

# FEMA Floodplain Mapping

By Luke Sturtevant

## Introduction

The National Flood Insurance Program (NFIP) has compiled massive databases containing information and maps of floodplains for the entire United States. The purpose for this is for floodplain mitigation and to calculate insurance premiums for property renters/owners within these areas. Traditionally these are hardcopy maps known as Flood Insurance Rate Maps (FIRMs) which show the base flood elevations (BFEs), flood zone type, and the effective boundary of the floodplain. When the technology became available the Federal Emergency Management Agency (FEMA) funded the conversion of the old hardcopy maps to digital versions which are known as DFIRMs. With any digitizing process, especially on a large scale, come errors mostly within the delineation process. There are also inherent problems with the old maps that were generated from old topographic maps causing the delineated floodplains to be inaccurate. Most of the major water bodies in the United States that are at high risk of flooding and have heavily populated areas are called Special Flood Hazard Areas (SFHAs). These SFHAs have had detailed studies done with current surveying technology to produce hydraulically accurate maps. However, even these highly studied areas are constantly being updated due to ever changing topography from human construction and natural events. For these reasons FEMA is currently funding a large scale "Redelineation" process to update all floodplain maps using the most current mapping software available with high resolution digital elevation models (DEMs) produced by Laser Imaging Detection and Ranging (Lidar) technology.

The GIS process involved for redelineation is extremely time consuming and the accuracy can vary depending on the person. The main goal is to create an ArcGIS tool that will completely automate the GIS process to increase productivity and consistency in order to get the final product to FEMA and the impacted communities.

## **Data Collection**

All the data for the GIS mapping process has come directly from the FEMA digital database. The lidar data for the creation of the DEMs is the most important data which allows for topographically sound redelineations. The geo-referenced FIRMs come as polygon shapefiles show the current location and shape of the SFHAs and polyline shapefiles that show the location of detailed study cross sections. All the shapefiles come with populated attribute tables according to FEMA standards. The shapefiles can be analyzed against the new DEMs to gain an understanding of what the old SFHA polygon shape is trying to capture. It is also essential to have the Flood Insurance Study (FIS) reports which contain the floodway tables and profiles for all detailed studies. The profiles have location descriptions, BFEs, and river mile distances for all cross section. For the purposes of this GIS process the SFHA zone types that will be redelineated are approximate zones (zone A), 500-year zones (Zone B), and detailed study zones (zone AE). Zone A are 1-percent-annual-chance flood (100-year) and zone B types 0.2-percent-annual-chance flood (500-year). They do not have cross sections or profiles and BFEs meaning the floodplains are approximated. Zone AEs are 100-year zones that have a detailed hydraulic analysis with profiles and BFEs. It is also useful to have access to the most current high resolution geo-referenced aerial maps which can be brought in from web map services

such as ESRI's ortho-imagery. Difference in vegetation can be seen on aerial photography by coloration changes and can be a good indicator of floodplain area. Aerial imagery is also helpful in determining the houses and developments that are impacted by the floodplain.

There are some major issues that are being addressed with this redelineation process. The most obvious can be seen in figure 1. The old digitized SFHA boundaries are clearly not accurately capturing the true floodplain. The zone AEs are normally more true to the topography, but the A zone and 500-year zone boundaries often appear to be shifted over ridges in some areas and do not delineate obvious topographically low areas in others. In some cases this includes houses that are being charged for insurance that may not be even close to the real floodplain boundary.

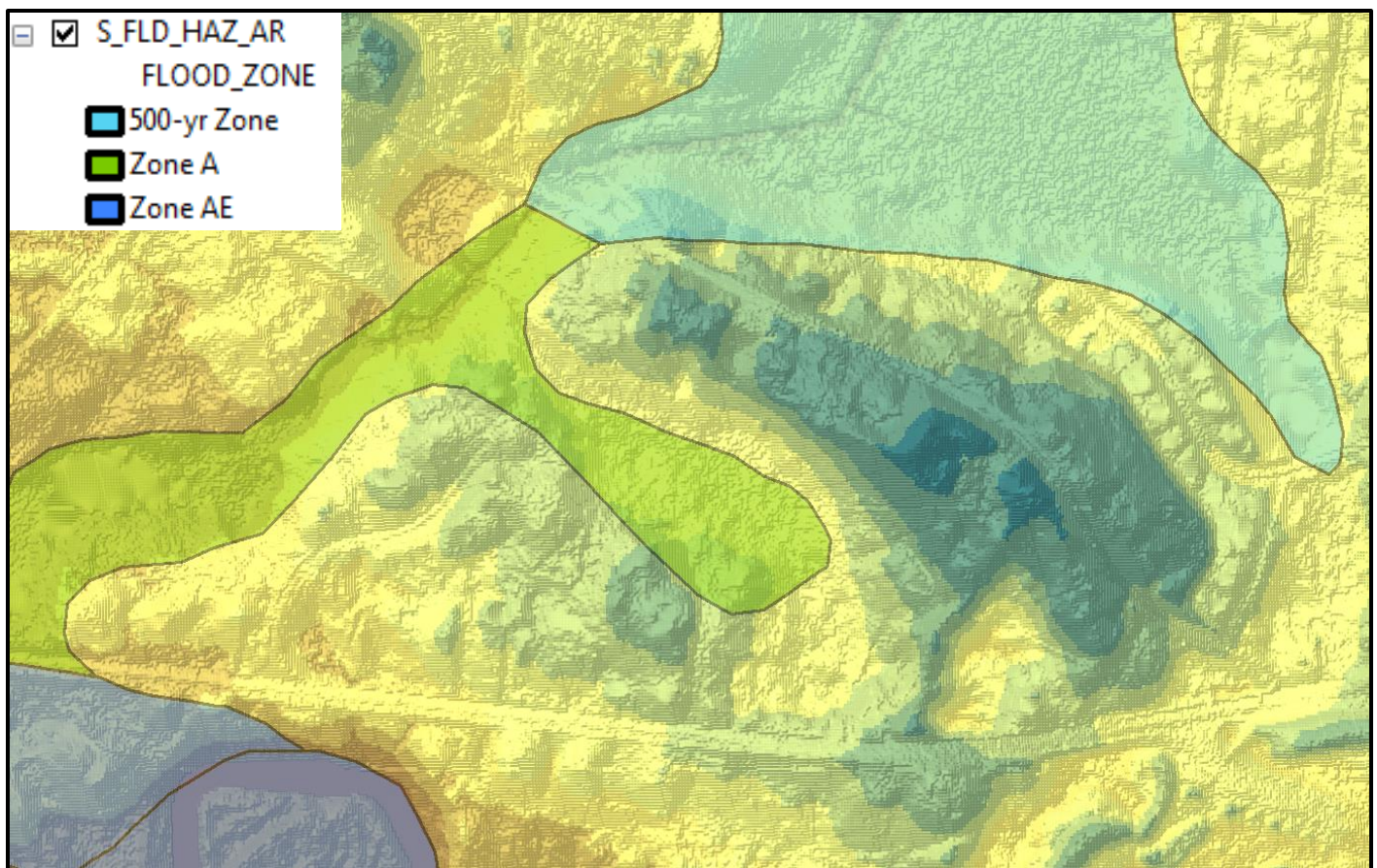


Figure 1: Old digitized SFHA poorly delineated

Some other minor issues with the data are the attribute tables for the shapefiles, especially the cross sections seen in figure 2. The tables come with all the pertinent information according to FEMA standards. However, some of the field values that are needed such as top width measurements for floodways have null values. Fortunately all these values can be found by searching through the FIS reports and locating the floodway data tables, but it is often time consuming. Also for the purposes of this study not all attribute fields are required and can be distracting for example the cross section attribute table as more than thirty fields and only seven are necessary. Another slight issue is that all measurements are in feet and the lidar linear units are in meters which mean all BFE values must be converted to meters.

VELOCITY	VEL_10PCT	VEL_2PCT	VEL_1PCT	VEL_02PCT	VEL_UNIT	SOURCE_CIT	BED_ELEV	TOP_WIDTH	XS_AREA	AREA_UNIT
3.9	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	48	SQUARE FEET
0.8	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	112	SQUARE FEET
4.2	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	87	SQUARE FEET
3.9	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	125	SQUARE FEET
-9999	0	0	0	0		FIRM	-9999	-9999	-9999	NP
1.7	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	212	SQUARE FEET
2.4	0	0	0	0	FEET / SECOND	FIRM	-9999	-9999	108	SQUARE FEET

Figure 2: Data Issues within cross section attribute tables

## Methodology

The purpose of this procedure is to delineate floodplains using the most current flood data available with high resolution lidar derived DEMs. The 100-year and 500-year floodplain boundaries can be redelineated, using ESRI mapping software, onto the DEMs to produce topographically correct polygons. The GIS process involves several steps and may need to be repeated multiple times to produce a reasonable polygon.

The process begins with creating a BFE layer that contains DEM derived elevations for the floodplain boundary elevation. For zone A and 500-year zones this requires creating fake

BFE cross sections along the reach at elevation inflections. For zone AEs, existing cross section can be assembled from the shapefiles provided by FEMA, but all elevation values must be converted to meters, extraneous attribute fields removed, and required attribute fields populated correctly. The best way to do this is to use classified symbology for the DEM being used with the old SFHA shapefile overlaying the DEM. Using the identify tool on the DEM or the 3D analyst profile tool to determine the range of relief. The natural breaks can be manipulated in the 'Classify' settings to be grouped in the determined elevation range. Selecting contrasting colors to differentiate elevations will help to display the approximate floodplain elevation the old SFHA attempts to capture.

A Triangular irregular network (TIN) is generated from the BFE layer using the specified DEM elevations as the input. The TIN is then converted into a water-surface elevation (WSE) raster and a raster math tool is used to generate a difference raster between the WSE raster and the DEM. A polygon is then generated from the difference raster and all GRIDCODES = 0 are removed to produce the floodplain polygon. This polygon is then further edited to smooth the edges, fill in holes, connect discontinuities, etc. If it is a zone AE then an additional floodway polygon will need to be assembled and edited to conform to all top widths at cross sections.

The above GIS processing alone can take anywhere between 10-20 minutes and the manual editing process can take upwards to two or more hours depending on the zone type, size, and shape of the resulting polygon. If the BFE placements and/or elevations are not accurate the resulting polygon will be unusable and all files created will need to be deleted and the entire GIS process redone.

When a final polygon is produced it must be tested for accuracy in compliance with FEMA's Floodplain Boundary Standards (FBS). All zone A and AE types must pass FBS with a minimum of 95%. Using a combination of Xtool Pro and ESRI GIS processing tools the perimeter of the polygon must be converted to 100 ft. equidistant points. A 38 ft. buffer is then placed around each point. Using the buffered points, zonal statistics are calculated using the DEM and sample statistics are taken using the WSE raster for comparison. Next a long series of attribute selections must be performed to determine all points from the WSE raster values that are within -1 to 1 ft. of the DEM elevation values. These points will be passing points. If the difference is greater than 1 ft. or less than -1 ft. all these points will be failing. Points along zone merges or panel (map extent) boundaries can be considered invalid. When all these attribute selections and calculations have been made the results of FBS can be determined. If less than 95% of the points pass then an issue with the final polygon is found and further steps need to be made or the entire redelineation process redone completely.

The FBS process alone can take anywhere between 30 minutes to an hour depending on the zone type and the size. From start to finish the process is extremely time consuming and is not efficient when considering the hundreds if not thousands of zones that must be completed within multiple watersheds.

## **Redelineation Automation**

To drastically reduce GIS processing time the previous tools can be strung together using ArcGIS model builder in conjunction with embedded python expressions and a python script. The first step was to simply string together the tools used for the floodplain boundary

polygon, as mentioned previously, with the final steps being a select by attribute and delete field tools to remove GRIDCODES = 0 to create the raw polygon from the raster. To significantly reduce manual editing on the final polygon the Boundary Clean tool is used on the WSE raster. This tool expands and shrinks the raster resulting in a much smoother yet topographically accurate edge for the polygon. As a result the FBS checks almost always turn up 95-100% passing points. This also constructs consistent polygons regardless of the person redelineating. To further reduce time spent on redelineation some additional tools were added to clean up the polygon. The eliminate polygon part tool is used to remove polygons or holes that are less than a specified area which is set as an optional parameter in the tool interface. In order for this tool to work properly the area must be calculated using '!shape.area!' Python Expression after the polygon is generated and GRIDCODES removed.

Another vital model builder variable that can reduce time is the Workspace and Output name. Using the Calculate Value tool to set up a python expression with wildcards (see figure 3) to search the specified workspace for the required input shapefile, the tool can automate output names for all files produced. The Workspace and Output name are set as input parameters for the tool interface which effectively removes the need to have seven output parameters. This makes the tool much easier and keeps a good consistent naming convention. These variables also make it possible to overwrite previously created files in the case that the initial polygon was not useable allowing for the tool to be rerun with the same input parameters multiple times. This also means that redelineators can concentrate all their time on producing good BFEs that will ultimately produce a much more desirable polygon.

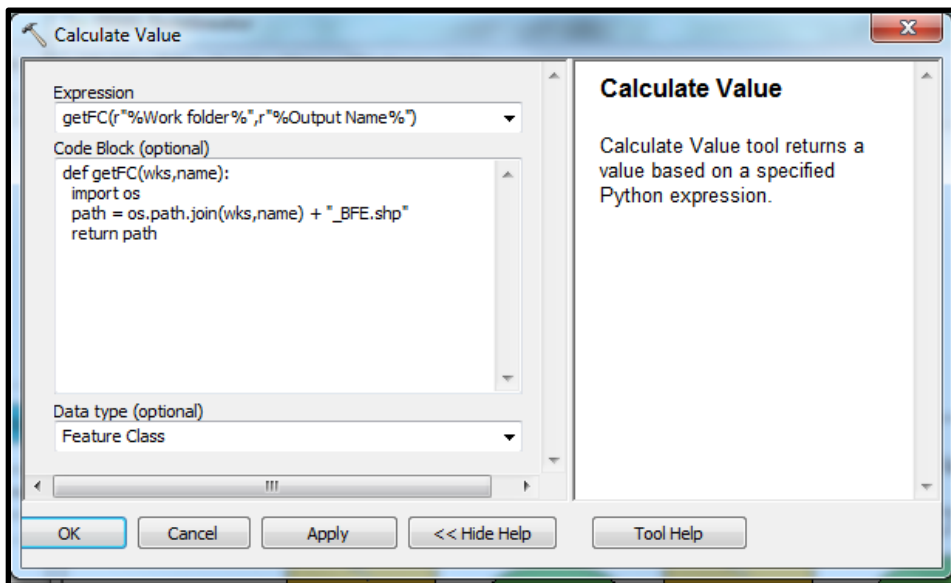


Figure 3: Python Expression for Workspace and Output name variables

The Redelineator Tool interface is set up with only three required input parameters; Work Folder, Output Name, and DEM. There is an optional Small Query Expression parameter to set the specified polygon size that will be removed (see Figure 4). All item descriptions for the tool have been modified to provide help tips and tool descriptions specific for each input parameter. Including inputting parameters, the automated tool creates all necessary output files in less than 10 seconds which is a vast improvement. The ability to run and rerun this tool multiple times to produce a good floodplain polygon significantly improves productivity and quality.

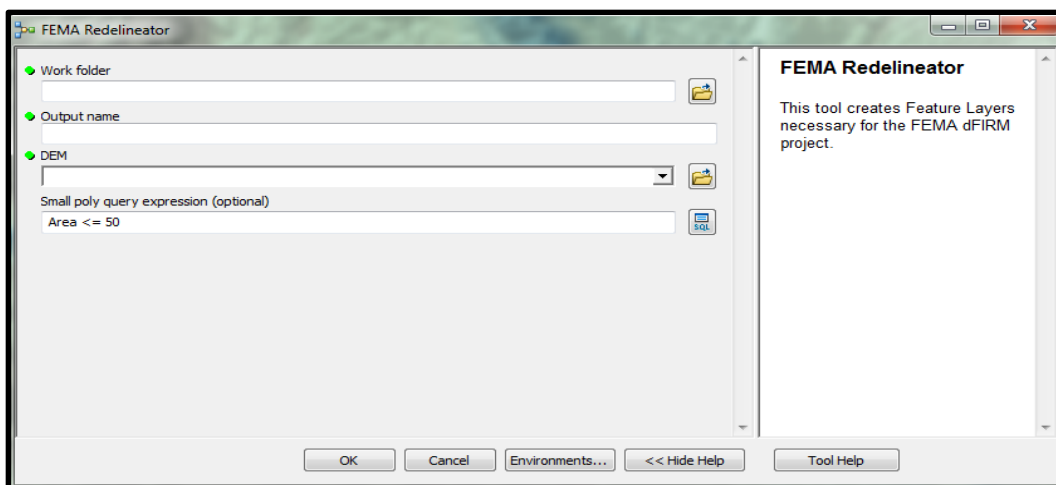


Figure 4: Redelineator Tool Interface



## FBS Automation

The FBS process was extremely difficult to work out to be an all in one tool with a simple interface. It took many trial and errors to work out all the kinks, but the effort was well worth it as it drastically reduced processing time. Again, the tool was set up by first stringing together all the necessary processes as mention in the methodology. The same python expression for workspace and output name as the redelineator tool was used, but modified to search for the “\_final\_poly.shp”. The final polygon was converted to a polyline and then converted to equidistant points. However, if it is a zone AE with a 500-year and floodway polygon, only the zone AE and floodway are required for FBS checks. For this reason a query selector was built into the tool as a variable to write an expression that would search for AE and floodway polygons then dissolve them and then continue with the process. For some time the XTools Pro convert to equidistant points tool was used, but now a standalone python script has been created to replace this. This tool converts the polyline feature into equidistant points by specifying the XY tolerance in feet or meters (see appendix). The FBS points are then buffered and pass through the sample and zonal statistics process to create required data tables. A series of required fields are then added that can be populated automatically. The FBS points are then passed through a series of attribute selections to determine passing and failing points.

The tool interface is set up similar to the redelineator tool with required input parameters for work folder and output name as well as DEM raster and WSE raster. There is also the optional query expression parameter that allows for zone type selection (See Figure 5). The tool’s item descriptions have also been modified to provide specific information for what the tool does and help tips for all input parameters. This tool completes the FBS point creation

and attributes calculations and population in less than 30 seconds. With the ability to run FBS for A and AE zones with floodways this tool is very versatile and markedly improves efficiency.

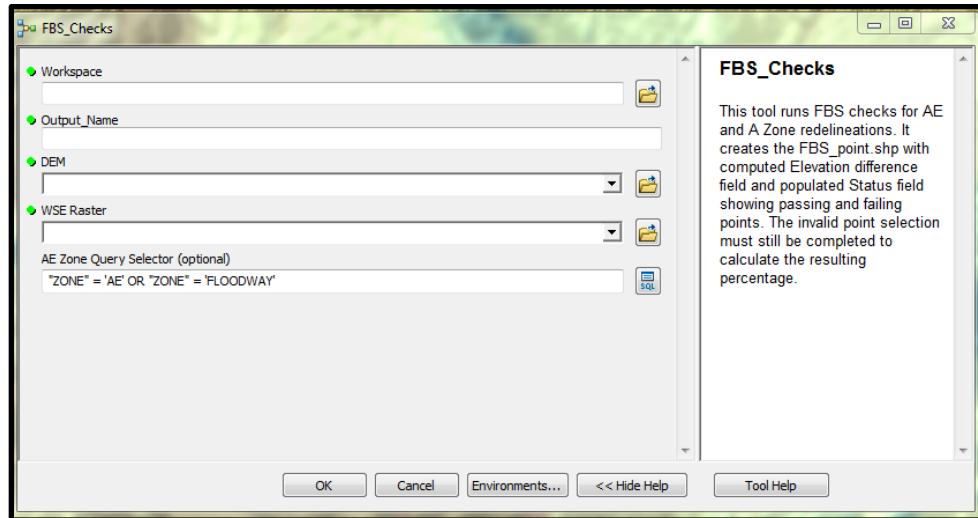


Figure 5: FBS Checker Tool Interface

## Issues and Recommendations

A major issue with the process that is not fully discussed within this paper is the use of panel boundaries for mapping purposes. This is an issue for zones that fall on multiple panels which is a very common issue. FEMA only funds certain panels to be redelineated, but also requires that all floodplain edges match for redelineated polygons and old SFHA polygons. This requires manually editing and in some cases where the old SFHA is shifted drastically away from the redelineated polygon it causes noticeable distortion. This could cause some obvious issues for people that may not really be in a floodplain, but according to the old SFHA they are. It would be highly recommended that either all watershed panels are funded for redelineation or place a hold on redelineated panels until all can be funded. As it stands the edge matching is

the only requirement on panels which, again, will most likely cause some issues within these communities when flood insurance premiums are issued.

## Conclusion

The redelineation process using new lidar and ESRI GIS mapping software produce much more accurate and updated floodplain risk maps for insurance and mitigation purposes. Although the GIS process is highly time consuming for redelineation and FBS checks, the automated tool set discussed in this paper drastically reduces process time. These tools also produce consistent results for all members of GIS teams involved. With good quality and consistent maps being produced in a much shorter amount of time, more funding will be brought to the companies that use this tool set. This will ultimately boost productivity and get these maps to FEMA and affected communities to aid in floodplain management.

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## References

Federal Emergency Management Agency. (2007). *Floodplain Boundary Standards Audit Procedure Version 2.0*. FEMA.

Federal Emergency Management Agency. (March 2009). *NFIP Floodplain Management GUIDEBOOK 5th Edition*. FEMA - Region 10.

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## Appendix

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```
'''-----
Script Name: CreateFBSPoints
Description: This Script converts polyline features
             to a 100ft equidistant point shapefile
             for Flood Base Standard (FBS) checks for
             FEMA Digital Flood Insurance Rate Maps.
Created By: Luke Sturtevant
Date:      4/10/2013
-----'''

import arcpy
import sys
from arcpy import env

#setup variables
arcpy.env.overwriteOutput = True
FC =sys.argv[1] # system argument for first input feature class parameter
interval =sys.argv[3] # system argument for third parameter linear unit interval
dist_units = sys.argv[3].split() # splits the interval value and unit string
dist = float(dist_units[0]) # converts interval value to float
units = dist_units[1] # interval unit
pointList = [] # empty array

# for loop to convert feet to meters
if units == "Feet":
    dist = dist * 0.3048

#create a search cursor for input polyline geometry
scur = arcpy.da.SearchCursor(FC, "SHAPE@")

#Set up a for loop that will calculate polyline length and interate point creation along
the line at set intervals
for row in scur:
    shapeLen = row[0] # row in polyline attribute table with geometry
    length = shapeLen.length
    print length #print the line length
    startPnt = 0 #set start point
    while startPnt < length: #iterate through the point creation along line while the
startPnt value is less than the total length of the polyline
        newPnt = shapeLen.positionAlongLine(startPnt) # create new point along the
polyline
```

```
pointList.append(newPnt) # append to the pointlist
startPnt = startPnt + dist # calculation to place point at set intervals along line
print startPnt

# Create FBS feature class from the pointList
print "Creating FBS Points"
fbsPnt =sys.argv[2] # system argument for second parameter output points
arcpy.CopyFeatures_management(pointList, fbsPnt)

print "Polyline converted to equidistant points."

del scur
```