

Post-wildfire Data Processing for Runoff Curve Number-based Models Using Custom GIS Tools

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Abstract

In the past several years, very large wildfires have become increasingly common. These wildfires cause short-term impairments to watersheds which can create dramatic increased threats from post-wildfire (post-fire) flooding and debris flows. Because of this, rapid assessments are needed to accurately identify potential threats to life and/or property. Post-fire watershed modeling is a key element in these emergency assessments.

Runoff Curve Number (CN) based models are frequently used for post-fire hydrology. However, these CN models rely on a significant amount of input data that is typically processed from a Geographic Information System (GIS). The numerous geoprocessing steps by an individual user can take several hours to develop the required input data.

This paper details the steps taken by the USDA Natural Resources Conservation Service (NRCS) in Washington State to develop a post-fire GIS Tool (GIS Tool) that automates these geoprocessing steps. This tool produces the required input data needed for CN based models in approximately five minutes whereas manually completing the process took several hours. The GIS Tool takes five different dataset inputs (layers and tables) – three included with the tool and two user inputs – and through a variety of operations, combines and processes the datasets into multiple products. The output layers and spreadsheets can then be analyzed for accuracy by the user and later may be utilized in different hydrologic models.

We will illustrate the features and functionality of the tool in a case study using data from the 2018 Cougar Creek fire in Washington State.

While there are improvements that can yet be made, the GIS Tool has proven its value in production, spanning multiple states and wildfire seasons.

Introduction

In the past several years, very large wildfires have become increasingly common. These wildfires cause short-term impairments to watersheds which can create dramatic increased threats from post-fire flooding and debris flows. Because of this, rapid assessments are needed to accurately identify potential threats to life and/or property. Post-fire watershed modeling is a key element in these emergency assessments.

Runoff Curve Number (CN) based models are frequently used for post-fire hydrology. However, these CN models rely on a significant amount of input data that is typically processed from a Geographic Information System (GIS). The numerous geoprocessing steps by an individual user can take several hours to develop the required input data.

Using Model Builder in ArcGIS Pro 3.0.2 (Esri) we have automated much of the geoprocessing required in the combining of several input datasets. Through the development of GIS tools with Model Builder, we were able to reduce the processing time for each project from several hours to a few minutes.

Input Datasets

Soil Burn Severity (SBS) (user-supplied): Post-fire surveyed layer that identifies areas as unburned or specific degree of soil burn severity (e.g., low, moderate, high). Some SBS datasets may also identify areas of some specific soil/geologic features such as rock outcrop and/or rubble lands. Doing so provides the ability to identify these areas geospatially. This layer is typically provided by Department of Interior or US Forest Service Burned Area Emergency Response (BAER) Teams.

StreamStats Watershed (user-supplied): StreamStats is a USGS tool that allows users to delineate a drainage basin and will generate a drainage basin boundary above the user-selected pour point. This basin will be utilized as the area of interest (AOI) for the Post-fire Analysis tool. The Post-fire Analysis tool allows the user to buffer the watershed to increase the AOI as needed for some hydrologic models (e.g., HEC-HMS Gridded CN method with the Modified Clark Transformation option).

National Land Cover Database (NLCD): The NLCD is a raster dataset created by the USGS that breaks the US into 30-square meter pixels and, using Landsat imagery, identifies each pixel as one of 16 land cover classes (e.g., mixed forest, barren land, cultivated crops, etc.). We converted the raster dataset to vector and clipped it to each state the tool has coverage for. The land cover designations are one parameter for determining CN's within the AOI.

Gridded Soil Survey Geographic Database (gSSURGO): Hydrologic Soils Group (HSG), Soil Map Unit Name, and Soil Map Unit Key. The gSSURGO dataset is soil geographic data developed by the National Cooperative Soil Survey and contains soil attributes in the tabular data. The HSG data derived from the gSSURGO dataset is combined with the NLCD to determine the pre-fire condition CN composition of the AOI. The map unit key is utilized to create a join with data from the Soil Data Access to determine the percent rock, rubble, water, and glacier of each soil map unit.

Soil Data Access Query: Natural Resources Conservation Service (NRCS)-hosted web services that allow querying of tabular soils data that may not be included in the gSSURGO dataset. For the Post-fire GIS Tool, a query was utilized that provided the percent of rock, rubble, water, and glacier for each map unit. The identification of the amount (acres) of rock, rubble, water, and glacier allows the user to identify the CN's and area (acres) within the selected AOI more specifically.

Runoff Curve Number Table: A user-defined table that provides CN's for burned and unburned conditions based on hydrologic soil-cover complexes. These complexes are a combination of land use and treatment classes (NLCD), SBS, and HSG. The CN is the most sensitive parameter of a CN-based model. Therefore, it is essential that each user edits this table to best reflect the site-specific conditions of each fire.

GIS Processes

The tool utilizes over 100 geoprocesses. Though several processes are used, the tool can be simplified into the following four steps:

- 1) Clip NLCD and Soil Burn Severity to Watershed boundary
- 2) Intersect, union, and or join NLCD layer, SBS layer, HSG layer, Rock/Rubble/Glacier/Water Soil Data Access Query table, and CN table
- 3) Dissolve into pre- and post-fire feature classes and Excel tables
- 4) Create CN rasters

Tool User Inputs

Users enter the following into the GIS Tool:

- Watershed boundary (AOI): Define in Datasets.
- Watershed buffer distance: May be buffered to expand the AOI for later conversion of end products (feature classes) to convert to raster for use with hydrologic models (e.g., HEC-HMS Gridded CN Method).
Default: no buffer
- Soil Burn Severity Layer: Defined in Datasets.
- Soil Burn Severity Field with Unburned, Low, Moderate and High values: User identifies the field in the attribute table that contains the soil burn severity levels.
- Unburned in SBS layer: User identifies, in the attribute table, the case-sensitive text used for an unburned value (e.g “unburned”, “Unburned”, “UNBURNED”). This is also the case for Low in SBS layer, Moderate in SBS layer, High in SBS Layer, Rock Outcrop in SBS layer, and Talus and Rubble in SBS layer.
Default: first letter upper case, remainder lower case (e.g., Low, Moderate, etc.)
- Output Geodatabase Location: Output location of produced geodatabase containing intermediate and final feature classes produced by GIS Tool.
- Output Geodatabase Name: Output name of produced geodatabase containing intermediate and final feature classes produced by GIS Tool.
- Pre-fire Output Layer: Output name of Pre-fire output layer generated by the tool.
Default: Pre_Fire_Output
- Post-fire Output Layer: Output name of Post-fire output layer generated by the tool.
Default: Post_Fire_Output
- Pre-fire Table Output Name and Location: Output name and location of generated Excel table of pre-fire results.
- Post-fire Table Output Name and Location: Output name and location of generated Excel table of post-fire results.
- Output Coordinate System: Output coordinate system for CN rasters.
- Grid Cell Size: Cell size of output CN rasters.
Default: 656.158 ft (200 m)
- Output Pre-Fire .tif – filename and location: Output name and location of generated raster of pre-fire results.
- Output Post-Fire .tif – filename and location: Output name and location of generated raster of post-fire results.

Products

The products of the GIS Tool are two feature classes – one pre-fire and one post-fire –, two Excel tables that are exports from the corresponding layers' tabular data, and two raster files created from the feature classes. The feature classes and Excel tables contain the data listed in Table 1 and the raster contains only the CN values. The user can utilize the Excel tables in hydrologic models that require tabular data (e.g., Wildcat5), while the CN rasters can be used for direct input into other hydrologic models (e.g., HEC-HMS Gridded CN Method).

Table 1. Pre and post-fire output Excel table and feature class attribute fields

Pre-fire Attribute Fields	Post-fire Attribute Fields
NLCD Land Cover Type	NLCD Land Cover Type
Hydrologic Soil Group	Hydrologic Soil Group
Pre-fire Curve Number	Soil Burn Severity
Total Acres	Burned (Yes/No)
Acres without Rock, Rubble, Water, and Glacier	Post-fire Curve Number
Acres of Rock	Total Acres
Acres of Rubble	Acres without Rock, Rubble, Water, and Glacier
Acres of Water	Acres of Rock
Acres of Glacier	Acres of Rubble
	Acres of Water
	Acres of Glacier

Case Study

Cougar Creek Fire in Washington

Fire Background: The Cougar Creek fire started from a lightning strike on July 28, 2018, and burned approximately 41,400 acres primarily in steep, rocky, forested terrain. It is primarily on lands managed by the Entiat Ranger District of the Okanogan-Wenatchee National Forest (USFS, 2018). The location of the strike (ignition) point is approximately 10 miles northwest of Ardenvoir, Washington. The fire was primarily encompassed within the area of the Mad River (MR) basin. The MR basin has a drainage area of 91.2 square miles, a mean basin slope of 36%, a relief of 5,700 feet, a maximum elevation of 6,970 feet, and a mean annual precipitation of 42.8 inches (USGS StreamStats). About 26% percent of the basin was burned in the fire with about 15% at moderate to high soil burn severity (SBS).

Fire Tool Implementation:

After the GIS Tool is opened using ArcGIS Pro, the Mad River Basin and Soil Burn Severity layers are added to the map (Figure 1).

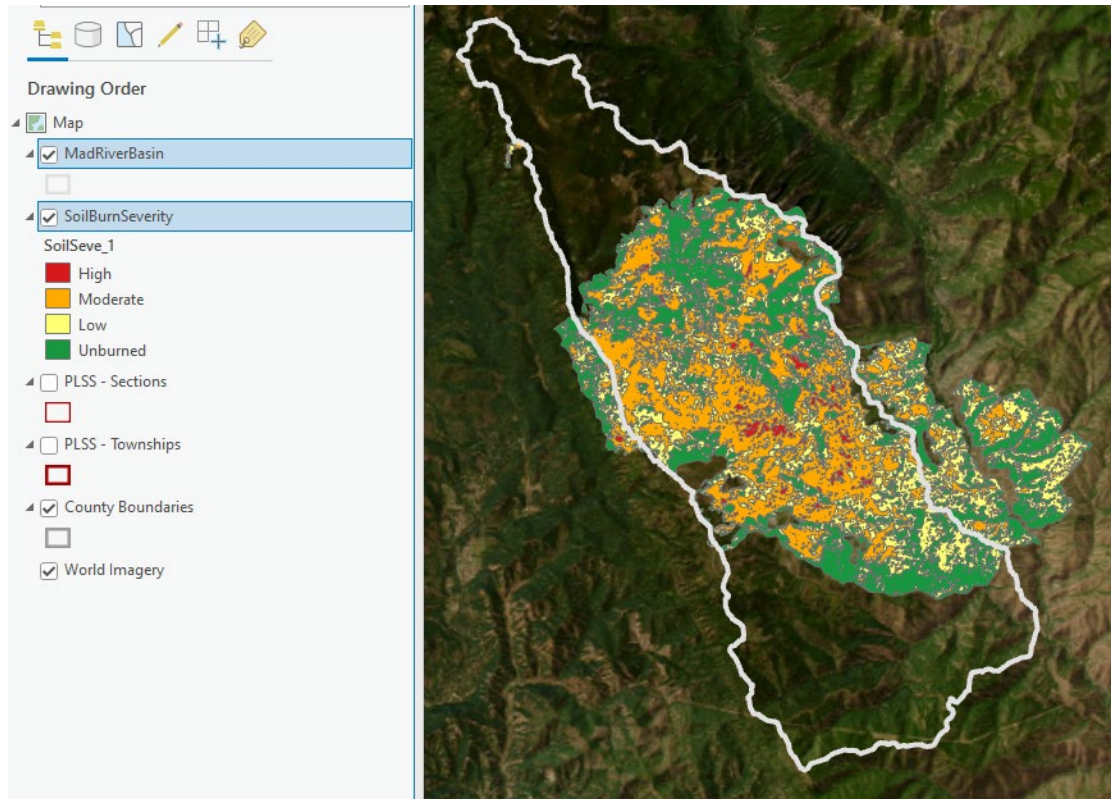


Figure 1. Watershed and SBS layers added to ArcGIS Pro project. The standard colors for SBS are: High – Mars red; Moderate – Solar yellow; Low – Tourmaline green; Unburned – Fir green.

The “1. Set AOI and Clip NLCD” tool is opened from the catalog pane (Figure 2).

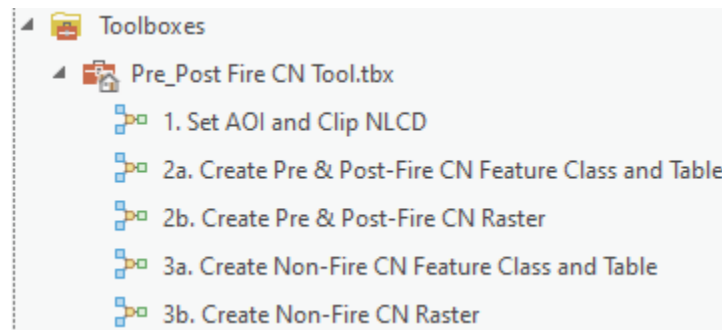


Figure 2. Toolbox containing five tools – the initial tool for setting the AOI and clipping the NLCD and the other four for generating CN grid data based on fire or non-fire analysis.

In the tool, the Mad River Basin is selected as the Watershed Boundary and a 5280-foot buffer is added (Figure 3) to facilitate the use of the output of this product in HEC-HMS.

1. Set AOI and Clip NLCD

Parameters Environments

Watershed Boundary
 MadRiverBasin

Watershed buffer distance/
 units - enter .01 for distance if
 none required
 5280 US Survey Feet

Figure 3. Parameters set for first tool.

The “2a. Create Pre & Post-Fire CN Feature Class and Table” tool is then opened. The Soil Burn Severity (SBS) layer for this project is selected for the first parameter (Figure 5). The attribute layer (Figure 4) is then opened to determine the next seven parameters. In this instance, the SBS field that contains the unburned, low, moderate, and high values is SoilSeve_1, which is entered for the second parameter (Figure 5). The SBS field name is not standardized and may be unique to each SBS layer. It’s also noted that the values in the SoilSeve_1 field begin with a single, capital letter and are followed by lower-case letters (i.e., Unburned, Low, Moderate, and High) and that there are no entries for “Rock Outcrop” or “Talus and Rubble Land”. Because of these details, the defaults for the following 6 parameters are maintained (Figure 5).

SoilBurnSeverity X								
Field: Add Calculate			Selection: Select By Attributes Zoom To Switch Clear Delete					
	FID	Shape *	OBJECTID	SSFinal_Ac	SoilSeveri	SoilSeve_1	Shape_Leng	Shape_Area
111	110	Polygon	111	0.098842	Low Soil Burn Severity	Low	80	400
112	111	Polygon	112	0.098842	Unburned or Underbu...	Unburned	80	400
113	112	Polygon	113	0.197684	Low Soil Burn Severity	Low	120	800
114	113	Polygon	114	0.296526	Low Soil Burn Severity	Low	160	1200
115	114	Polygon	115	0.395369	High Soil Burn Severity	High	160	1600
116	115	Polygon	116	0.098842	Low Soil Burn Severity	Low	80	400
117	116	Polygon	117	0.197684	Moderate Soil Burn Se...	Moderate	120	800
118	117	Polygon	118	0.098842	Unburned or Underbu...	Unburned	80	400

Figure 4. SBS layer attribute table with the field highlighted which contains the information needed to complete the second through the seventh parameters of the second tool.

← 2a. Create Pre & Post-Fire CN Feature Cl...

Parameters Environments

Soil Burn Severity Layer
 SoilBurnSeverity

Soil Burn Severity Field with Unburned, Low, Moderate, and High values
 SoilSeve_1

Unburned in SBS layer (case sensitive)
 Load Save Remove

SQL ☐

Where Soil Burn is eq Unburned X

+ Add Clause

Low in SBS layer (case sensitive)
 Load Save Remove

SQL ☐

Where Soil Burn is eq Low X

+ Add Clause

Moderate in SBS layer (case sensitive)
 Load Save Remove

SQL ☐

Where Soil Burn is eq Moderate X

+ Add Clause

Figure 5. First five parameters of the second tool.

In the eighth through the thirteenth parameters (Figure 6), the locations and the names of the products are selected. In this case, I've chosen to save the generated products in the same folder as the GIS Tool, but they may be saved elsewhere. After the parameters are completed, the tool is run.

Output Geodatabase Location

Output Geodatabase Name

Pre Fire Output Layer - Do Not Change

Post Fire Output Layer - Do Not Change

Pre Fire Table Output Name and Location (ensure.xlsx at end of filename)

Post Fire Table Output Name and Location (ensure.xlsx at end of filename)

Figure 6. The final six parameters.

The two output layers – pre and post-fire – are automatically added to the map (Figure 7) and the Excel files (Figure 8 and Figure 9) are added to the location specified in the final two parameters. A copy of the layers is also located in the file geodatabase located in the location specified in the eighth parameter.

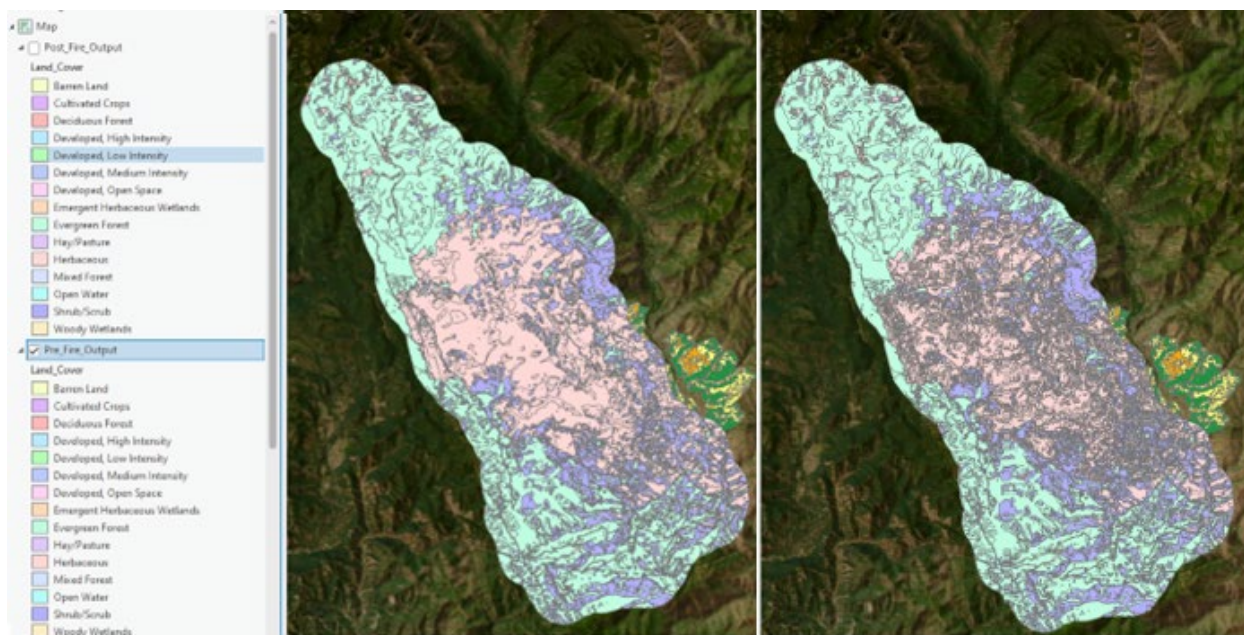


Figure 7. Pre-fire output layer (left) and post-fire output layer (right), symbolized to land cover attributes. Post-fire contains more features than the pre-fire output layer as it was unioned with the SBS layer.

Land_Cover	Hydrologic_Soils_Group_or_MUKEY	Pre_Fire_CN_or_MUNAME	Total Acres	Acres Without Rock, Rubble, Water, Glacier	Rock Acres	Rubble Acres	Water Acres	Glacier Acres
Evergreen Forest	67704	Rock outcrop	20	2	18	0	0	0
Evergreen Forest	67724	Rubble land-Rock	2	0	0	1	0	0
Evergreen Forest	68119	Water	0	0	0	0	0	0
Evergreen Forest	A	28	3562	3562	0	0	0	0
Evergreen Forest	B	51	11171	11150	22	0	0	0
Evergreen Forest	C	66	2899	2536	363	0	0	0
Evergreen Forest	D	73	1621	1560	61	0	0	0

Figure 8. Pre-fire output table showing only the “Evergreen Forest” land cover (full table not shown).

Land_Cover	Hydrologic_Soils_Group_or_MUKEY	Soil_Burn_Severity	Burned	Post_Fire_CN_or_MUNAME	Total Acres	Acres Without Rock, Rubble, Water, Glacier	Rock Acres	Rubble Acres	Water Acres
Evergreen Forest	67704	Unburned	Unburned	Rock outcrop	20	2	18	0	0
Evergreen Forest	67724	Low	Burned	Rubble land-R	0	0	0	0	0
Evergreen Forest	67724	Unburned	Unburned	Rubble land-R	2	0	0	1	0
Evergreen Forest	68119	Unburned	Unburned	Water	0	0	0	0	0
Evergreen Forest	A	High	Burned	63	0	0	0	0	0
Evergreen Forest	A	Low	Burned	37	6	6	0	0	0
Evergreen Forest	A	Moderate	Burned	55	3	3	0	0	0
Evergreen Forest	A	Unburned	Unburned	28	3552	3552	0	0	0
Evergreen Forest	B	High	Burned	74	1	1	0	0	0
Evergreen Forest	B	Low	Burned	58	38	37	1	0	0
Evergreen Forest	B	Moderate	Burned	69	12	12	0	0	0
Evergreen Forest	B	Unburned	Unburned	51	11120	11099	21	0	0
Evergreen Forest	C	High	Burned	82	0	0	0	0	0
Evergreen Forest	C	Low	Burned	70	60	55	5	0	0
Evergreen Forest	C	Moderate	Burned	78	17	15	2	0	0
Evergreen Forest	C	Unburned	Unburned	66	2822	2466	356	0	0
Evergreen Forest	D	Low	Burned	77	21	16	6	0	0
Evergreen Forest	D	Moderate	Burned	83	1	1	0	0	0
Evergreen Forest	D	Unburned	Unburned	73	1599	1544	55	0	0

Figure 9. Post-fire output table showing only the “Evergreen Forest” land cover (full table not shown).

If raster outputs (Figure 12) are desired from the Pre-fire and Post-fire outputs created earlier, the “2b. Create Pre & Post-Fire CN Raster” tool (Figure 11) is utilized. Before using this tool, all values in the both the Pre_Fire_CN_or_MUNAME field in the Pre_Fire_Output layer and the Post_Fire_CN_or_MUNAME field in the Post_Fire_Output layer must be integer values. Any non-integer values exist in these fields will result in holes in the raster outputs. Soil Map Unit Name (MUNAME) values in the two aforementioned fields must be updated to the appropriate CN values. MUNAME values are in the CN fields because some soil map units from gSSURGO do not have corresponding Hydrologic Soil Group values (Figure 10).

Post_Fire_Output X							
Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy							
	OBJECTID *	Shape *	Land_Cover	Hydrologic_Soils_Gro...	Soil_Burn_Severity	Burned	Post_Fire_CN_or_MUNAME
35	35	Polygon	Herbaceous	68119	Unburned	Unburned	Water
36	36	Polygon	Developed, Medium In...	D	Unburned	Unburned	93
37	37	Polygon	Emergent Herbaceous...	C	High	Burned	90
38	38	Polygon	Emergent Herbaceous...	B	Moderate	Burned	88
39	39	Polygon	Evergreen Forest	67724	Low	Burned	Rubble land-Rock outcrop...
40	40	Polygon	Developed, Open Space	A	High	Burned	76
41	41	Polygon	Developed, High Inten...	A	Moderate	Burned	93
42	42	Polygon	Developed, Low Inten...	67704	Unburned	Unburned	Rock outcrop

Figure 10. Post-fire output layer attribute table containing a mix of CN and MUNAME values in the “Post_Fire_CN_or_MUNAME” field. The MUNAME values (highlighted) must be manually updated to CN values.

The first input value is the output coordinate system. The default projection is USA Contiguous Albers Equal Area Conic USGS (feet). This projection was selected as the default because this is the projection currently required by HEC-HMS. The second input is the raster cell size and can be changed as needed to suite the project. The cell size linear unit (e.g., feet or meters) will match the projection selected in the previous step. The final two inputs are the output names and locations for the two raster products.

←
2b. Create Pre & Post-Fire CN Raster
+

Parameters
Environments
?

Output Coordinate System - Import
usa_contiguous_albers_equal_area_conic_usgs_feet.prj
from the Support Data folder unless a different projection
is desired.
USA Contiguous Albers Equal Area Conic USGS_fi

Grid Cell Size (feet or meters - determined by projection
selected in previous parameter - the linear unit of the
default projection in the previous parameter is feet)
656.168

Output Pre-Fire .tif - filename and location
Pre_Fire_CN.tif

Output Post-Fire .tif - filename and location
Post_Fire_CN.tif

Figure 11. Create Pre & Post-Fire CN Raster tool.

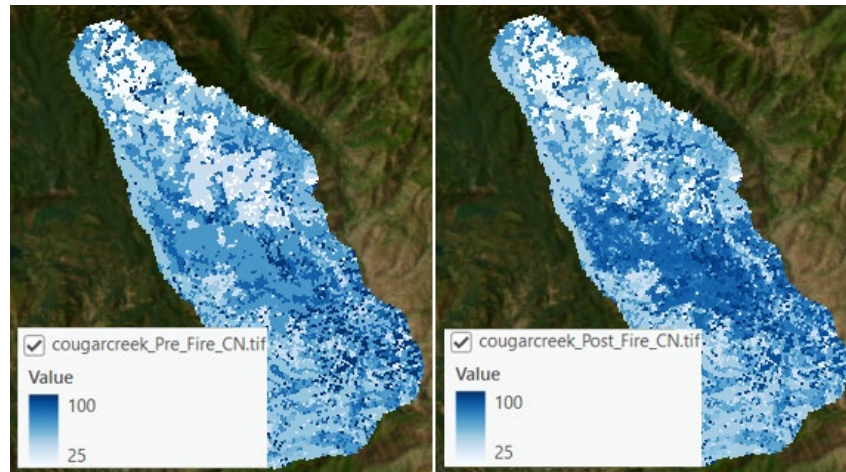


Figure 12. Pre-fire and Post-fire output rasters.

Results and Discussion:

Scaling: Due to file size limitations for distribution of a national tool, the datasets for this tool must be built individually for each state that chooses to adopt this tool and the tool must be updated to accept the datasets for the new states. The tool is currently available for Washington, New Mexico, Montana, and Indiana. The soil and NLCD datasets are not static and need to be updated occasionally. The tool for each state is approximately a gigabyte in size or larger which can create issues with hosting and distribution. These attributes all lead to a fair amount of overhead. We are investigating the use of webservices and other options to reduce overhead and increase scalability.

gSSURGO Gaps: There are large portions of the western US without SSURGO data (Figure 13). Many of these areas are US Forest Service lands and have some coverage of USFS Soil Resource Inventory or STATSGO2 soils data. We are currently investigating the possibility of using the USFS Soil Resource Inventory or NRCS STATSGO2 data to compliment the SSURGO data.

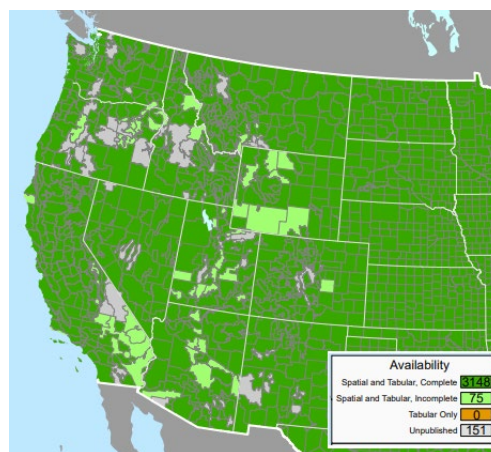


Figure 13. SSURGO availability in the western US.

Conclusion

The GIS Tool's value has been proven in production for multiple fire seasons and has continually been updated and improved to better suit the needs of the user. This tool will likely continue to evolve and be refined and will be potentially adopted by other users and states.

Acknowledgements

The creation of this GIS Tool was greatly aided by Steve Campbell, Soil Scientist, USDA – Natural Resources Conservation Service. His continued support was integral in the creation and enhancement of this GIS Tool and implementation of soils datasets.

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