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# Developing detrended river corridor maps for habitat restoration using the Geomorphic Grade Line (GGL) tool

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## SHR-COE Technical Bulletins

Technical Bulletins are published by the Salmon Habitat Restoration Center of Expertise (SHR-COE) in Pacific Region as a means of disseminating technical information, guidelines, and workflows relevant to restoration practitioners.

This bulletin describes the workflow for applying the Geomorphic Grade Line tool[1], which is a GIS-based method that removes the underlying gradient from elevation data to produce detrended river corridor maps. The resulting maps can be used in the strategic planning and design of process-based stream restoration projects.

## Introduction

Process-based approaches to stream restoration are increasingly recognized as effective strategies for addressing geomorphological and ecological limitations in degraded and incised river channels. These approaches rely on identifying and characterizing the natural system processes to support strategic planning and design of projects that will achieve long-term, self-sustaining outcomes. A useful tool for such projects is the Geomorphic Grade Line tool (GGL, Powers et al. 2018). The tool works by removing the underlying longitudinal gradient of the river corridor from topographic data (and bathymetry, if available) captured in a digital elevation model (DEM). This action effectively *de-trends* the landscape while retaining the relative elevation of key corridor features to produce a

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[1] https://github.com/pausoto7/GGLREM-Pro-V3.0

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*relative elevation model* (REM). Herein, the term river corridor refers to the channel, floodplain, and other physiographic features of interest (Nelson et al. 2023).

The resulting REM product can be used to support a range of restoration applications such as

- evaluating the spatial extent of channel incision within floodplains
- designing Stage-0 projects
- identifying relic floodplain features for natural reactivation
- delineating historical off-channel habitat which may not currently be accessible to fish
- locating barriers to lateral connectivity and floodplain access
- siting low-tech process-based restoration (LTPBR) projects such as beaver dam analogues or post-assisted log structures
- supporting the development of final grading plans for project construction

The GGL tool offers a flexible approach to developing detrended river corridor maps; however, users should be aware of data and processing requirements to generate satisfactory results and limitations of the approach. These caveats are discussed in more detail throughout the text. This document assumes a basic working knowledge of ArcGIS Pro and common GIS functions.

# Input Data & Technical Requirements

## Input Data

The DEM is the most important piece of input data. The GGL tool will work with most data resolutions, however, a high resolution DEM such as that developed from LiDAR will provide the best results. Note that the DEM should be cropped[2] to match the approximate river corridor boundary prior to performing this analysis. Additionally, the DEM should be inspected for negative values or outliers and corrected as necessary. Negative values are common if part of the DEM intersects with tidal areas. If the cropped area is too large (e.g. 50 km$^2$ for a high-resolution DEM) or negative values are present in the DEM, the GGL tool may crash.

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[2] https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/clip.htm

## Computational Requirements

Computational requirements to develop a REM using the GGL toolset are at least 6 GB of RAM, a processor with minimum 4 cores, 4 GB of graphics memory, and at least 32 GB of free storage space. Depending on the size and resolution of the dataset to be analyzed, processing time can be substantial.

The tool requires ArcGIS Pro software with the Spatial Analyst extension enabled. Familiarity with the ArcCatalog, Toolbox, and Editor features within ArcGIS Pro is recommended. Guidance on the use of these features can be found through the ArcGIS Pro help webpages[3]. To undertake the analysis described herein, the *GGLREM Pro* toolbox[1] (Helstab and Hornby, 2024) must be downloaded and de-compressed to a suitable folder location. Once decompressed, the tools will be accessible within ArcGIS Pro by opening the Catalog window and navigating to the designated folder. It may be necessary to expand the red toolbox icon to view the tools, which will appear as shown in Figure 1. Upon successful decompression and confirmation of tool access within ArcGIS Pro, the procedure can begin.
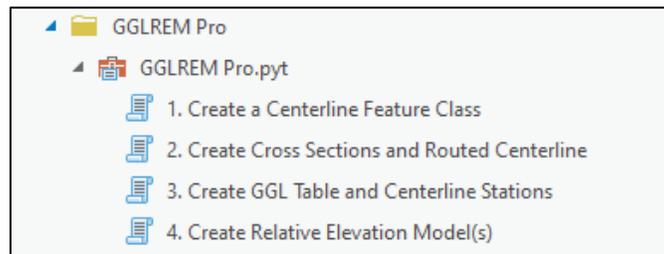


*Figure 1. List of GGLREM Pro functions as shown in ArcCatalog.*

# Model Development

## Getting Started

Within ArcCatalog, a folder and geodatabase should be created to store and organize all files associated with the workflow. Alternatively, the default database provided by ArcGIS Pro may be used. As generating an REM can be an iterative process, it is advisable to create a new geodatabase for each iteration. This approach helps ensure the output files remain organized and clearly indicates from which iteration each file originates.

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[3] https://pro.arcgis.com/en/pro-app/latest/help/main/welcome-to-the-arcgis-pro-app-help.htm

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For the purposes of this guidance document, the working folder location will be a hypothetical project folder named *Tranquille_Fan_V0.1*. Within this folder, create a subfolder and geodatabase with informative titles. In this case they are named, respectively, *GGL Outputs 100m* and *GGL_Outputs_100m.gdb*. The "100m" notation was chosen in this case as it indicates the distance from the centerline of the river corridor over which the analysis will occur. Any distance appropriate for the study area can be chosen. The resulting folder structure is shown in Figure 2.
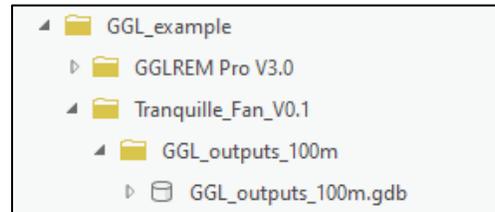


*Figure 2. Example folder structure for a GGL project. Note that the GGLREM Pro package is contained within the project folder.*

To begin, upload the DEM of the study site to the project folder and then set the DEM's symbology[4] to clearly illustrate the river channel(s), if not already visible with the default settings. Although not mandatory, generating a hillshade[5] of the input DEM (Figure 3) can facilitate the delineation of the channels and floodplain centerline.



*Figure 3. Hillshade of the input DEM for analysis. Hillshades can be helpful for visualizing features based on topographic relief.*

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[4] https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/symbology-pane.htm
[5] https://pro.arcgis.com/en/pro-app/3.3/help/analysis/raster-functions/hillshade-function.htm

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## Processing Steps

The necessary steps required to generate an REM from a DEM using the GGL procedure are illustrated in Figure 4 and outlined in sequential steps below. Note that the steps must be followed in order.
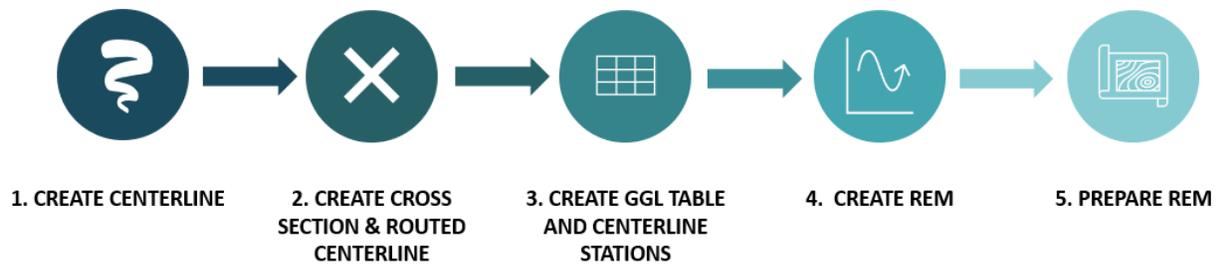


1. CREATE CENTERLINE  2. CREATE CROSS SECTION & ROUTED CENTERLINE  3. CREATE GGL TABLE AND CENTERLINE STATIONS  4. CREATE REM  5. PREPARE REM

*Figure 4. Sequence of steps for creating a relative elevation model from a digital elevation model using the Geomorphic Grade Line tool. Note that the steps must be followed in order.*

## 1. Create Centerline

**1.1** Open the **1. Create a Centerline Feature Class** tool by selecting it in the Catalog window and entering the required parameters to run the tool (Figure 5). Upon successful completion, a feature class named *Centerline_xxx* should appear in the Contents panel on the left. If it does not appear, check the geodatabase to confirm whether the feature class was created but not automatically added to the map.
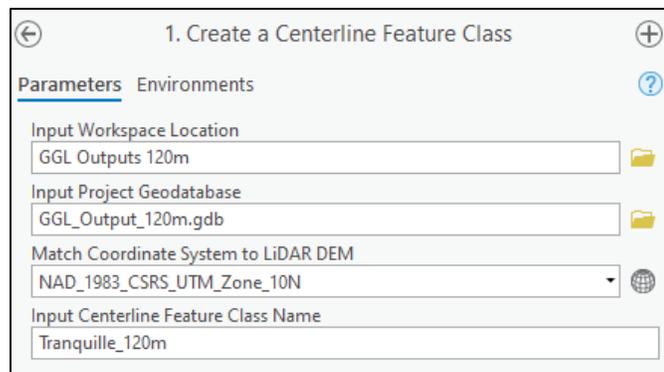


*Figure 5. Input parameters for Step 1 of the GGL process,* Create a Centerline Feature Class*.*

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**1.2**  Digitize a polyline that follows the river within the newly created feature class. This process requires creating and editing[6] a new feature following these steps in sequence:

**1.3**  Navigate to the **Edit** tab and click **Create**.

**1.4**  Under the **Create Features** tab, select the *Centerline* feature class from the list on the right.

**1.5**  Create a line feature by roughly tracing along the river system. The initial iteration does not need to trace over the river exactly. The goal is to capture the approximate center of the floodplain. This step may need to be repeated several times as it often takes numerous iterations, along with review and field verification, to produce the best possible output for the coverage area.

**1.6**  Once complete, click the square icon with the green check mark to finalize the digitized line.

**1.7**  Click the purple **Save** icon on the left side of the **Edit** tab to save the work. The resulting map should resemble the example in Figure 6.
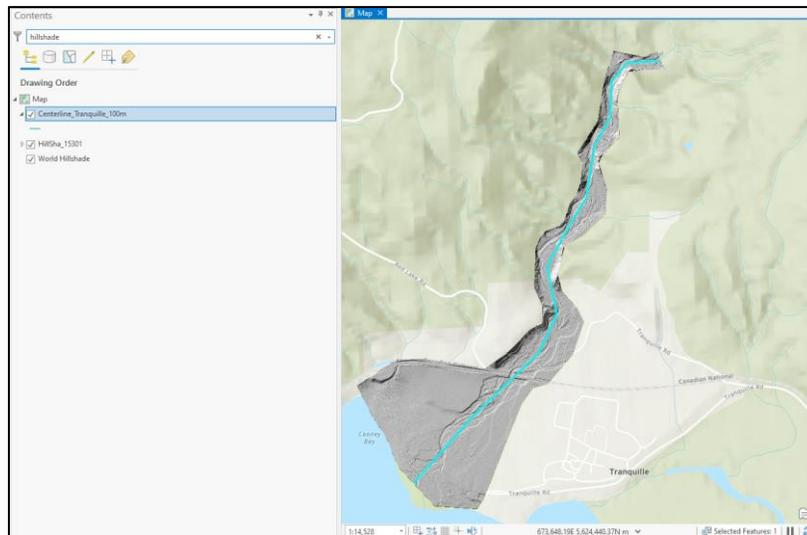


*Figure 6. Example centerline overlaid on the DEM to be detrended.*

**1.8**  With the Centerline Feature Class saved, open the corresponding attribute table[7] (Figure 7) and assign a *RouteID* name specific to the project. In this example, the *RouteID* is named *Tranquille_Fan.*

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[6] https://pro.arcgis.com/en/pro-app/latest/help/editing/get-started-editing.htm
[7] https://pro.arcgis.com/en/pro-app/latest/help/editing/edit-feature-attributes.htm

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*Figure 7. The attribute table for a digitized centerline. The highlighted "ROUTEID" cell must be edited and
then saved.*

**1.9**   Confirm that the *RouteID* metadata are saved by selecting the purple ***Save*** icon; otherwise it
will result in an error during Step 2.

## 2.   Create Cross Sections and Routed Centerline

**2.1**   Select the ***2. Create Cross-Sections and Routed Centerline*** tool from the GGLREM Pro
functions list in ArcCatalog (Figure 1). Input appropriate information into the tool (Figure 8).
Note that it does not matter in what direction the procedure is initiated.



*Figure 8. Input parameters for Step 2 of the GGL process,* Create Cross Sections and Routed Centerline*.*

**2.2**   After running Step 2, the map and Contents pane should resemble Figure 9. Note the creation
of new outputs in the Contents pane.

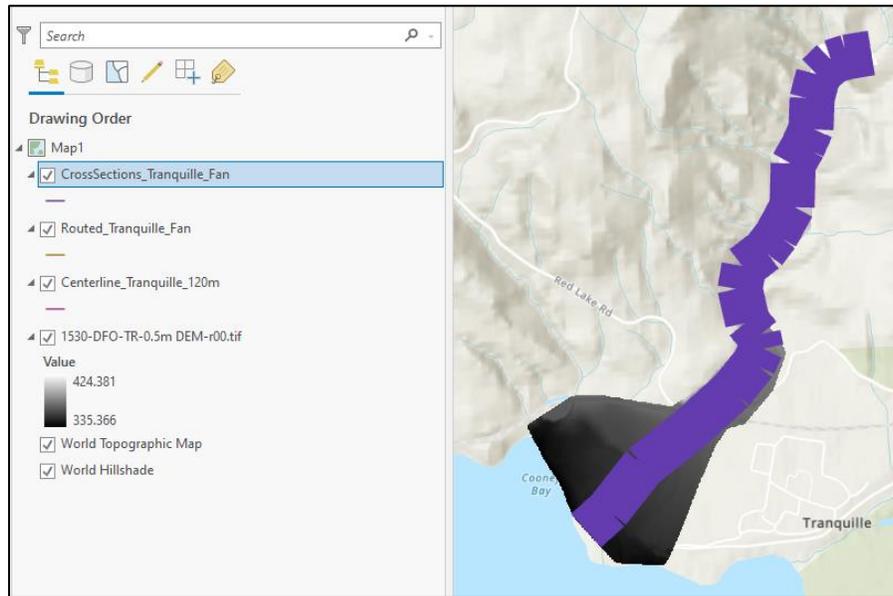**Salmon Habitat Restoration Technical Bulletin Series**



*Figure 9. Example output following Step 2 of the GGL process. The purple shaded area shows where the cross-sections have been created. The REM will be created where the cross-sections and original DEM overlap.*

## 3. Create GGL Table and Centerline Stations

**3.1** Open up tool **3. Create GGL Table and Centerline Stations** from ArcCatalog and select **No** under buffer distance.

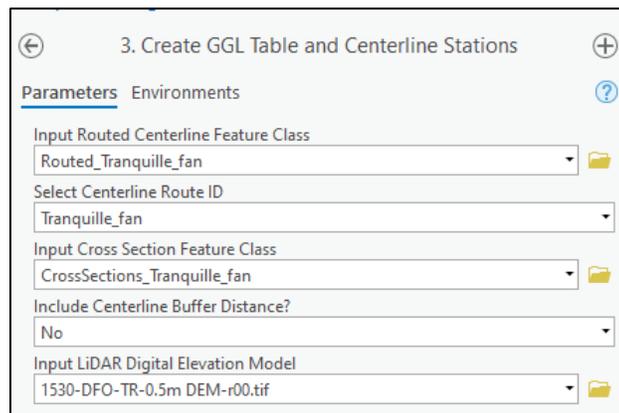**3.2** Complete the input parameters according to the details in Figure 10 and proceed with running the tool.



*Figure 10. Input parameters for Step 3 of the GGL process,* Create Table and Centerline Stations*.*

**3.3** The map and contents pane should resemble Figure 11. If the offset distance from centerline extends past the DEM, the cross section should be clipped to the DEM's extent.
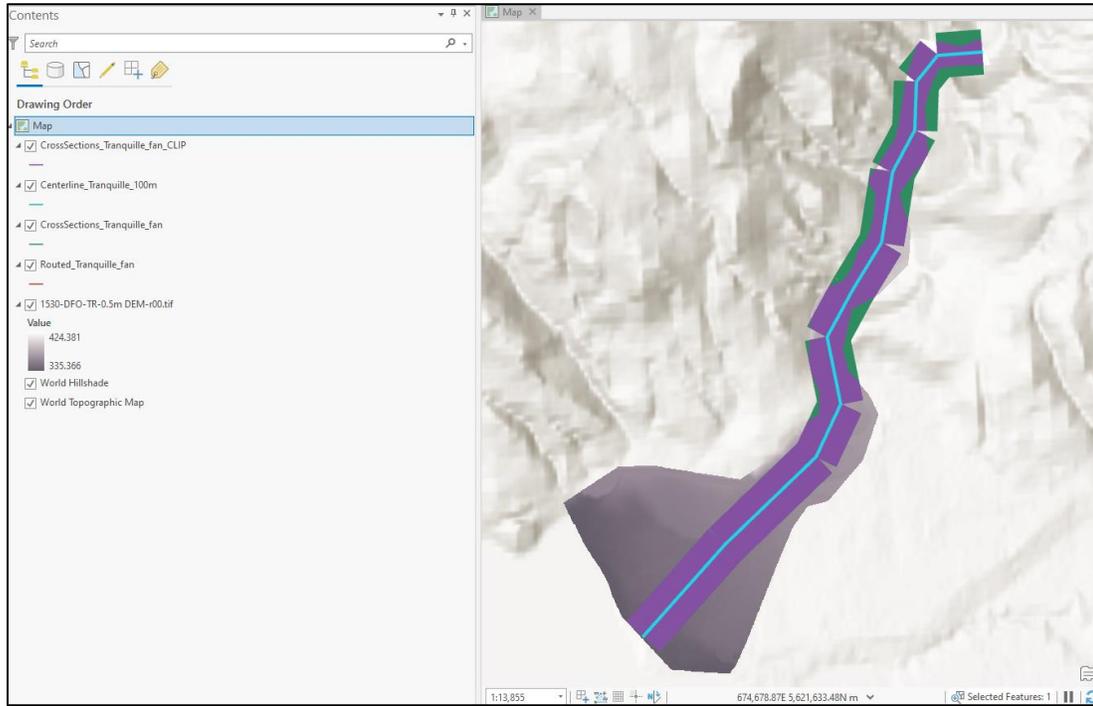


*Figure 11. Example output from Step 3. Note how the cross-sections (purple) have now been cropped by the underlying DEM.*

## 4. Create Relative Elevation Model

**4.1** Open the CSV file that was created in the working directory. A table should appear displaying seven columns, five of which correspond to different "fit" options for the detrended centerline. The task at this stage is to evaluate which model fit is most appropriate.
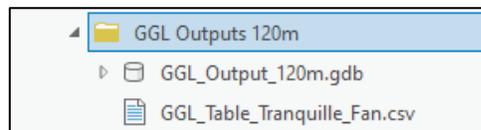


*Figure 12. File structure showing location of CSV file within it.*

**4.2** To assist in this evaluation, create a scatter plot with *Location* set to the x-axis and *Lidar* as the y-axis. Each linear and polynomial profile can then be compared against the original land surface for best fit (Figure 12).

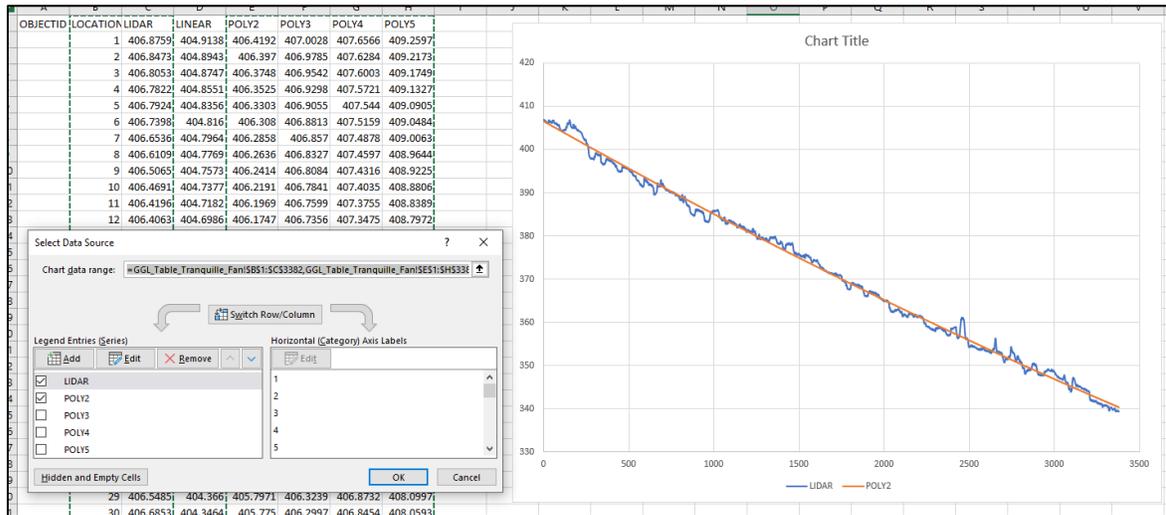**Salmon Habitat Restoration Technical Bulletin Series**



*Figure 13. Example output of an elevation profile and different model fits generated in Excel. Plotting different model fits allows comparison to decide which is most appropriate for the application.*

**4.3** Choosing the appropriate model to construct the REM is enhanced with knowledge of historical land features and by comparing the linear and polynomial plots. The hillshade map in ArcGIS Pro may provide additional insight into which features are most important to capture. In cases where the river corridor does not exhibit a consistent gradient, a low-order polynomial fit may be preferable to represent broader-scale curvature in the elevation profile. If major breaks in gradient are observed, it may be necessary to divide the river corridor into segments with more uniform or gradually changing gradients.

**4.4** After selecting the appropriate value/model for constructing the REM, complete the remaining fields with the appropriate parameters (Figure 13) and then run step 4. If any cross-sections extend beyond the bounds of the original DEM, it is essential to select the CLIP cross section feature class to avoid processing errors.

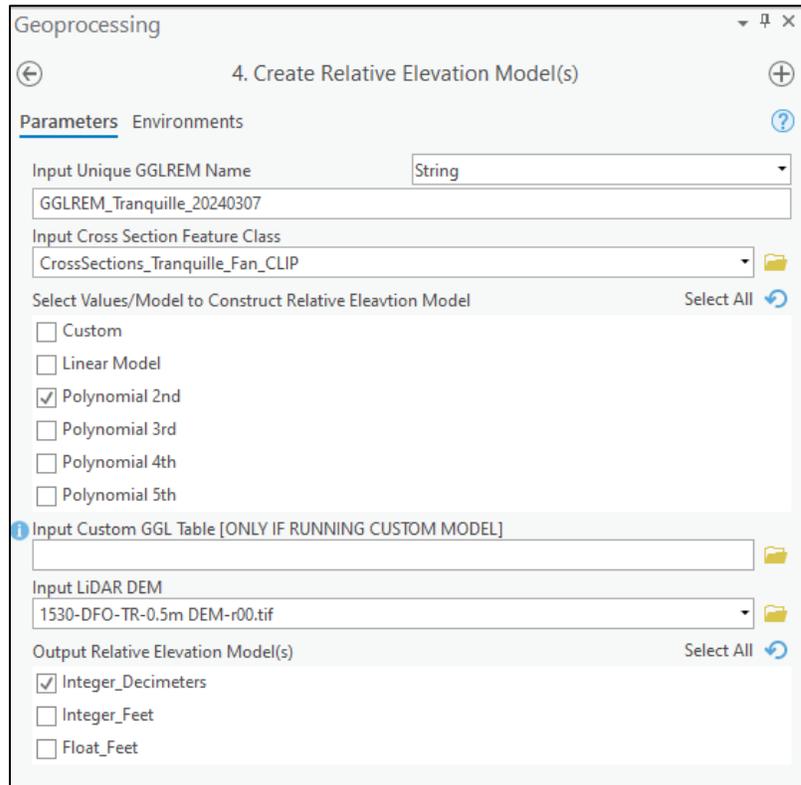**Salmon Habitat Restoration Technical Bulletin Series**



*Figure 14. Input parameters for Step 4 of the GGL process,* Create Relative Elevation Model(s)*.*

**4.5** The resulting DEM should open automatically upon completion. If not, this may be due to a change in the active map during script execution. To manually open the DEM, select the file corresponding to the REM unit that was previously specified. The resulting map should resemble the example in Figure 14.

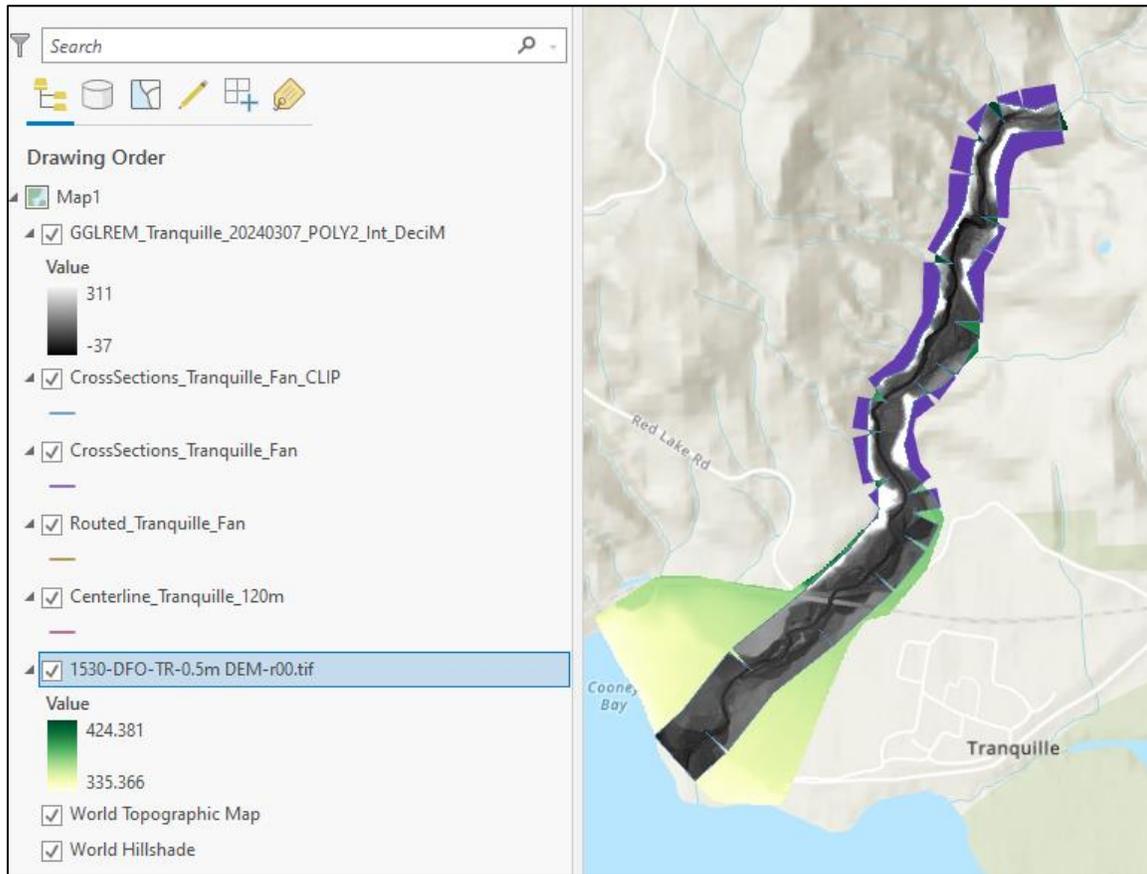**Salmon Habitat Restoration Technical Bulletin Series**



*Figure 15: Example output from Step 4 of the GGL process. The dark shaded area corresponds to the newly created REM.*

## 5. Prepare REM for Use

**5.1** To improve interpretation of the REM, adjust the symbology to highlight topographic variation. A symbology scheme similar to the example in Figure 15 is recommended as it effectively distinguishes areas above and below 0 m elevation.

**5.2** The REM is now ready for use. It can be exported from ArcGIS Pro[8] as a standard raster file (.tif) for use in other GIS software and can be used within ArcGIS Pro to produce high-quality maps.

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[8] https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/export-or-convert-raster-datasets.htm#:~:text=Right%2Dclick%20on%20the%20raster,then%20click%20Data%20%3E%20Export%20Raster

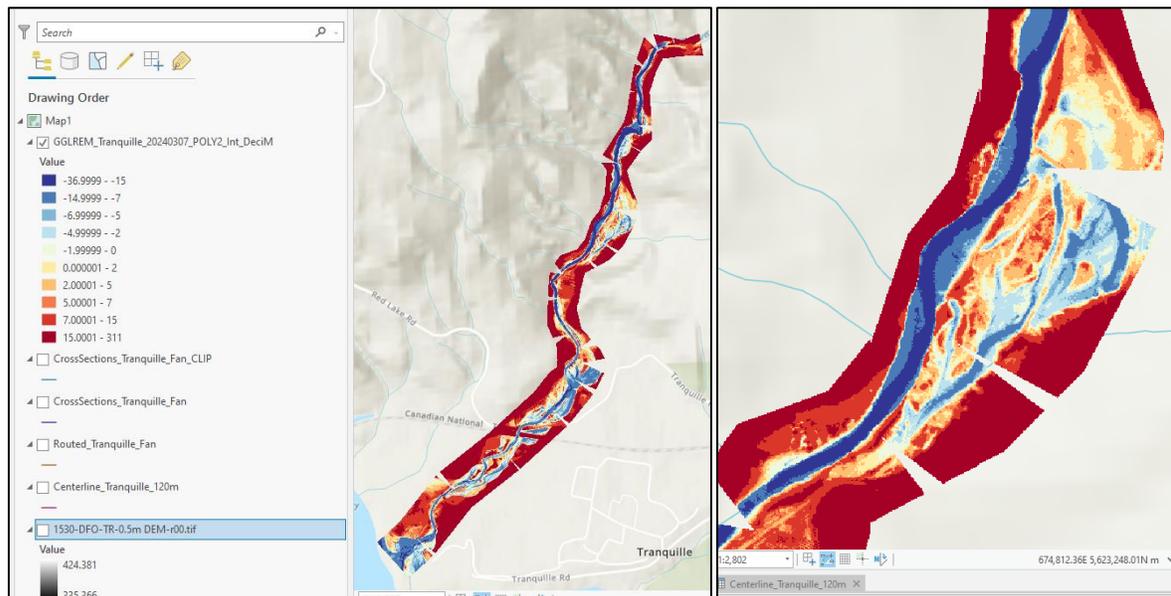**Salmon Habitat Restoration Technical Bulletin Series**



*Figure 16. REM with adjusted symbology to enhance visualization of relative elevations along the river corridor.*

## Interpretation

The REM effectively represents the surface elevation within the river corridor relative to the digitized centerline. Negative values correspond to areas lower than the centerline such as parts of the main river channel and off-channel habitats. Positive values represent areas above the centerline such as elevated floodplain features. Once a satisfactory REM has been generated, it can be used to support a range of restoration applications, such as those listed in the Introduction.

## Limitations of the approach

There are several limitations to applying the GGL tool that users should be aware of. First, the utility of the REM will largely be a function of the quality of the input data, and also the sinuosity and complexity of the surface to be detrended. More complex river corridor geometries can lead to small missing segments in the REM, especially on floodplain areas adjacent to sharp outer bends. Additionally, many iterations of the tool execution may be necessary to fine tune the appropriate elevation model and the resulting outputs are sensitive to the input parameters, especially the model fit used. Lastly, as with any desktop analysis, field verification is critical before moving ahead with further analyses.

# Concluding Remarks

The GGL tool provides a flexible approach for generating REMs from standard DEMs of river corridors and has value in supporting various habitat restoration objectives. The GGL tool provides distinct advantages in terms of flexibility, particularly the ability to select multiple models and adjust the centerline geometry. This flexibility, however, often necessitates iterative refinements to achieve optimal results. Field verification, historical analysis, and complementary lines of evidence should be consulted prior to undertaking any subsequent work based on REM outputs.

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