**Automated Web-Based Relative Elevation Model Generator**

User Manual

A map of a river

AI-generated content may be incorrect.

Figure 1: Snake River running out of Grand Teton National Park. Created from a 1-meter resolution Digital Elevation Model and National Hydrography Dataset river centerlines.

Version 1.0

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# Introduction

This software was created on behalf of Kleinschmidt Associates for the Professional Science Masters program at the University of Utah. Encompassed in this software is a User Interface, web-based system that allows a user to select an area of interest on a map, download Digital Elevation Models (DEMs) and National Hydrography Dataset (NHD) river centerline data, and compute Relative Elevation Models (REMs) based off the data gathered. This software allows the user ease of use and efficiency of computing REMs without having access to Geospatial software. The software allows for the user to input their own DEM and river centerline data as well for REM computation. A geotiff of a REM and colorful PNGs with scale bars (if selected) are also produced for the user. A comprehensive manual and descriptions of outputs/concepts are detailed below.

## 1.1 Relative Elevation Model

A Relative Elevation Model (REM) is a specialized terrain representation that shows the elevation of every location relative to the nearest river or stream, rather than relative to sea level like traditional elevation models.

## 1.2 DEM vs REM

A Digital Elevation Model (DEM) shows elevation above sea level compared to a REM which is relative to the nearest river/stream. DEMs are useful for regional topography whereas REMs are useful for floodplain analysis, habitat analysis, and public planning around rivers. The reason DEMs are not used alone for floodplain analysis compared to REMs is due to DEMs having difficulty identifying low-lying flood prone areas. Since DEMs are mainly used for regional analysis, REMs highlight flood prone areas, terraces, and disconnected channels easier and make them useful for floodplain analysis.

A map of a river

AI-generated content may be incorrect.A satellite image of a black rectangle

AI-generated content may be incorrect.

## 1.3 How to read REM values

When analyzing a REM, 0 meters is at river level (active channel). 1-2 meters are typically low floodplains, where 2-5 meters are considered high floodplains and terraces. 5-10 meters are seen as valley margins. Negative values are areas that are found below the river reference, which can be deep pools, tributary confluences, disconnected channels, etc.

## 1.4 Why REMs Are Useful?

REMs make it easier to identify and map areas that are topographically connected to rivers such as floodplains. This is critical for these areas of concern:

* Flood Risk Assessment: Quickly identify areas vulnerable to flooding
* Habitat Mapping: Delineate wetlands, floodplains, and riparian zones
* River Restoration Planning: Identify potential restoration sites and reconnect floodplains
* Infrastructure Planning: Assess risk to roads, buildings, and utilities near rivers
* Geomorphic Analysis: Study channel migration, terrace formation, and valley evolution

Instead of looking at absolute elevations which can be confusing in mountainous terrain, REMs provide an intuitive view of the landscape from the river’s perspective.

## 1.5 Software Capability

The Automated Web-Based Relative Elevation Model Generator streamlines the creation of high-quality REMs for any river in the Continuous United States and Alaska. What used to take hours of manual GIS work, downloading data, and deciphering data can now be done in minutes through an automated, web-based interface. The software consists of several capabilities: Automatic Data Retrieval, Interactive Map Selection, Manual Data Upload Option, Automated REM Calculation, Professional Outputs, Customizable Visualization, Quality Assurance, different ways to run, and processing speed.

### 1.5.1 Automatic Data Retrieval

Downloads of USGS DEM tiles are automated and require no need for the user to manually download, clip, and mosaic DEM tiles together. River centerline data is automatically collected from the National Hydrography Dataset, clipped, and combined line segments together if needed. This system requires no need for the user to search for data on either government website and manually change it, the software handles everything for the user.

### 1.5.2 Interactive Map Selection

The software allows users to draw an area of interest directly on an interactive map and check for DEM resolutions as well. Once the area of interest is drawn, the user is able to scan for DEM resolutions and rivers within the area and select multiple different DEM resolutions and rivers as needed. The software also handles all coordinate system transformations automatically so the data is always projected correctly for REM calculations later down the pipeline.

### 1.5.3 Manual Data Upload Options

If the user has their own DEM data and river centerline data, the software can handle it. Upload the DEM (Geotiff format), upload the river centerline (shapefile, geopackage, geoJSON), then click run. The coordinate system of the DEM will be used if the two datasets are of different coordinate systems. If the coordinate system vertical data is not in meters, the EPSG 5070 CONUS Albers Equal Area CRS will be used. A warning in the software will flash if this is the case and explain the upcoming CRS transformations for REM calculations.

### 1.5.4 Automated REM Calculation

Once DEM and river centerline data is inputted and specific parameters (which will be explained later), the software will automatically calculate the REM by following these steps:

* Samples elevations along the river centerline
* Smooths river profile to remove noise and bridges
* Interpolates river elevation surface using Inverse Distance Weighting (IDW)
* Subtracts interpolated river surface from DEM to create REM

### 1.5.5 Professional Outputs

Once the REM calculations are final, a professional geotiff (.tif) is produced which is a georeferenced raster for use in ArcGIS, QGIS, or other GIS/Hydraulic software. High quality PNGs (.png) are created for publication ready maps with customizable color schemes. A metadata file is produced with complete documentation of processing parameters, coordinate systems, and statistics of the data used and produced.

### 1.5.6 Customizable Visualization

17 gradient color schemes are available for the user to pick from ranging from solid colors to multi colors. Hill shade, aerial, or no backgrounds are available, and the user can adjust transparency and blending.

### 1.5.7 Quality Assurance

During the pipeline, the user is given a Quality Assurance/Quality Check of the DEM either picked from drawing on the interactive map or from a manual upload, turned into hill shade, and river centerline laid over the hill shade to ensure the DEM and river centerline are correct and line up as the user needs them to do.

### 1.5.8 Two Ways to Run

The software has two distinct ways to operate. One is through the web interface which is recommended for most users. It is a browser-based point and click interface which is easiest to use. Terminal Interface is meant for advanced users and is a command line workflow with additional control over parameters.

### 1.5.9 Processing Speed

The speed from start to finish is noted below for each process:

* Data download: 2-10 minutes depending on area size, resolution, and internet speed
* REM calculation: 1-30 minutes depending on DEM resolution, extent, and REM parameters such as nearest neighbors and spacing
* PNG output: 1-10 minutes depending on DEM resolution and available core workers on system

## 1.6 System Requirements

It is recommended to use this software on Windows, macOS, and Linux systems newer than 2013 for CPU, RAM, and Disk space use. Some REMs (depending on DEM resolution and area size) can exceed 3gb of disk space and high usage of RAM for calculations. The recommended operating systems for running the software are listed below:

* Windows 10/11
* macOS 10.14+
* Linux (Ubuntu 18.04+)

Python versions 3.11 and newer are recommended for ease of use and package compatibility. Anaconda/Miniconda are required for package management. A web browser (Chrome, Firefox, Safari, or Edge) are required for interface interaction.

## 1.7 Internet Connection

An internet connection is required for automatic DEM and river data downloads. It is not required if the user uploads their own DEM and river centerline data.

## 1.8 Geographic Coverage

The automatic DEM and NHD river centerline data cover the continuous United States (Depending on DEM resolution) and Alaska. The manual file upload works worldwide.

## 1.9 Supported File Formats

The following file formats are supported:

* Inputs
  + DEM
    - Geotiff (.tif, .tiff)
  + River Centerline
    - Shapefile (.shp), Geopackage (.gpkg), geoJSON (.geojson)
* Outputs
  + REM Rasters
    - Geotiff (.tif)
  + Visualization
    - PNG (.png)
  + Hillnshade
    - Geotiff (.tif)
  + Metadata
    - Text file (.txt)

# 2.0 Installation

This section guides the user through installing all the software needed to run the software. Follow the steps carefully, and refer to the troubleshooting sections and FAQs guide for handling any errors if encountered.

## 2.1 Install Anaconda/Minicoda

Anaconda/Miniconda is a Python distribution that includes package management tools essential for installing the geospatial libraries the software requires.

### 2.1.1 Download Anaconda

To get started, download Anaconda/Miniconda from this site:

<https://www.anaconda.com/download>

Once downloaded, the installer needs to be downloaded from the “recent downloads” folder in the web browser.

### 2.1.2 Verify Installation

Once Anaconda/Miniconda is installed, open the Anaconda Prompt (if on windows)/Terminal, type in the command:

*conda –version*

This will list off the Anaconda/Miniconda version installed on the system. If there is an error, make sure to check the “Add to PATH” during Anaconda/Miniconda instaltion.

## 2.2 Create a conda environment

A conda environment is an isolated space for the software’s packages, preventing conflicts with other Python projects.

### 2.2.1 Open Terminal/Anaconda Prompt

On macOS/Linux, open the terminal application. On windows, in the operating systems search bar, type:

*Anaconda Prompt*

### 2.2.2 Create the Environment

Run the following command to create a new environment of your choice with Python 3.13:

*conda create -n (Environment name of choice) python=3.13 -y*

This creates the Environment name of choice on Anaconda/Miniconda, installs Python 3.13 (also is compatible if 3.12 or 3.11 is chosen), and *-y*  will flag automatically the confirmation of the environment being installed. The expected outcome from the Anaconda Prompt/Terminal when finished should look similar to this:

Collecting package metadata…

Solving environment…

Preparing transaction…

Executing transaction…

#

#To activate this environment, use:

#conda activate (Environment name of choice)

If Python 3.13 is not available, try using Python 3.12 or Python 3.11.

### 2.2.3 Activate the Environment

Every time a REM is needed to be created through the software, the Environment must be activated. To activate, use this command in the Anaconda Prompt/Terminal:

*conda activate (Environment Name)*

The Environment, once activated, will be shown on the far left side of the Anaconda Prompt/Terminal. If the Anaconda Prompt/Terminal indicates the Environment name is not found, type the command below to list off Environments downloaded currently on Anaconda:

*conda env list*

## 2.3 Install Dependencies

The proper Python packages need to be installed once the Environment is activated. There are two methods: automated (recommended) or manual.

### 2.3.1 Navigate to Software Directory

The cd (current directory) needs to be set to where the software folder lives. Once you activate the Environment, type the command below:

*cd (file link where software is on operating system)*

If the file link is incorrect, an error message will show. Make sure the link to where the software folder is correct and re-run the command above.

### 2.3.2 Method 1: Automated Installation (Recommended)

The easiest way to install all dependencies is to use the included installation script *install\_requirements.py*. This script automatically detects if conda is available, installs geospatial packages via conda which is faster and more reliable, installs remaining packages via pip, shows colored indicators of progress for downloads, and verifies installation at the end. To run the script, the Environment needs to be activated and the cd needs to be pointing towards the folder where the software is:

*Python install\_requirements.py*

The installation time should take between 5-15 minutes depending on internet speed. If the installation completes successfully, skip to section 2.3.5 (Verification).

### 2.3.3 Method 2: Using requirements.txt

If the automated installer dosen’t work, try unstalling from the requirements file. To install, make sure the Environment is active and the cd is pointing to the software folder, then type this command:

*pip install -r requirements.txt*

This command reads the requirements.txt file and installs all packages listed with their specific versions. A warning about using this method: it uses pip which may have trouble installing geospatial packages on some systems. If there are errors, proceed to method 3 (manual installation).

### 2.3.4 Using manual method

If both automated methods fail, packages can be installed manually. This gives the user more control and helps identify which specific package is causing the problems. To manually install the packages, make sure the Environment is activated and the cd is pointing towards the software folder. Open the requirements.txt file and look under the sections *Core Scientific Computing, Geospatial Core Libraries, Geospatial Data Acquisition.* These sections will use the conda forge command to download:

*conda install -c conda-forge (package)=(package version) -y*

The other packages can use the conda command found below for installation:

*conda install (package name)=(package version) -y*

The manual method can take some time, so be aware of the number of packages needed to run the software from Requirements.txt.

## 2.4 Installation Troubleshooting

### 2.4.1 Error: “Could not find a version that satisfies the requirement”

The cause for the error is the specified package version is not available for the Python version or operating system. To solve, install the package using the command below without the version number:

*conda install (package name)*

The user can also use a different Python version such as 3.11, 3.12, 3.13.

### 2.4.2 Error: “Failed building wheel for (package name)”

Packages require compilation, but the system or Environment doesn’t have the necessary compilers. The solution is to use the command above for the package of concern.

### 2.5 Clean Reinstall

If the package installation has failed, the last resort it to completely wipe the environment from Anaconda and try again. To accomplish this, follow the commands below:

*conda deactivate*

*conda env remove -n (Environment name)*

To check to make sure it is gone, use this command:

*conda env list*

Once the Environment is gone, update conda and create a new one:

*conda update -n base conda -y*

*conda create -n (Environment name) python 3.13 -y*

2.6 Getting Help

If every option in the REM manual has been exhausted, visit the REM FAQs document for more information. If information from that document does not help, please reach out to:

Ethan Muhlestein

[Ethan.Muhlestein@Kleinschmditgroup.com](mailto:Ethan.Muhlestein@Kleinschmditgroup.com)

3.0 Running the Software

Now that Anaconda and all packages have been downloaded, the software is ready to be run. There are two ways to use the software: A web interface (recommended for most users) and a terminal interface (for advanced users who prefer command-line workflows).

## 3.1 Prerequisites for Software

Before running the software, these steps must be completed every time the Anaconda Prompt/Terminal is open:

### 3.1.1 Activate the Conda Environment

The Environment where the packages are installed must be activated and the current directory must be set to where the software is in the operating system:

*conda activate (Environment Name)*

*cd (file link to where software folder is)*

### 3.1.2 Activating Web Interface

Once the Environment and cd are activated, the command below will automatically launch the Web Interface from the users internet browser (Chrome, Edge, Firefox, etc…)

*Python run\_app.py*

The software will take a minute or two to load everything into the browser for optimal use. The software interface will be located at a URL similar to this example:

http://localhost:8501

### 3.1.3 If browser doesn’t open automatically

If the browser doesn’t open, go ahead and navigate to the Anaconda Prompt/Terminal and look for the local browser which will look similar to this:

<https://localhost:8501>

Copy the URL and paste into the browser of choice. Do not use internet explorer, use Chrome/Edge/Firefox.

### 3.1.4 Software Interface

Once the software has fully loaded, the user will see this dashboard:

\*\*\* insert picture of interface\*\*\*

The web interface workflow is explained in section 4.0.

### 3.1.5 Stopping the Web Interface

To stop the server and close the interface, go to the Anaconda Prompt/Terminal and type the command below:

*Control+c*

This will completely cut off the server from the Anaconda Prompt/Terminal. Once this happens, the user can close the web interface from the browser of choice. The Anaconda Prompt/Terminal will still have the Environment and cd from before ready to go, so the user can re-run the *Python run\_app.py* command again for use.

## 3.2 Terminal Interface (Advanced Users)

The terminal interface provides a command line workflow with step by step prompts. It offers the same control as the web interface, but does not require a web browser to run.

### 3.2.1 Launch the terminal interface

To launch the terminal interface, make sure the Environment and currentl directory are set in the Anaconda Prompt/Terminal, then type the command below:

*Python run\_rem\_guided.py*

Once the command is typed out, a terminal interface will appear. The terminal interface will guide you though a series of prompts.

### 3.2.2 Project Name

A project name will be required where all inputs/outputs will be. The folder will be located in the “Project” folder of the software.

### 3.2.3 Data Source Selection

This section allows the user to provide data for the REM generator though Drawing an AOI on the interactive map or uploading DEM and river centerline data. Type 1 for automatic download and type 2 for own file uploads. The terminal interface follows the same inputs as the web interface which is explained in section 4.0.

## 3.3 Troubleshooting Startup Issues

### 3.3.1 Error: “ModuleNotFoundError: No module named ‘streamlit’”

The main cause of this error is the Environment is not activated. Activate the Environment and make sure the cd is pointing to the right file link where the software folder is located.

### 3.3.2 Error: “FileNotFoundError: [Erno 2] No such file or directory: ‘app.py’”

The cause for this error is a wrong cd file link. Please double check the cd link is correctly pointing to the right software folder.

### 3.3.3 Terminal Interface: Map dosent open

The reason for this error is the operating system dosent have a default browser set, or the browser is blocked. To remedy the issue, make sure your system has a default browser and make sure to allow software to be used in the browser.

### 3.3.4 Error: “Address already in use” or “Port 8501 is already in use”

Another streamlit app is running on the same port. To solve, either kill the streamlit which is using the port, or use a different port for the software. To use a different port, use this command:

*Python -m streamlit run\_app.py –server.port 8502*

### 3.3.5 Interface loads, but shows errors about missing modules

This means the installation of packages did not fully develop and the Environment is missing critical packages. To solve this, refer to section 2.0 in the manual about downloading packages.

3.4 Performance Notes

For the first time loading the web interface, it can take anywhere from 5-30 seconds to fully load since it is importing all libraries needed. For processing DEM and river centerline data, calculating REMs, and making PNGs, this can take time. The web interface will not show the progress of these tasks, refer to the Anaconda Prompt/Terminal for updates on processes. **DO NOT** refresh the page in the web interface, all progress on REMs will be lost.

# 4.0 Web Interface Guide

This section provides a detailed walkthrough of using the web-based interface to create REMs. The interface is organized into logical steps, guiding the user from data acquisition through parameter configuration to final output generation.

## 4.1 Web Interface Description

This section provides a detailed walkthrough of using the web-based interface to create REMs. The interface is organized into logical steps, guiding the user from data acquisition through parameter configuration to final output generation.

### 4.1.0 Interface Overview

A screenshot of a computer

AI-generated content may be incorrect.When the web-based interface is launched, the user will see this dashboard:

The main title ‘Automated Relative Elevation Model (REM) Generator’ is shown with a sentence below explaining the software in simple terms.

### 4.1.1 Project Folder/Dataset

A ‘project’ folder tab is the first parameter to set. This is where to set the project folder where all data, inputs, and outputs will be stored during creation. A simple file link to a folder will suffice. Below the ‘project folder’ there are two buttons for ‘Run Mode’: AOI+NHD(3DEP download) and Custom DEM & River. This is where users can choose between using the automated data collection for REM creation or use their own data. If Custom data is selected, the user will have two options: Option A to input direct file links to DEM and river centerline data. Option B allows the user to drag and drop data that is below 200mb each for ease of use. Both allow for data upload, but Option A allows massive data sets (such as 4gb DEM) to be directly used. Only .tif/.tiff files will be allowed for DEMs and only .shp, .gpkg and .geoJSON can be used for river centerline data. If a .shp is used, all of these files must accompany it:

* .shp
* .shx
* .dbf

After Data is uploaded into the specific areas, the software will look at each to verify the DEM has correct pixel values and the river centerline is a single straight line and not multi line or corrupted. If any data is bad, a message will pop up in the main screen which will alert the user about the problem for the data that’s affected. If the DEM’s crs has a vertical datum in feet, the software will show a message about coordinate system reference transformation into meters for calculation and alert the user of the change as well.

### 4.1.2 Interactive Map

If ‘AOI+NHD (3DEP download)’ is selected, the user will be prompted to draw a specific area on the map. The top left has options for the user to draw a polygon or a square/rectangle polygon around a specific area. If an area is drawn and the user wants to edit it or delete it, the next two buttons below the polygon drawings allow for editing and deletion. Zoom in and zoom out as well as full screen mode are also located on the left side. A search bar is located at the top right of the map where the user can search known cities within the United States for easier river reference. A measurement tool is located below the search bar to make specific measurements of areas/lengths. Finally, different basemaps can be switched between from aerial to topographic with names. If the user is unsure of the DEM resolutions within the area, ‘Scan Current Map Area’ button is available which will show within the current map frame the available DEM resolutions. Once the user draws a rectangle/polygon around the river of choice, the next step is to scan for resolutions and rivers within the specific area.

### 4.1.3 DEM Resolutions and River Data

Once an area has been drawn on the interactive map, the user will click ‘Scan AOI for Rivers & Resolutions’ button. This will send specific data to the United States Geological Survey’s API and the National Hydrography Datasets API about specific DEM resolutions available and available NHD river centerline data. A banner will pop up below the button which will list the available resolutions for the user to choose from. Below the banner, the user can select the DEM resolutions available (usually ranging from 1m-30m in continental United States and 2-60m in Alaska). Below the DEM resolution selection, the user can pick/search for a river in the dropdown menu from the data sent back from the NHD API request. This allows the user to select any waterway that has been documented by the NHD team for REM creation.

## 4.2 Processing Parameters

Now, the specific processing parameters are available for the user to use. A dropdown menu is located above the parameters which explains to the user what each does and how it affects REM calculation time.

### 4.2.1 Spacing (Meters)

The Spacing (meters) is the distance between elevation sample points along the river centerline. The default is 10 meters, but the range is between 1-150 meters. 5 meter spacing or less gives REMs very accurate river surface outputs, however increase the calculation time overall. 5 meters or less is ideal for small creeks and streams. 10 meters is the default for most rivers and results in good REM production with excellent time. 20 meters or more results in coarse looking REMs and is mainly used for large river systems such as the Mississippi or Columbia River size.

### 4.2.2 K Neighbors (IDW)

This parameter uses the number of nearest river points used for Inverse Distance Weighting interpolation at each DEM pixel. The default is 8 with the range going from 4-200. The lower the nearest neighbors, the faster the processing time. However, detail can be lost due to lower neighbors. Low neighbors is good for simple channels. 50 neighbors creates a balanced smoothness and takes average speed to process. This is good for most applications. 100-200 neighbors creates a very smooth surface and publication quality outputs, however it can create extreme calculating times depending on DEM resolutions and size. To increase smoothness of REM outputs, use different neighbors to affect the outputs.

### 4.2.4 CPU Usage

This option allows the user to select the percentage of total CPU usage for parallel processing. The range is 10-100% usage using a slider. The higher the percentage, the slower the system becomes as more resources are allocated for calculation and output production. The recommended usage is 75% for most projects as to not slow down a system from other core functions. A user can set the usage on the low end and allow the software to run in the background as other projects are running as well.

### 4.2.5 Max REM (meters)

The Maximum elevation above the river for computation is set here. Pixels higher than this are excluded as NoData. If left blank, the entire DEM is calculated for REM (which includes distant hillslopes). The average height to use for most river features is 30 meters.

## 4.3 Visualization Settings

These settings control how the final PNG images look. They don’t affect the geotiff REM calculation.

### 4.3.1 Color Ramps

Color schemes applied to the REM visualization:

* FloodAlertRed: Black to bright yellow to deep red
* NeonFloodCyan: Dark purple to neon cyan and green
* TropicWarning: Indigo to lime, magenta, and orange
* VolcanicEruption: Bright yellow to red to dark violet
* AquaCopper: Deep teal to beige and copper
* PeacockBronze: blue-green to cream and bronze
* GlacierLava: Navy to white to deep red
* SunsetDune: Violet to pink and orange-browns
* ESRIClassic: Navy and pruple to pale blue and tan
* CyanDeepBlue: Pale cyan to deep navy
* MagmaRamp: Bright orange to deep blue
* SolidBlue: Medium blue
* SolidPurple: Deep purple
* SolidGold: mustard gold
* SolidGray: Medium gray
* SolidRed: Firebrick red
* SolidBlack: Pure black
* SolidOrange: Dark orange
* SolidNavy: Navy blue
* SolidGreen: Pure green

To select one or multiple color schemes, click on the dropdown menu bar and select the color schemes. To get rid of a color scheme, simply press the ‘x’ next to the color name inside the color schemes menu.

### 4.3.2 Background

The background is the basemap of the PNG output where the REM calculation has transparent pixels due to Nodata set in the Max Rem computation earlier. The background consists of 3 options:

* Hillshade
* Aerial
* None

### 4.3.3 BG Transparency

This setting controls the opacity of the background layer. 0.0 is fully transparent and 1.0 is fully opaque. The default is set to 0.5.

### 4.3.4 REM Transparency

This setting controls the opacity of the REM color scheme overlay. 0.0 is fully transparent and 1.0 is fully opaque. The default is 1.0.

### 4.3.5 Max REM (meters) Visualization

This is the maximum elevation to display in color scheme scale. Values above this are shown at the maximum color. If left blank, the full color elevation is shown from the Max REM calculation set earlier. The Max REM Visualization **MUST** be equal or less than the Max REM Computation.

### 4.3.6 Discrete Colors

Discrete colors switches from smooth gradient to distinct color bands (elevation zones). A legend is created which shows 5-8 classes with heights in meters of the active REM. This setting is useful for quick analysis of floodplains in PNG format for extracting elevation zones without GIS software.

# 5.0 Running the REM Pipeline

Once all parameters above are filled out to the users desire, click “Run REM Pipeline”. This will activate the software and follow the same logic as the web interface organization with adding a Quality Assurance/Quality Check of the DEM data in hill shade format with the river data centerline laid over the hill shade to allow the user to visually check to make sure what is going to be used for REM calculations is correct.

## 5.1 Start Processing

Once the ‘Run REM Pipeline’ is clicked, the automated pipeline begins. The buttons and colors on the dashboard become disabled (grayed out) and the settings become locked in. Status messages will be shown below “Status & Outputs”. Depending on the mode the user selects, different events will transpire.

### 5.1.1 Stop Application

Below the ‘Run REM Pipeline’ button and below ‘Status & Outputs’ banner there are two ‘Stop Processes’ buttons. During any part of the REM data retrieval or calculations or visualizations, these buttons can automatically stop any process and return the user to the main screen with the ability to alter settings.

### 5.1.2 AOI+NHD (3DEP) Data Retrieval

If the ‘AOI+NHD (3DEP) data retrieval is chosen, immediately after clicking ‘Run REM Pipeline’, the software sends the Area of Interest geojson from earlier to the USGS and NHD API’s to collect the specific DEM tiles and river centerline information. Depending on the DEM resolution, multiple tiles can be selected for download. Internet connection plays a significant part in the speed of downloading DEM data. This can take 2-20 minutes depending on AOI size and resolution. Once all tiles have been downloaded, the software transforms the Coordinate Reference System (CRS) of all the tiles to the EPSG 5070 CONUS Albers Equal Area for REM calculation ease of use, then stitches all the tiles together to create one DEM. The DEM is then clipped to fit the exact AOI shape drawn on the map. River data is collected and then transformed to the same CRS as the clipped DEM for ease of use for next steps. After the transformation, a hill shade of the DEM is created and then placed under the ‘Status & Outputs’ page on the web interface where the river centerline is placed on top of the hill shade. This creates a “Quality Assurance/Quality Check’ of the data for the user to visually verify both the DEM and river centerline data are correct. Below the QA/QC image, the user will be prompted to select whether the image and its contents are correct or not. If it is not correct, the image will disappear and the settings will be unlocked so the user can re-upload the correct data again. If the image is correct, the next steps or processing begins.

### 5.1.3 Own DEM and river centerline data

If the custom DEM and river centerline data is chosen, immediately after clicking ‘Run REM Pipeline’, the software will look at the DEM CRS and then the river centerline coordinate system. The software will transform the river centerline CRS to the DEM’s for ease of use and accuracy. Once the transformation happens, a hill shade of the DEM is created and then placed under the ‘Status & Outputs’ page on the web interface where the river centerline is placed on top of the hill shade. This creates a “Quality Assurance/Quality Check’ of the data for the user to visually verify both the DEM and river centerline data are correct. Below the QA/QC image, the user will be prompted to select whether the image and its contents are correct or not. If it is not correct, the image will disappear and the settings will be unlocked so the user can re-upload the correct data again. If the image is correct, the next steps or processing begins.

### 5.1.4 Memory Check

After the QA/QC check, the software checks the DEM and system memory to make sure no errors happen later on. Higher resolutions (1 meter, 5 meter) are used, memory of the operating system can be strained and have a higher chance of becoming maxed out depending on the AOI size. If the memory is sufficient for REM calculations, a message will pop up saying “Sufficient memory available”. If the system detects low memory for a REM which requires a lot of memory, a warning message will pop up for the user about it. If a memory warning appears, use the ‘Stop Processes’ button to end the REM calculation. This will give the user the ability to use a lower DEM resolution or setting the Max REM values to lower numbers, or to restart the system to free up memory.

### 5.1.4 REM Calculation

After QA/QC and memory safety checks are complete, the REM calculation begins. Messages in the web interface will show prompts such as “Processing REM…” and “Interpolating elevation surface…” during REM calculation. During REM calculation, the timeframe can range significantly depending on DEM resolution, AOI size, and parameters chosen. During the calculation phase, the software is:

* Extracting elevations along river at specified spacing
* Smoothing profile with specified window
* Using KDTree to find K nearest neighbors for each pixel
* Applying Inverse Distance Weighting
* Subtracting interpolated surface from DEM

### 5.1.5 Visualization

Once REM calculation is complete, the visualization process happens. Messages in the web interface will appear giving indications of how many PNGs have been created and when the whole process is complete. Once all PNGs are created, the web interface will show all completed PNGs , QA/QC hill shade, and outputs with file links shown on the right side of the web interface for the user to verify visually.

## 5.2 Common Interface Issues

### 5.2.1 Map not loading or Map is blank

If the interactive map is not loading or is blank, shut the server down and restart the web interface. If that does not work, try opening the server on a different browser. If that does not work, clear the browser cache and try opening again.

### 5.2.2 Upload failed or File not recognized

This error happens if the DEM is not a geotiff (.tif or .tiff) file. Verify the DEM is a valid geotiff file in Arcpro or QGIS. If using the automated DEM collection, make sure a strong internet connection is present. Check to make sure the DEM file size is less than 75 gb in size as well. For river centerline data, make sure all 3 of the shapefile files have been properly uploaded (.shp, .sbx, .dbf) or .gpkg extensions were properly loaded. If that fails, check the geometry type of the shapefile to make sure its LineString and not Point of Polygon.

### 5.2.3 Processing hangs or freezes

If after 30 minutes there are no status updates, CPU usage drops to 0%, or the interface is unresponsive, check the Anaconda Prompt/Terminal for error messages. If nothing is shown, try using the ‘Stop Processes’ button to end all activities. If that does not work, close the server completely and restart the web interface. Most cases in persistent hangs or freezes, try to lower the DEM resolution, use a smaller AOI, set a Max REM computational height to a lower number, and use a lower number of nearest neighbors.

### 5.2.4 Out of Memory Error

If the system warns the user about out of Memory or the software crashes, close out of the software server, close out of all other applications, restart the operating system, then try using a smaller AOI/Lower DEM resolution for analysis. If a large AOI is needed for 1 meter resolution, break the AOI into smaller sections and run one after the other.

## 5.3 Tips for Best results

For the best possible quality, try running the AOI of interest on a 10 meter DEM resolution with default settings, review the output, then adjust parameters accordingly.

\*\*\*insert REM with 8 nearest neighbors vs 40

When reviewing the QA/QC hill shade, make sure to look for missing data (black pixels within the area) which can affect REM calculations. The DEM should be clear of errors for absolute REM calculations.

# 6.0 Understanding Outputs

After processing completes, the software generates a collection of files organized in the project folder. This section explains what each file contains, how to interpret the data, and how to use the outputs in analysis.

## 6.1 Output Folder Structure

All the outputs are saved to the project folder designated earlier in the software. The folder is organized as follows:

* Project folder
  + Hillshade.tif
  + hillshade\_qa\_qc.png
  + REM.tif
  + river\_reprojected.gpkg
  + REM\_[colorscheme]\_[DEM Resolution].png
  + REM\_Project\_Stats.txt
  + AOI\_streamlit.geojson
  + mosaic\_clipped.tif
  + NHD\_[Area of Interest River]\_centerlines.gpkg

Each of the files plays a crucial role/output for analysis.

### 6.1.1Hillshade.tif

The Hillsahde.tif is the hill shade output from the used DEM for REM calculations. This file gives the user the ability to reference the geotiff inside other geospatial softwares for ease of use.

### 6.1.2 hillshade\_qa\_qc.png

The hillshade\_qa\_qc.png is the quality assurance/quality check of the DEM to river centerline before REM calculations begin. This is crucial for the user to verify data is full and complete before continuing on.

### 6.1.3 REM.tif

The REM.tif is the final output of the REM calculations and holds all the information pertaining to the specific AOI area drawn/uploaded prior. It is in meters and is found in EPSG: 5070 CONUS Albers Equal Area. The Nodata values are marked as 999.0

### 6.1.4 river\_reprojected.gpkg

This is the final river centerline data which is projected into ESPG: 5070 CONUS Albers Equal Area.

### 6.1.5 REM \_[colorscheme]\_[DEM resolution].png

The high quality output png selected within the web interface. The color scheme name and DEM resolution are included within the naming convention.

### 6.1.6 REM\_Project\_Stats.txt

A complete metadata file documenting all processing parameters, statistics, and coordinate systems. This file is critical because is gives the software more credibility for reproducibility, documentation, quality control and troubleshooting. The metadata file consists of 5 sections: Source DEM Metadata, REM Output Statistics, Processing Parameters (For Reproducibility), Coordinate Reference Systems, Output Files. Each section gives valuable information for the user to review once a REM is complete to use for further analysis.

\*\*Insert screenshot of text file\*\*\*

### 6.1.7 AOI\_streamlit.geojson

This is the file which contains the bounding box information of the AOI which is used to gather the specific DEM resolution data and NHD river centerline data.

### 6.1.8 mosaic\_clipped.tif

This is the final DEM from the AOI+NHD(3DEP) data download. Multiple tiles are gathered, reprojected into EPSG: 5070 and stitched together. Once everything is stitched, the DEM is clipped to the AOI drawn earlier to maximize memory control and disk space.

### 6.1.9 NHD\_[Area of Interest river]\_centerline.gpkg

This is the original NHD data brought in from the NHD API before reprojection.

# 7.0 Interpreting REM Values

REM values represent elevation relative to the nearest river point, not absolute elevation above sea level. A traditional DEM river pixel can have a point such as 1,245 meters, where as a Relative Elevation model pixel in the exact same area can have a pixel value of 15 meters. The REM flattens the river to a reference surface, making it easy to identify areas at similar heights above the channel regardless of absolute elevation.

## 7.1 Negative Values

Negative values are common within REMs and are nothing to worry about, they can mean several different things.

### 7.1.1 Tributary Confluences

Tributaries enter at lower elevation than interpolated mainstem surface. This creates a local “dip in the REM”. Try uploading the REM.tif to geospatial software and search the pixel values near tributaries/confluences to see negatives.

### 7.1.2 Deep Pools

Pool bottoms below average channel elevations can cause negative values. Disconnected channel pools can cause negative values due to different environmental changes that could have happened.

## 7.2 When Negative values are bad

If a negative value is more than -5 meters, this can signal either bad DEM data or areas that include too much information. If the DEM quality is poor/bad data, large negative REM values can appear. To fix, try a different DEM resolution or AOI. An AOI that includes too much information is an area that includes more than one valley/floodplains. This can cause large negative rem values due to different elevations between the two as well as skewing the original AOI REM area. To fix, simply focus the AOI on a more specific floodplain area.

# 8.0 Frequently Asked Questions

If there are any questions or concerns with starting up the software, REM outputs, PNG outputs, or any other sort of questions, please refer to the REM FAQs file located within the software folder package.