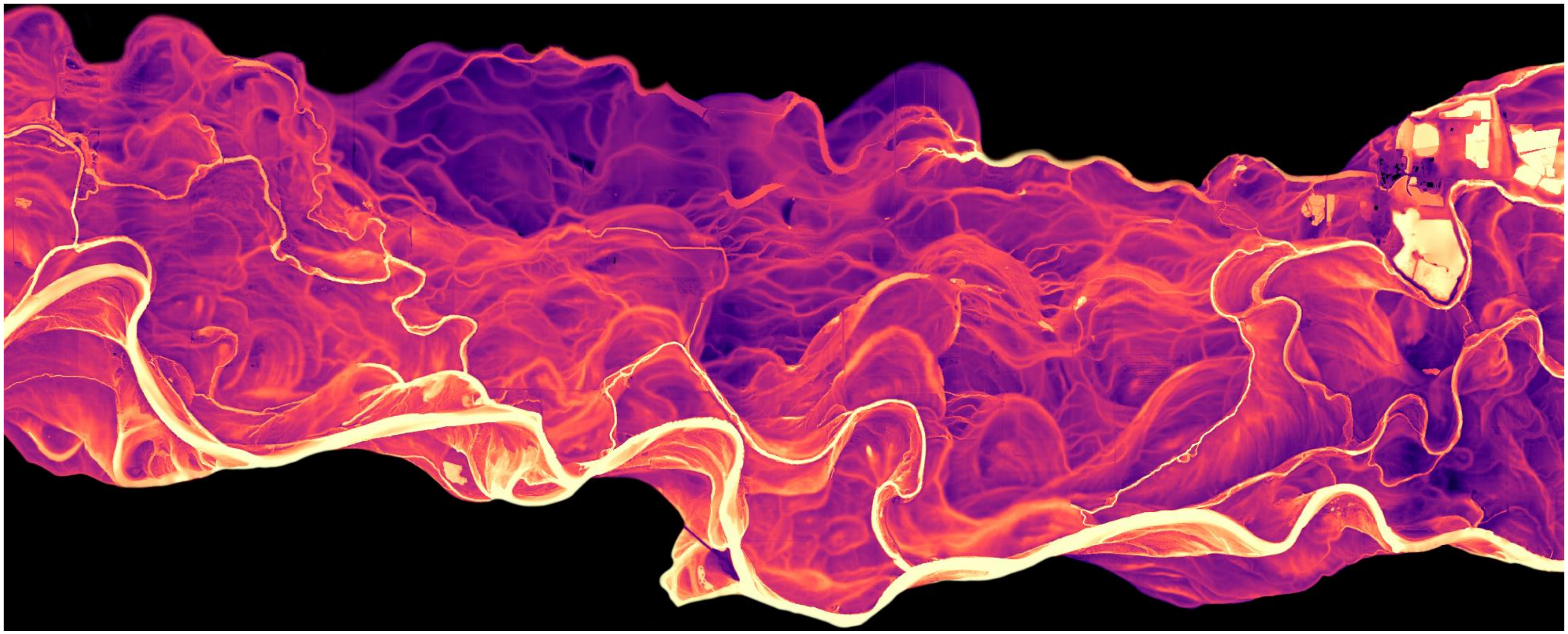

Figure 15: Detrended Willamette River Floodplain - Peoria, OR - Bathymetry-Supplemented LiDAR

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