3D Printed Terrain Maps

A DIY Approach

by … A. J. Griggs

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3D Printed Terrain Maps

- Objective
  To describe the process by which a terrain map can be made using free tools.
- Assumptions
  - No knowledge of Graphical Information Systems (GIS) concepts or software
  - No experience with 3d printing
  - Familiar with personal computers and a graphical application

Benefits of 3D Terrain Maps

- Contours are easily perceived
  - Hills
  - Watercourses
- Provides another learning modality
  - Adds Touch to Visual
    - Locate a high point on the map and relate it to a paper map contour plot
- Attention getting
  - 3D Terrain maps are novel

People and Organizations

Eightmile River Wild and Scenic Coordinating Committee (ERWSCC)

The Eightmile River Wild & Scenic Coordinating Committee mission:

- Coordinate and champion implementation of the Watershed Management Plan.
- Bring the stakeholders in watershed management together on a regular and ongoing basis to facilitate continued cooperation and coordination.
- Provide a forum for all watershed interests to discuss and resolve watershed related issues.
- Monitor the outstanding resource values with respect to the degree they are protected, degraded or enhanced during implementation of the plan.
- Assist in securing additional funding to facilitate implementation of the watershed management plan.
- The Outreach and Education subcommittee initiated the creation of the Eightmile River Watershed terrain map.

People and Organizations

Riley Doherty

ERWSCC Environmental Program Coordinator

Riley worked at the Eightmile River Wild & Scenic Watershed as their environmental program coordinator.
In January of 2023, Riley joined the Office of Aquatic Invasive Species at the CT Agricultural Experiment Station.

Riley was the GIS Technical Lead on the terrain map project

Pat Young

Program Director ERWSCC

Pat has a professional career spanning nearly forty years working to protect the natural resources in the State of Connecticut and has served as the Eightmile River Watershed Program Director since 2009.

People and Organizations

- Tony Griggs
  ERWSCC Board Member
  ERWSCC Outreach Subcommittee

Tony is a retired Electrical Engineer with an interest in CAD, 3d printing, and embedded software systems. Over his diverse career he has done analog and digital electronic design and software development.

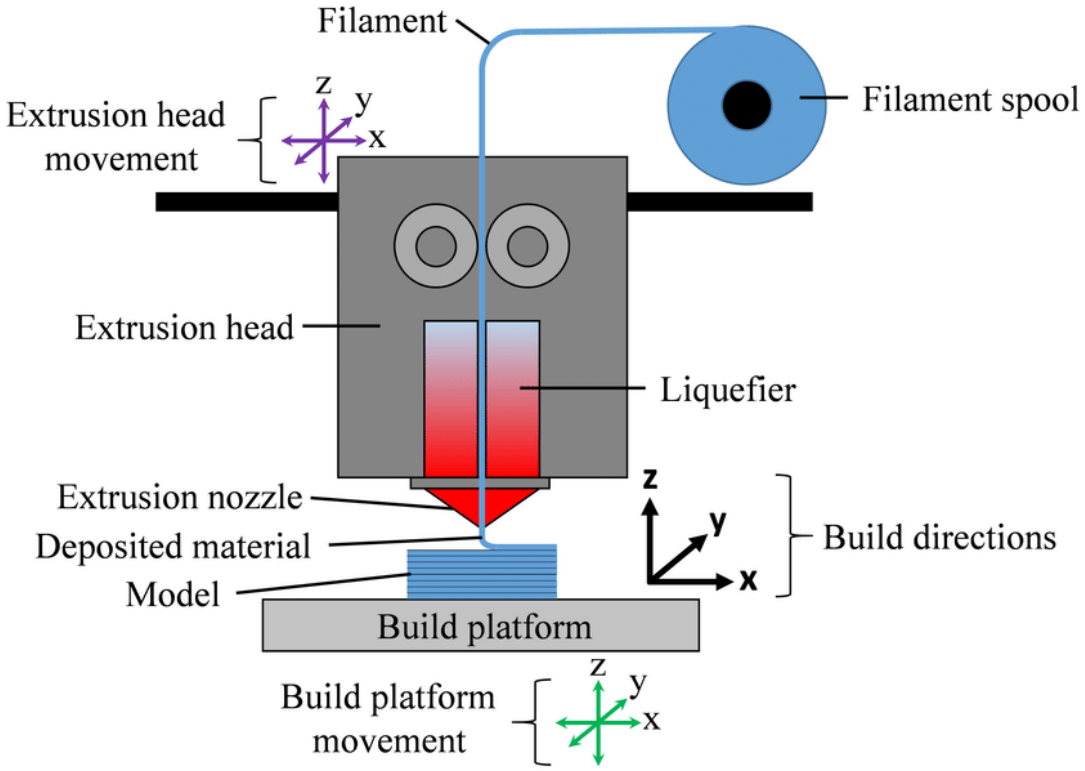
He enjoys the great outdoors and is a volunteer for Salem Land Trust and ERWSCC.

Printer Types and Specifications

Fused Deposition Machining (FDM)

- An additive process where hot filament fuses with previous layers building up a model in many layers.
  - Layer thickness is 0.1 to 0.4 millimeters (mm)
  - Nozzle size is typically 0.4 mm diameter
- Supports various plastic filaments
  - Polylactic Acid (PLA) filament is a natural thermoplastic polyester that is derived from resources such as corn starch or sugar cane. Best for indoor models.
  - Polyethylene terephthalate glycol (PETG) (Think soda bottles).
    More durable than PLA and would withstand outdoor use.
    Slightly more difficult to print than PLA.
- Most hobby machines are FDM

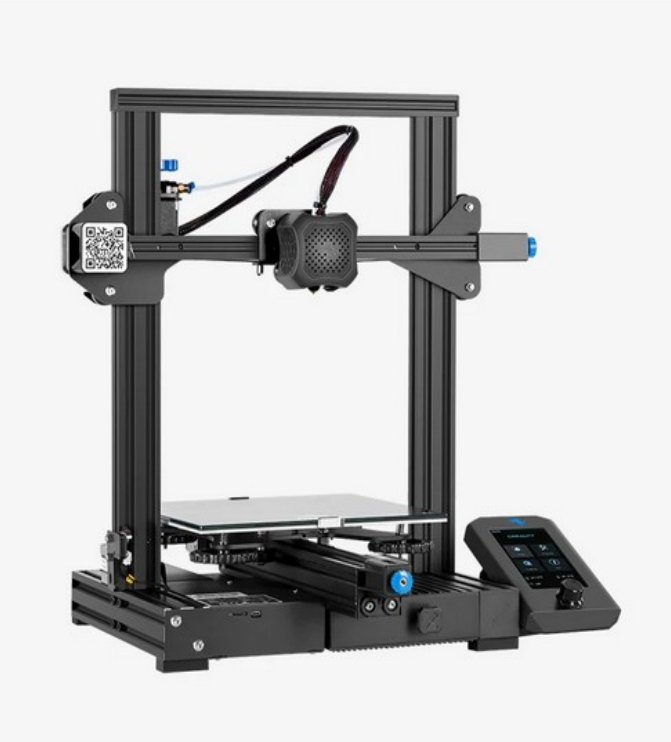
FDM Printing



(Image by Philipp R. Thies)

Typical Hobby 3D Printer

Creality Ender 3 (under $200 on Amazon)



Printer Types and Specifications

- Stereolithography (SLA)
  - An optical process with a photopolymer resin where each layer is selectively solidified by a (UV) light source.
  - Higher resolution than FDM
    Minimum feature size of 0.1mm vs 1.0 mm for FDM
  - Not recommended for home use due to toxicity of resins
    - Prints must be washed in alcohol and curing completed in UV light
    - But, if you use a print service, you don’t care. That’s their problem.
  - SLA machines and resin are more expensive than FDM

Typical Hobby SLA Printer

ELEGO Saturn S (about $400)

Optional Washing and Curing Station (about $220)

Terrain Model Files

- The typical model description for a 3D printer is a stereolithography (.STL) file.
  - Also referred to as Standard Triangle Language or Standard Tessellation Language.
  - STL files define surfaces using many triangles.
    - The objects they define are hollow
- 3D Printers are programmed in millimeters (mm)
- Slicer
  - A software tool that creates the printer path from the model file and will ‘infill’ the hollow space with a support structure to some percentage of material (10% → 100%)

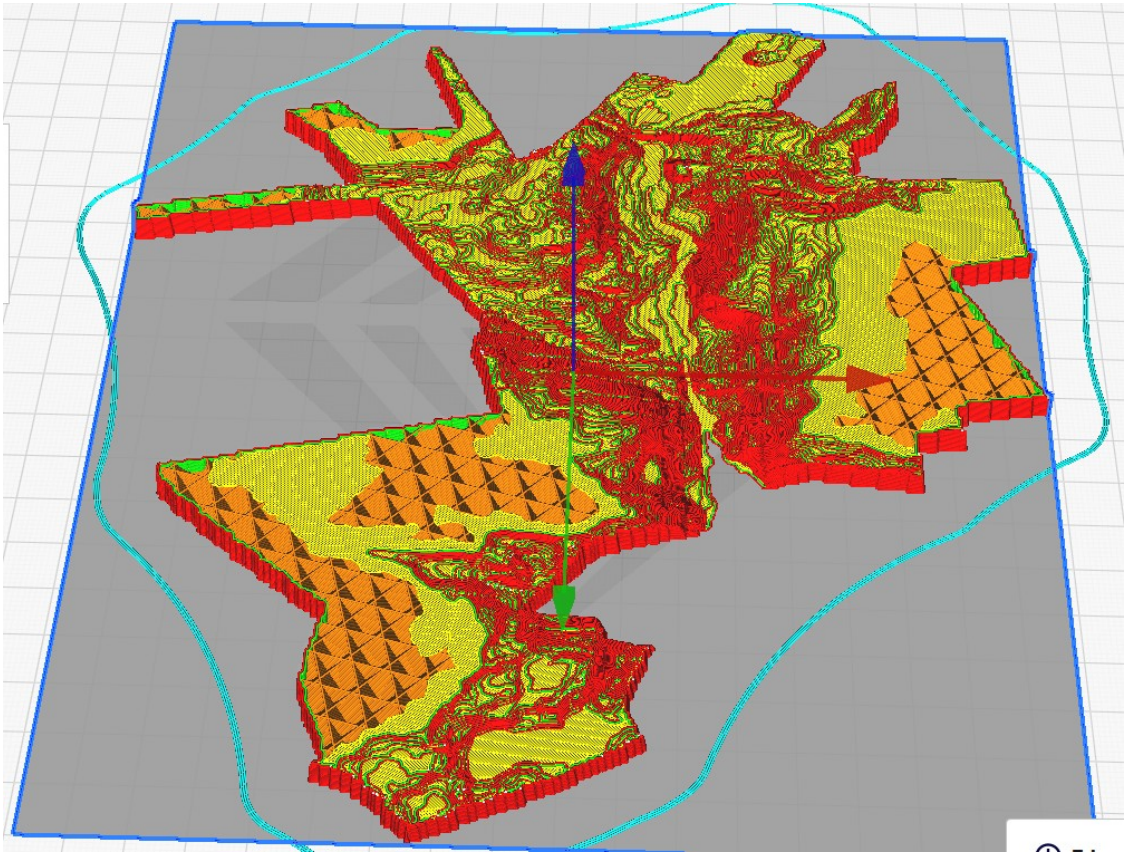
Touch Terrain Live Demo

- Let’s make a model of Devil’s Hopyard State Park
  - We will use the Touch Terrain print generation service from Iowa State University via a Web browser
  - Select the patch of the earth defining a the desired area
  - Answer some questions about the target printer and model size
  - The service will create the .STL model files for our printer

Simple and Quick Method

- Process:
  - Go to https://touchterrain.geol.iastate.edu/
  - Click on the area of the World that you want a terrain map
    - Refine Selection by town, city, state, …
  - Decide on the size of the map in tiles and 3D Printer bed size
    - Recommend < 200 mm in X or Y dimension for compatibility
  - Set other printer parameters like nozzle size (0.4 mm typical for FDM)
  - Create the print set which will be nX * mY .STL files in a zip archive
- View Your .STL Files with Cura or Windows 3D model viewer

Devil’s Hopyard model layers from Cura slicer



Simple and Quick (continued)

- If you don’t have a 3D printer
  - Get on-line quotes from 3D printing services.
    - FDM printing with PLA material with 10-20% infill will be cheapest.
    - For our museum model, Riley used Xometry, but there are other services.
  - Upload your .STL files, pay and wait for delivery
- If you do have a 3D printer
  - Slice your .STL files and produce a G-Code file for your printer
    - G-Codes are the motion language for the printer
  - Print them in the material and color of your choice

Simple and Quick (continued)

- If all you need is a print of a Touch Terrain generated model, then you are done. Have a nice day!
- Some caveats:
  - The boundaries of the model are defined by the selection rectangle
    - You may want the boundary of a specific property
    - It is possible to define a polygonal boundary using a KML file in Touch Terrain
  - Only the information from the DEM will be shown
    - No trails, roads, smaller streams ...
  - In the rest of the presentation, you will be shown how to overcome these deficiencies

Use Case: Eightmile River Watershed

- The ERWSCC Outreach and Education subcommittee proposed a display about the watershed for the East Haddam Historical Museum.

- There would be a map and informational plaques

People and Organizations

- East Haddam Historical Society and Museum

  Dr. Marianne Halpin – Museum Director

- ERWSCC Outreach and Events Subcommittee

Museum Display

- Riley investigated terrain models
  - She found a company could produce foam models with satellite imagery overlay
  - It would be a compelling display, but outside the budget
  - Could we get something equivalent for less?
- Tony had some experience with Touch Terrain
  - He proposed creating a small demo on his 3D printer
  - Because of the limitations on printer bed size, it would be composed of multiple tiles
    - Pat and Tony independently had the idea of tiles creating a Watershed Puzzle

Use Case: Eightmile Watershed

- The model was presented at the next Outreach and Education Meeting
  - Touch Terrain generated the .STL files
  - The entire model could be produced for less than $230 using a print service. Depending on your application, you might want a frame for the tiles. The frame box from a local vendor was less than $150.
  - There were two suggestions from the Group
    - Show only the boundary of the watershed
    - Include the rivers and streams

Use Case: Meeting Expectations

- To meet these two requirements, Tony set out a research mission to find a ready made solution.
  - QGIS is an open source GIS tool
    - DEMTO3d is a plug-in that creates .STL files from a Digital Elevation Model
  - Riley could provide a Shape File that outlined the watershed boundary
    - Shape files are GIS vector format files
    - The boundary shape file could be used like a ‘cookie cutter’ on the DEM
  - Riley could also provide Shape Files that defined the watercourses
    - A guide groove for the watercourses could be etched into the DEM which could be colored with a paint pen once printed

Tools and Data Preliminaries

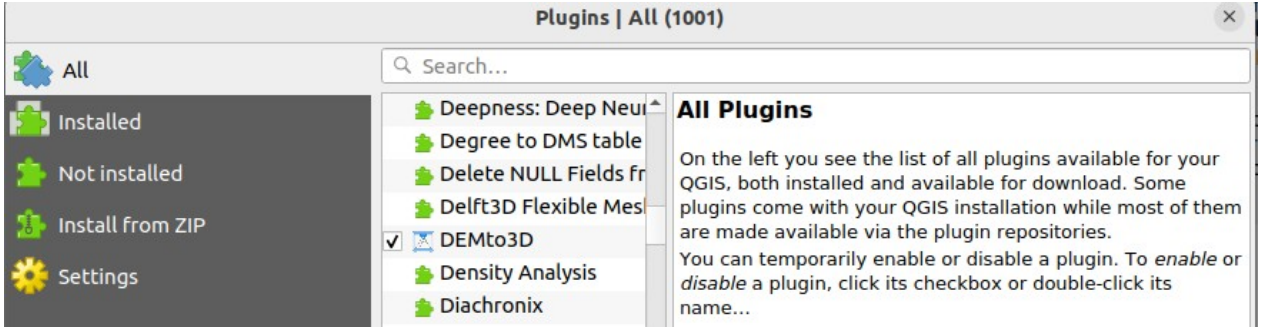
- Before actually making the Eightmile River watershed model, we need to familiarize ourselves with some tools and techniques
  - QGIS
  - Digital Elevation Model download
  - Selecting DEM Regions
  - Etching in the watercourses with StreamCut.py
  - Creating STL print files with DEMto3D Plug-in

Using QGIS for Greater Functionality

- QGIS is an open source GIS tool similar to ArcGIS
  - QGIS may import different DEM files
    - Touch Terrain is limited to the DEMs they provide
  - DEMTo3D is a QGIS plug-in that creates .STL files from a DEM
- QGIS + DEM + DEMTo3D -> equivalent results to Touch Terrain
  - Why bother when we can use Touch Terrain?
    - Polygon ‘cookie cutter’ selection of a DEM area using various masks
    - DEM may be modified (‘etched’) external to QGIS and processed by DEMTo3D
      - Shape files needed for etching program may be drawn or imported including GPS tracks
    - Higher resolution DEMs may be available

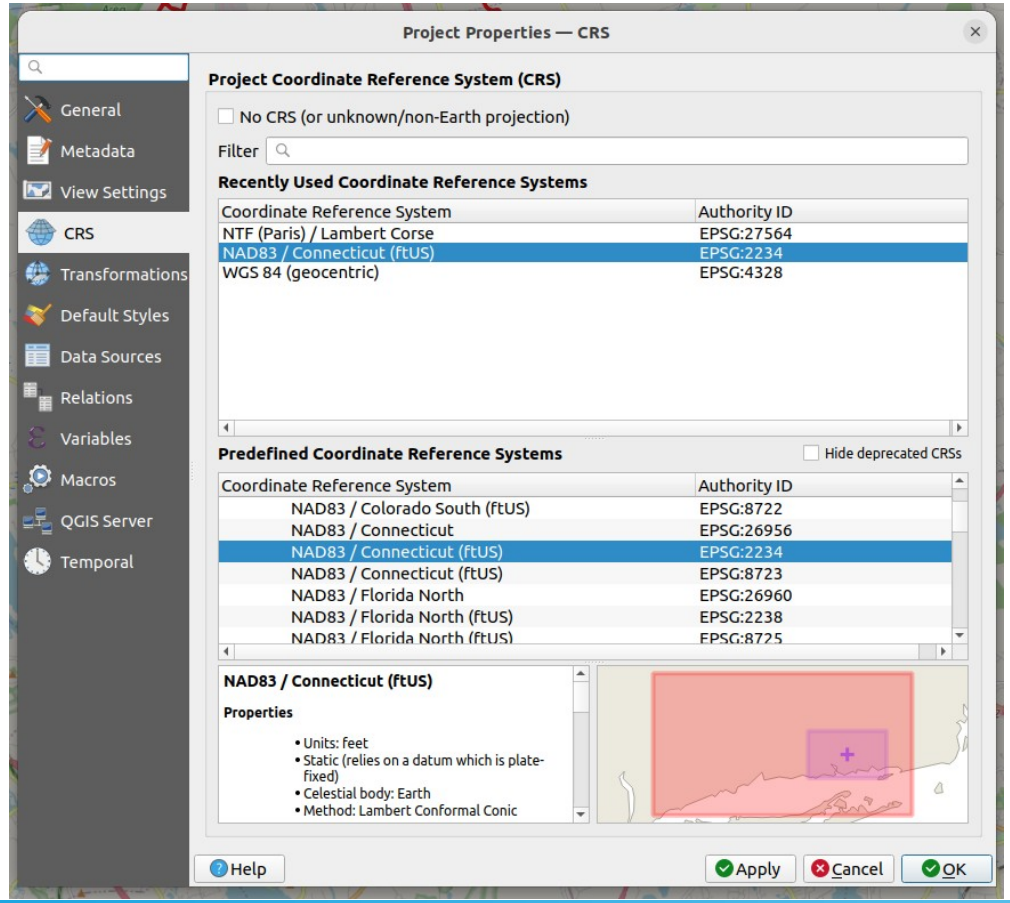
Installing QGIS and DEMto3D

- QGIS is available for PC,Mac and Linux computers.
  - I have not tested the MAC version
  - https://www.qgis.org/en/site/forusers/download.html
- Once QGIS is installed, DEMto3D may be added with the plug-in manager
  - Plugins → Manage and Install Plugins



- Set the Project CRS to be in a linear format (Feet or Meters) if etching

Project Coordinate Reference System



Digital Elevation Model (DEM) Files

- A Digital Elevation Model (DEM) is a representation of the bare ground (bare earth) topographic surface of the Earth excluding trees, buildings, and any other surface objects.
- DEMs are available for download from several sites
  - Unfortunately, each User Interface is different :-(
- The DEM grid may be defined in longitude / latitude or linear offsets
  - For etching the DEM, it must be in a linear format (Feet / Meters) to be compatible with the current version of StreamCut.py

Digital Elevation Model Sources

- One source is https://cteco.uconn.edu/download.htm
  - 2016 Elevation DEM and LAS
  - Select DEM Tiles and download
- Import DEM Tiles into QGIS
  - Add Layer → Add Raster Layer → Select files
  - Merge into one DEM
    - Raster → Miscellaneous → Merge
    - Select imported DEM Tiles
    - Remove source DEMs if desired
  - Set Merged DEM's CRS (Coordinate Reference System) to be same as other layers by Export → SaveAs → Set Name and CRS

Digital Elevation Model Sources

- DEM Data Download: https://apps.nationalmap.gov/downloader/
  - Select Elevation Products (3DEP)
    - Recommend highest resolution (smallest arc second sampling)
  - Draw bounding box or polygon by selecting Extent/Polygon
  - Search Products within the extent/polygon
  - Verify Region
  - Add to cart
  - Download from Cart (geoTIF format)
- Import as New Raster Layer in QGIS
- https://epsg.io/ references DEM transforms Worldwide

Selecting a DEM Region

- Export a region from a DEM to a new (smaller) DEM
- QGIS → Raster → Extraction
  - Clip Raster by Extent
    - Change the output CRS if required, or define as the common CRS
- Clip Raster by Mask Layer
  - Predefined Shapefile (Vector Layer)
    - Layer → Add Layer → Add Vector Layer
    - Add a Shapefile

Clip Raster by Creating a Mask Layer

- Create Layer → New Shapefile Layer
  - Set CRS to same CRS as DEM
  - Select new layer and turn on Editing (Pencil Icon)
  - Add Polygon Feature is now highlighted
  - Draw the Polygon
  - Save the Shapefile layer in the same CRS as the DEM
- Select Raster to be clipped
- Raster → Extraction → Clip Raster by Mask Layer
  - Set output CRS if needed

Clipping a Raster

- Clipping Failure
  - No features found in region : May be due to incompatible CRS
    - Save the generated Shapefile before clipping using Raster’s (Project) CRS
    - Re-import with a new name
  - Open Log window under Views
    - Information may be useful to diagnose the problem

Using Predefined Shapefiles

- https://portal.ct.gov/DEEP/GIS-and-Maps/Data/GIS-DATA
- Navigate to CT DEEP GIS Open Data Website
  - CT Parcels
    - Land Conservation and Outdoor Recreation
    - Connecticut Parcels
      - Select parcels by drawing region and downloading
      - Import in QGIS as Add Vector Layer
  - Watershed Regions
    - Hydrography
    - Subregional Basin Polygon
      - Select regions and download
      - Import in QGIS as Add Vector Layer

Filtering Shapefiles

- When multiple polygons are included in a Shapefile and some are not wanted, use the Filter Tool to build a query to select only the ones you want
  - Example : Eight Mile River Watershed
    - Select Shapefile layer
    - Turn on Editing
    - Select → Select regions (Use ctrl key for multiple select)
    - Edit pull down → Edit Geometry → Merge Selected Features

Make a Watershed Model using QGIS

- Create a New Project
- Use Open Street Map background as a guide
- Import a DEM covering the area
- Import or define a shape file outlining the boundary of the watershed
- Cut the DEM with the boundary and export to a file
- Etch the cut DEM with stream shapefile
- Import the cut DEM
- Create the .STL files with DEMto3D

Etching the DEM

- Cut watercourses into the clipped DEM
  - As a shape file or a GPX format GPS track
    - Riley provided the watercourses as a shape file
  - Import the shape file as a separate layer to verify compatibility
- Define the parameters for the StreamCut program
- Run StreamCut against the DEM using the shape file
  - Note: The shape file And the DEM must be in the same Coordinate System (CRS).
- Import the modified DEM

StreamCut

- StreamCut.py is a Python 3 program that relies on external libraries. These must be loaded using the Python PIP command.
- Required libraries
  - Shapely
  - Numpy
  - shapefile
  - rasterio
  - os.path
  - math
  - sys

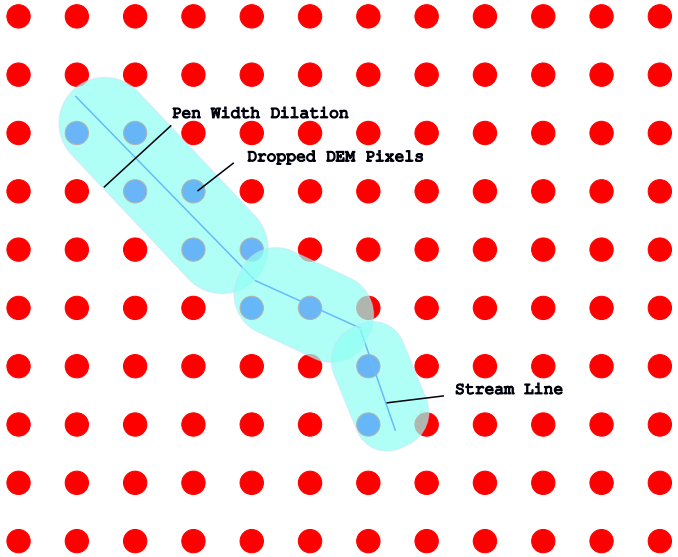
StreamCut.py

- Put StreamCut.py, the DEM file to etch and the cutting Shapefile in the same directory.
- From the command window :

  python StreamCut.py MyDemToEtch.tif Cut.shp <max Y> <PenTipD>
- If all goes well, you will be rewarded with MyDemToEtch**Cut**.tif
  - This could take a long time to process

StreamCut Processing

- DEMs are regular grids of elevation points
- A shapefile is used to define where the DEM is to be etched



Creating and Finishing the Tiles

- Use the etched DEM to create tiles with DEMto3D
- Print the tiles
  - Your printer or a printing service
- Paint the etched tracks with paint pens
  - Sharpie Oil Based Extra Fine pens (0.3 mm tip)
- Overcoat the tiles with a clear protective coating
  - Light coats are best to avoid runs in the painted tracks
- Bask in the glory of your completed project

Eightmile River Watershed Map Delivered

Future Considerations

- Color 3D Printing
  - Home printers are getting cheaper, but still over $1000
  - Investigate printing service capabilities
    - Problem: How to code the .STL models for color?
- Is SLA printing an advantage?
  - Pro: Higher resolution, faster if full layer exposure
  - Con: toxic materials and increased costs

The End

- This presentation will be available on the CLCC web site
- Give me your email if you need the StreamCut.py program
  - Or contact me at ajgboomer@gmail.com
- Questions or Comments?

Thanks for attending this talk!
A. J. Griggs