Gridded CN Method for Post-Fire Hydrology

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Abstract

Wildfires can create short-term impairments to watersheds (basins) which may increase threats from post-fire flooding and debris flows. Because of this, rapid assessments are needed to accurately identify new potential threats to life and/or property.

Using the Distributed runoff curve number (Distributed CN) method, in lieu of the Weighted runoff curve number (Weighted CN) method, will simulate more accurate and consistent hydrologic model results of post-fire conditions. Currently there are only two hydrologic models known to use the Distributed CN method: WILDCAT5 and a specific procedure contained in the US Army Corps of Engineers (USACE) Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) software. Of the two hydrologic models, only HEC-HMS provides the functionality of modeling multiple subbasins and flood routing, which is often required when hydrologic modeling the effects from large fires.

This paper details the Gridded CN Method for Post-fire Hydrology procedure developed by the USDA Natural Resources Conservation Service (NRCS) in cooperation with the USACE HEC. The procedure utilizes the Gridded SCS Curve Number Loss Model with the Modified Clark Transformation option (Gridded CN/ModClark Loss Model) available with the HEC-HMS software. This procedure is applicable when modeling requires analysis of the effects from large basin areas and flood routing. This paper presents a case study using data from the 2018 Cougar Creek fire in Washington State (WA) to illustrate the procedure and comparative analyses of the Distributed CN method to the Weighted CN method.

Introduction

Wildfires can create short-term impairments to basins which may cause dramatic increased threats from post-fire flooding and debris flows. Because of this, rapid assessments are needed to accurately and consistently identify new potential threats to life and/or property.

While the NRCS National Engineering Handbook, Hydrology, Chapter 10, “Estimation of Direct Runoff from Storm Rainfall” (NRCS 2004) states that there is no reason for choosing the Weighted (Average) CN over the Distributed CN, current practice within NRCS continues to favor using the Weighted (Average) CN. If the CNs for the various hydrologic soil-cover complexes are similar or close in value, both methods of weighting give close results for runoff. However, where differences in CN for a watershed are large, this method (Weighted CN) either under- or over-estimates runoff, depending on the size of the storm (NRCS, 2004). There are typically large differences in CN for watersheds recently impacted by wildfire. The method of weighted Q (Distributed CN) provides a more accurate estimate (in terms of the given data), but it requires more work than the weighted-CN (Average CN) method especially when a basin has many hydrologic soil-cover complexes (NRCS, 2004). However, with recent advancements in computer software, the previous statement regarding more work no longer applies. Therefore, using the Distributed CN method, built into WILDCAT5 and the HEC-HMS Gridded

CN/ModClark Loss Model, will provide more accurate and consistent results of post-fire hydrologic conditions.

Hawkins and Barreto-Munoz (2016) developed WILDCAT5 as an interactive Windows™ Excel software package designed to assist basin specialists in analyzing rainfall-runoff events to predict peak flow and runoff volumes generated by single event rainstorm for a variety of basin soil and vegetation conditions. The distinct advantage that WILDCAT5 offers over most other models is the ability to easily and quickly calculate direct runoff using the Distributed CN method. Although WILDCAT5 has several advantages, it also has limitations. Most notably the inability to account for multiple subbasins in an individual simulation, the inability to account for flow routing, and the inability to analyze data spatially. That said, WILDCAT5 is appropriate for use in post-fire hydrologic modeling where these limitations do not impair the results: small basins that do not require flow routing.

HEC-HMS is designed to simulate hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. Advanced capabilities are also provided for gridded runoff simulation using the ModClark linear quasi-distributed runoff transform (USACE, January 2022).

In the past several years, large wildfires have become increasingly common. Hydrologic modeling the effects from these large fires can often be difficult and expend a great deal of workforce time when the results are promptly required. Because of the limitations with WILDCAT5, there has been a need for a hydrologic CN based model that will accurately, consistently, and timely analyze the hydrologic effects from large fires. Efforts have been attempted to resolve these modeling issues. Some models use the Weighted CN method and/or use short duration storms distributed over an entire large basin, both of which can lead to inaccurate and inconsistent results. With recent advances, the HEC-HMS Gridded CN/ModClark Loss Model can now fill this gap.

Case Study

This section presents a case study which describes the Gridded CN/ModClark Loss Model using data from the 2018 Cougar Creek fire in WA. NRCS in cooperation with USACE utilized the HEC-HMS Gridded CN/ModClark Loss Model to develop the case study which will be incorporated into the NRCS Technical Note Number 4, “Hydrologic Analyses of Post-Wildfire Conditions” (NRCS, August 20016). A tutorial with step-by-step instruction is also being developed to assist the User in developing a post-fire model using the Gridded CN/ModClark Loss Model.

Wildfires in WA frequently occur in ungaged areas making hydrologic assessments more difficult. The case study location was chosen because it encompasses a large fire area and has an active USGS Stream Gage (12452890) located within the study basin with 20+ years of record. The presence of stream gage data will allow for future model calibration and validation.

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 (Figure 1). Based on information from the Burned Area Emergency Response (BAER) report (USDA-FS, 2018), the fire was mostly on federal lands managed by the Entiat Ranger District of the Okanogan-Wenatchee National Forest. The location of the lightning strike (ignition point) was approximately 10 miles northwest of Ardenvoir, Washington. 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, 2018). About 36% percent of the basin was burned in the fire (Figure 2) with about 20% at moderate and about 1.5% at high soil burn severity (SBS). Fire-induced or altered hydrophobicity occurred on 100% of high and 50% moderate SBS (USDA-FS, 2018). For the selection of CN values, 100% high SBS was designated as hydrophobic, while 0% moderate SBS was designated as hydrophobic.

Figure 1 – Photo of Cougar Creek Fire Post-Fire Conditions

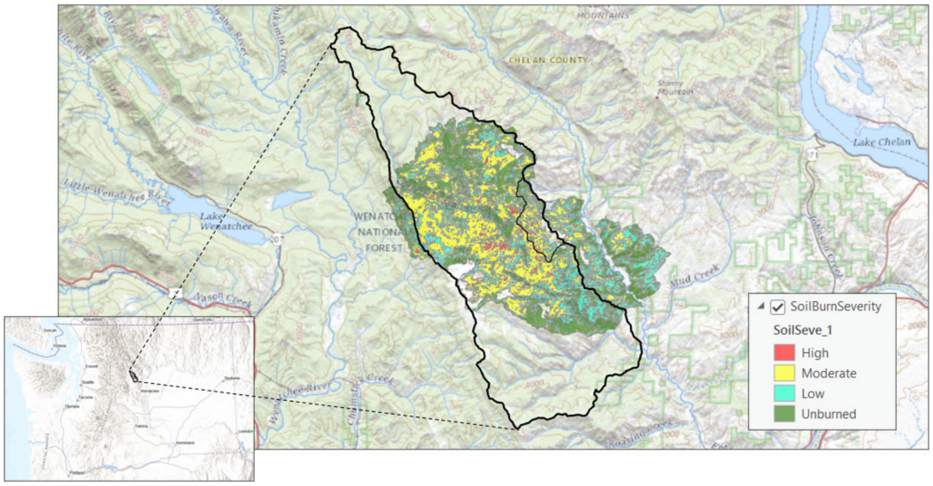


Figure 2 – Mad River Basin, Windy Creek Subbasin, and Cougar Creek Fire SBS

Method: This case study provides an example of a rainfall-runoff model utilizing the HEC-HMS Gridded CN/ModClark Loss Model. For a comparative analysis, two separate models were developed: one using a single large basin and the other using 21 subbasins. Additionally, each of these models then consisted of a HEC-HMS Gridded CN/ModClark Loss Model (Distributed CN) and a HEC-HMS SCS Curve Number Loss Model (Weighted CN) for both the pre- and post-fire conditions and two different storm events. HEC-HMS version 4.9 was used for this study due to agency approved software. The models were used to simulate the expected runoff response for both pre- and post-fire conditions.

When using the ModClark Transformation option with the Gridded CN Loss Model, each grid cell within a subbasin receives its own precipitation and losses/excess and are computed using the grid cell's CN value. Both the Gridded CN Loss Model and the ModClark Transformation option must be selected in HEC-HMS for this process to mimic the Distributed CN method. This procedure resolves the limitations associated with WILDCAT5 hence enabling the analyses of multiple subbasins and flood routing, both of which are typically required when modeling the hydrologic effects from large fires.

Gridded CN/ModClark Loss Model Workflow:

1. Create terrain data, new project, and import terrain data
2. Create CN grid data
3. Create DSS CN grid file
4. Import precipitation-frequency grid
5. Delineate subbasin and reach elements from terrain data
6. Input subbasin parameters
7. Create meteorological model
8. Create control specification

Terrain Data: The terrain data was prepared using a 1/3 arc-second (~10-meter) digital elevation model (DEM) raster from open-source elevation data (USGS, TNM Download, v2.0) and a 1-mile buffer area of the MR basin.

CN Grids: Pre- and post-fire CN feature layers, with a 1-mile watershed boundary buffer, were created using the NRCS GIS Tool for Post-fire Hydrology Data (NRCS GIS Tool) (Burken and Lange, 2023) in ArcGIS Pro version 3.0.2 (ESRI, 2022). The CN feature layers were converted into rasters with 200-meter grid cells (Figure 3) and then imported into HEC-HMS. A date storage system (DSS) CN Grid file was then created for each pre- and post-fire CN raster using HEC-DSSVue (USACE, 2021). The NRCS tutorial for the Gridded CN/ModClark Loss Model will provide step-by-step instructions to assist the User in developing the pre- and post-fire gridded CN rasters and DSS files. The Zonal Statistics as Table geoprocessing tool (ArcGIS Pro) was used to develop basin and subbasin Weighted CN values since the Expression Calculator was not available in HEC-HMS version 4.9.

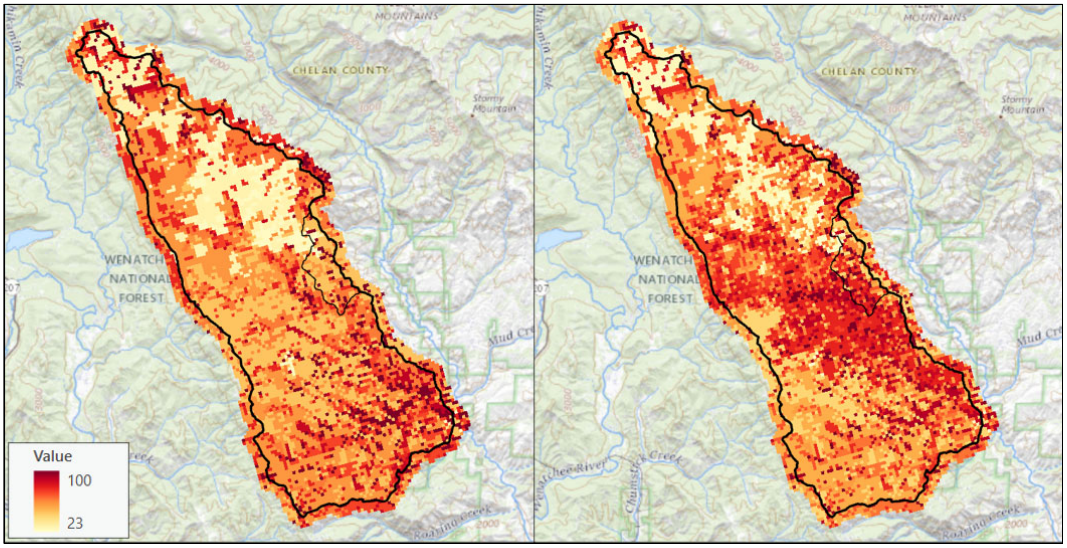


Figure 3 – Pre-Fire (left) and Post-Fire (right) CN Rasters

Precipitation-Frequency Grids: In North Central WA there are two common types of meteorological storms: very isolated convective events with high intensity and short duration which typically occur during the summer, and very broad maritime events with low intensity and long duration which typically occur during the winter. A precipitation-frequency grid was used for the long duration (24-hr) maritime event that could potentially occur over the entire basin. A precipitation-frequency grid was not used for the short duration (1-hr) convective event because it is not physically possible to occur over the entire basin. In WA, NOAA Atlas 2 is the formal precipitation source for durations between 2- and 24-hrs. However, precipitation-frequency grids are only available for the 2-yr and 100-yr from NOAA Atlas 2. Since the 25-yr was defined as the design storm, the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Precipitation-Frequency Grids (MGS, 2006) were used for the 25-yr frequency grid.

Subbasin and Reach Elements: Terrain preprocessing and watershed delineation (Figure 4) was done using the GIS functions in HEC-HMS and the terrain data. The outlet was placed at the USGS Gage 12452890 location. The subbasins (21) were limited to a maximum size of approximately 5-square miles by adjusting the stream threshold parameter. The purpose of the 5-square miles subbasin area limitation is based on the approximate physical maximum size of a convective storm. This allows an isolated convective storm to be modeled within each specific subbasin. Further explanation of this is described in the Meteorology – Weighted Gage section.

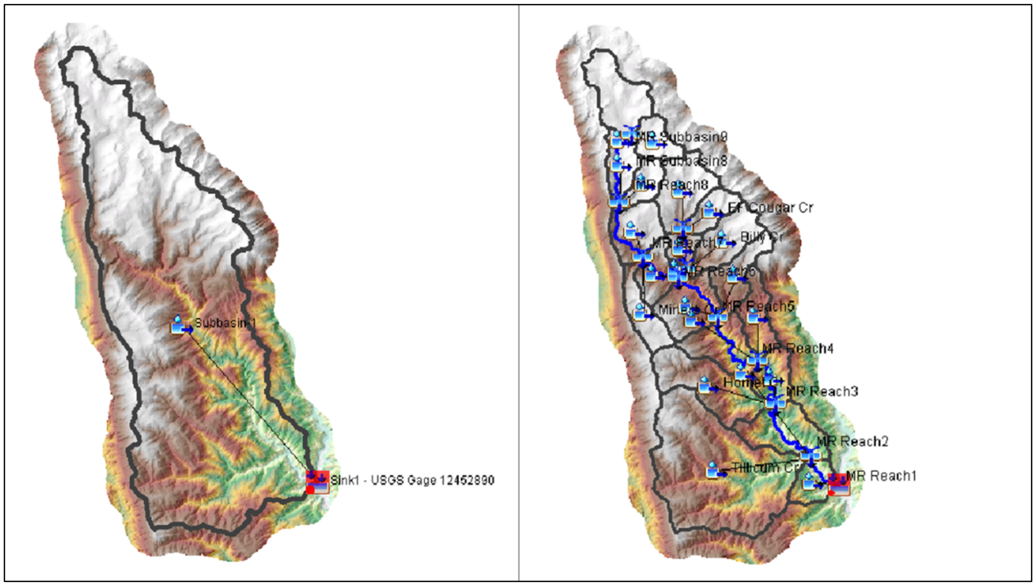


Figure 4 – Mad River Delineated Single Basin (left) and 21 Subbasin (right)

Subbasin and Reach Parameters: For the Gridded CN/ModClark Loss Model Subbasin parameters, the Discretization Method was set to Structured, the Loss Method was set to Gridded SCS Curve Number, and the Transformation Method was set to ModClark. The gridded data for the Curve Number grids were created from the DSS CN pre- or post-fire files and imported for the subbasin Loss method. The Loss Ratio, or initial abstraction (Ia) ratio (Ia divided by the maximum potential storage S or Ia/S), also referred to as lambda (λ) was set to 0.05. The Global Editor in HEC-HMS was used with the delineated subbasin and reach elements to calculate the time of concentration (Tc) based on the Kirpich equation. The Kirpich equation does not account for the change in CN values from pre- to post-fire, which results in a shorter

Tc, and a higher peak flow. This conservatism is advantageous when dealing with emergency situations where there may be a risk to loss of life.

For the SCS Curve Number Loss Model Subbasin parameters, the Discretization Method was set to Structured, the Loss Method was set to SCS Curve Number, and the Transformation Method was set to SCS Unit Hydrograph. The pre- or post-fire raster was used for the discretization input file. For the Loss Method, the λ was set to 0.05, the Weighted CN was calculated for each subbasin using GIS geoprocessing, and the impervious amount was 0%. For the Transformation Method, the Standard (PRF 484) Unit Hydrograph was used, and the same process as the Gridded CN/ModClark Loss Model was used for calculating the subbasin Lag Times.

For the Reach parameters, the Muskingum-Cunge routing method was used. Parameters for channel length and slope were obtained from the Reach Characteristics within HEC-HMS. A value of 0.045 was estimated for the Manning's n roughness coefficient. The Celerity Index Method was used with a value of 5.0 feet per second. An eight-point channel shape was used with Manning's n values of 0.10 for both the left and right overbank regions. The station-elevation data for the eight-point channel shapes were estimated using Google Earth Pro.

Meteorology: Two meteorological methods were used: The Gridded Precipitation and the Specified Hyetograph. The Gridded Precipitation was used to simulate the long duration (24-hr) maritime event that could potentially occur over the entire MR basin. The Specified Hyetograph method was used for the short duration (1-hr) convective event that could possibly occur over a single subbasin.

Both meteorological methods used a custom storm pattern. The Gridded Precipitation method used a 24-hr design storm pattern represented by a paired data percentage curve which was based on precipitation records from nearby climate stations for four historically significant maritime storm events between 2006 and 2015. The Specified Hyetograph method used a 1-hr storm pattern based on a short duration convective storm event (Arkell and Richards, 1985). The custom storm patterns were compared to the historical storms, NRCS Type-IA, NRCS Type-II, and uniform storm patterns (Figure 5).

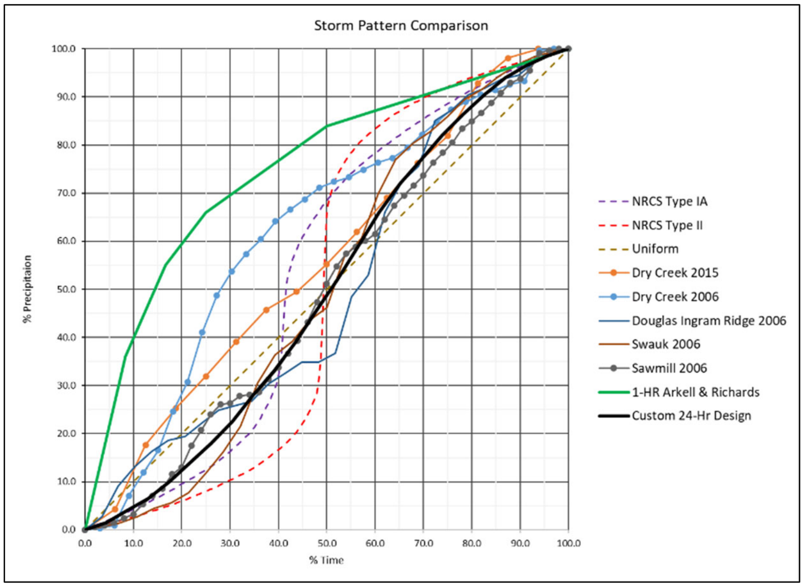


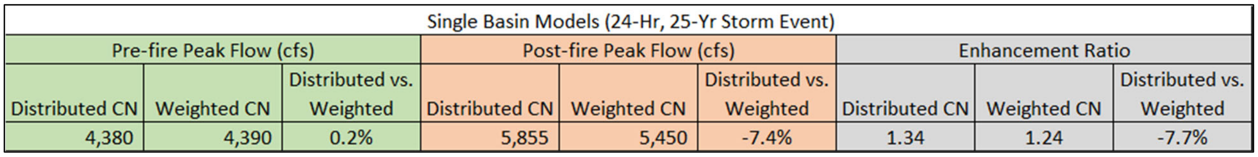
Figure 5 –Storm Distribution Percentage Curves

The Specified Hyetograph used two precipitation gages, one with precipitation (Precipitation Gage) and one with no precipitation (Zero Gage), to simulate a 1-hr convective storm for a specified subbasin(s). Each subbasin was set to a specified gage. This was the rationale for using a maximum 5-square mile subbasin from adjusting the stream threshold size. By specifying the Precipitation Gage, a subbasin will be modeled with precipitation. By specifying the Zero Gage, a subbasin will be modeled with no precipitation. This allows the User to systematically model a convective event by subbasin and to resolve errors in modeling a convective event basin wide.

Results and Discussion: The 2019 NLCD layer was originally used for the pre-fire conditions in the NRCS GIS Tool. However, the initial model resulted in extremely high peak flows for the pre-fire condition. Upon review of the data and steps, it was found that the incorrect NLCD (2019) layer was used in the NRCS GIS Tool. Since the Cougar Creek fire occurred in the summer of 2018, the 2019 NLCD represented the post-fire landcover condition and not the intended pre-fire landcover condition. Therefore, for this case study, the 2019 NLCD layer was replaced with the 2016 NLCD layer in the support data for the NRCS GIS Tool.

Comparative analyses of the HEC-HMS Gridded CN/ModClark Loss Model (Distributed CN) to the HEC-HMS SCS Curve Number Loss Model (Weighted CN) were performed using pre- and post-fire peak flows from the 24-hr, 25-yr event (gridded hypothetical storm) and the 1-hr, 25-yr event (specified hyetograph storm).

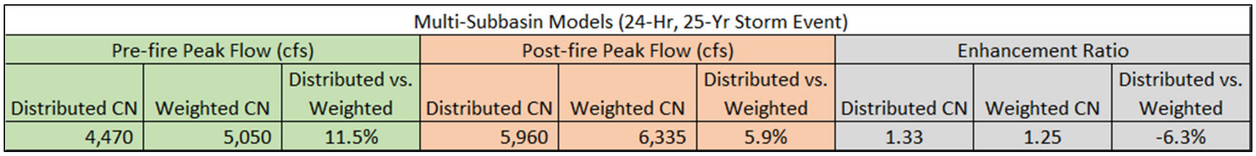
Results from the single basin models (Table 1) show that the pre-fire peak flows from the two methods are essentially the same (0.2% difference). However, for the post-fire flow, the Weighted CN procedure underpredicts by 7.4%. Comparison of the peak flow (un-bulked) enhancement ratio (Qpost/Qpre) shows that the Weighted CN procedure also underpredicts the enhancement ratio by 7.7%. Peak flow enhancement ratios can be used to easily communicate the degree to which the watershed hydrology has been affected by fire.



Single Basin Models (24-Hr, 25-Yr Storm Event)								
Pre-fire Peak Flow (cfs)			Post-fire Peak Flow (cfs)			Enhancement Ratio		
Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted
4,380	4,390	0.2%	5,855	5,450	-7.4%	1.34	1.24	-7.7%

Table 1 – Single Basin Comparison of Pre-fire and Post-fire Peak Flows

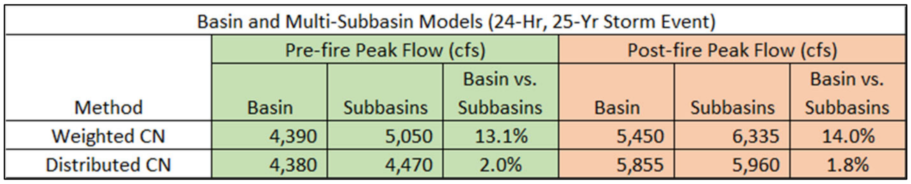
Results from the multi-subbasin models (Table 2) show that for both the pre- and post-fire peak flows, the Weighted CN procedure overpredicts by 11.5% and 5.9% respectively. However, comparison of the peak flow (un-bulked) enhancement ratio shows that the Weighted CN procedure underpredicts the enhancement ratio by 6.3%.



Multi-Subbasin Models (24-Hr, 25-Yr Storm Event)								
Pre-fire Peak Flow (cfs)			Post-fire Peak Flow (cfs)			Enhancement Ratio		
Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted
4,470	5,050	11.5%	5,960	6,335	5.9%	1.33	1.25	-6.3%

Table 2 – Multi-Subbasin Comparison of Pre-fire and Post-fire Peak Flows

Results from the basin and multi-subbasin models (Table 3) show that for both the pre- and post-fire peak flows, the Weighted CN procedure overpredicts by 13.1% and 14.0% respectively when going from a single basin to a multi-subbasin model. However, there is little change (~2%) with the Distributed CN procedure when going from a single basin to a multi-subbasin model.

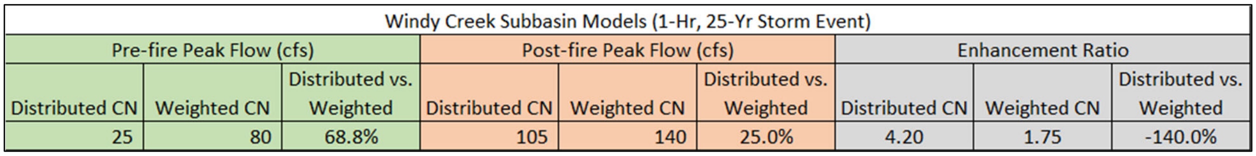


Basin and Multi-Subbasin Models (24-Hr, 25-Yr Storm Event)						
	Pre-fire Peak Flow (cfs)			Post-fire Peak Flow (cfs)		
Method	Basin	Subbasins	Basin vs. Subbasins	Basin	Subbasins	Basin vs. Subbasins
Weighted CN	4,390	5,050	13.1%	5,450	6,335	14.0%
Distributed CN	4,380	4,470	2.0%	5,855	5,960	1.8%

Table 3 – Basin to Multi-Subbasin Comparison of Peak Flows

The Windy Creek subbasin was used for the comparative analyses of the 1-hr, 25-yr event. Windy Creek has a drainage area of 3.3 square-miles, a mean basin slope of 28.9%, a relief of 3,000 feet, a maximum elevation of 5,470 feet, and a mean annual precipitation of 37.3 inches (USGS StreamStats). About 67% percent of the subbasin was burned in the fire with about 38% at moderate and 7% high SBS (USDA-FS, 2018).

Results from the Windy Creek subbasin models (Table 4) show that for both the pre- and post-fire peak flows, the Weighted CN procedure overpredicts by 68.8% and 25.0% respectively. However, comparison of the peak flow (un-bulked) enhancement ratio shows that the Weighted CN procedure significantly underpredicts the enhancement ratio by 140%. The results indicate that the variability with the Weighted CN procedure is significantly greater from a short duration storm than that from a long duration storm.



Windy Creek Subbasin Models (1-Hr, 25-Yr Storm Event)								
Pre-fire Peak Flow (cfs)			Post-fire Peak Flow (cfs)			Enhancement Ratio		
Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted	Distributed CN	Weighted CN	Distributed vs. Weighted
25	80	68.8%	105	140	25.0%	4.20	1.75	-140.0%

Table 4 – Subbasin Comparison of Pre-fire and Post-fire Peak Flows

The results shown in Tables 1 through 4 validate that where differences in CN for a basin are large, the Weighted CN procedure either under- or over-estimates flow. In this case study, the differences in CN range from a minimum of 23 to a maximum of 93. This difference is significant with a range of 70, yet typical for post-fire CN values. The Weighted CN procedure under-estimated by as much as 7.4% while at other times over-estimated by as much as 68.8%, making the results of the Weighted CN procedure extremely inaccurate and inconsistent.

The results validate the consistency of the Distributed CN procedure, and that the Distributed CN procedure provides more accurate and consistent results (in terms of the given data). With HEC-HMS, the Gridded CN/ModClark Loss Model (Distributed CN) estimates consistent flow regardless of the precipitation amount or number of subbasins.

A sensitivity analysis was performed for the Gridded CN/ModClark Loss Model. The original CN rasters were developed with a cell size of 200-meters and modeled using a 200-meter discretization. CN rasters were then developed using a cell size of 20 meters and modeled using a 20-meter discretization. The SBS maps also used a 20-meter cell size. Based on results from this case study, a change in magnitude for the raster resolution and discretization relates to little change in peak flows (<1%), while significantly increasing the simulation time (~14 times). That said, the simulation times, at 200-meters and 20-meters, was only ~30-seconds and ~6-minutes, respectively.

Accuracy and Limitations: As with any CN based model, the proper selection of CNs for both pre- and post-fire conditions is one of the most essential parameters. This paper does not detail the specific pre- and post-fire CN values as this would be an extensive paper in itself. Furthermore, there are no accepted CN values for Forest cover conditions which is often the most prominent condition in a wildfire area in the Western United States. Until further research is completed the User must demonstrate good professional judgement and utilize information from soil burn severities and soil-cover complexes for the specific fire. Good communication with BAER teams is key for obtaining this information.

CN based models are applicable in cases where overland flow is a major component of the runoff process. However, there are several watershed runoff response patterns that are not in accord with CN conditions (Hawkins, 2009). In these cases, there is little evidence of overland flow. Such a case is frequently observed in mature forests (Dun et al., 2009; Srivastava et al., 2013 and 2015; Elliot et al., 2016). These watershed characteristics could be present in the pre-fire (unburned) condition of some mature forest areas. However, these watershed characteristics may not be present in the post-fire (burned) condition. Therefore, the CN method may be applicable for post-fire modeling of forested watersheds. That said, the User will be faced with a significant challenge when watershed characteristics are represented in a wide mosaic of burned and unburned mature forest conditions.

In addition to the CN values for forest cover condition issues mentioned above, there are also CN issues related to λ, HSG, and Antecedent Runoff Conditions (ARC). CN values were originally represented using $\lambda = 0.20$ (Mockus, 1954). However, later works (e.g., Jiang, 2001) found the relation to more appropriately be $\lambda = 0.05$. Several equations have been developed for conversion of CNs between 0.20 and 0.05. For this case study, the CN were based on a $\lambda = 0.05$.

CN values from handbook tables based on HSG and land use are not precise and will vary among different Users. Those CN tables are estimates of the potential hydrologically defined values but based on perceived soils and land use descriptors. Numerous studies have demonstrated a lack of overall correlation between data-defined and handbook-estimated (Hawkins, 1984; Hossein et al., 1989; D'Asaro et al., 2014, Hawkins and Ward, 1998; Tedela et al., 2012; and Woodward et al., 2010). While extremes are much greater, about half of the CN differences are in the general range of about ±10 CNs. These differences can be attributed to an uncertainty in the definition of HSG, in the natural variability occurring within a site and soils classification, and the land use/conditions descriptions are by nature imprecise and/or subjective in addition to seasonal variability.

The NRCS (2004) states that rainfall-runoff data do not fit the curve number runoff concept precisely. The variability in the CN results from rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature. These causes of variability are collectively called the Antecedent Runoff Condition (ARC). ARC is divided into three classes: II for average conditions, I for dry conditions, and III for wetter conditions. For this case study, the CN values were based on ARC II.

There are two limitations with soils data: Gridded Soil Survey Geographic (gSSURGO, 2023) Database data gaps, and no geospatial representation for special soil features (e.g., rock, rubble, water, glaciers, etc.). The gSSURGO data gaps can be supplemented with United States General Soil Map (STATSGO2, 2023) data, but at a much lesser scale of detail. Based on the tabular output from the NRCS GIS Tool, the percentage of special soil features within the MR basin are ~5% for rock and ~0.5% for rubble. It was assumed that the amount for either would be insignificant in the final model results. Therefore, no geospatial representation for special soil features was done for this case study.

Recent updates to HEC-HMS (version 4.11 or newer) includes the process of transposing gridded precipitation data. Gridded storm transportation will allow a User to use historical gridded precipitation data from actual storm events and transpose the storm center to another location. In addition, there is also an optimization feature that will automate the transposition process for a set of User defined parameters. This process addresses one of the single most problematic errors of post-fire modeling which is Users applying a convective hypothetical storm over an entire large basin (approximately greater than 5 square miles) where this type of meteorological condition does not naturally exist.

Conclusion: The case study demonstrates that the HEC-HMS Gridded CN/ModClark Loss Model can be used to simulate the Distributed CN method. With HEC-HMS, the ability and time to use the Gridded CN/ModClark Loss Model is basically the same as that required for the SCS Curve Number Loss Model, yet the Gridded CN/ModClark Loss Model is more accurate and consistent. That said, the Gridded CN/ModClark Loss Model should usually be selected when post-fire modeling requires multiple subbasins and/or flood routing.

As software tools continue to improve over time, it is likely that the input data will also need to improve. The case study demonstrates that the Gridded CN/ModClark Loss Model simulates acceptable results, however the quality of the input data is essential for obtaining accurate and consistent results.

Even though this case study demonstrates how to effectively model hydrologic effects from large fires using the HEC-HMS Gridded CN/ModClark Loss Model, the post-fire effects on small areas should not be overlooked. Neary (2005), stated that the largest discharges often occur from smaller areas. Biggio and Cannon (2001) examined runoff after wildfires in the Western United States and found that specific discharges were greatest from relatively small watersheds less than 0.4 mile^2 (Figure 6). Therefore, modeling the effects of smaller watersheds should not be discounted as these may pose the greatest risk to loss of life and/or property. This also supports the reasoning for modeling the effects of convective storms over a small area.

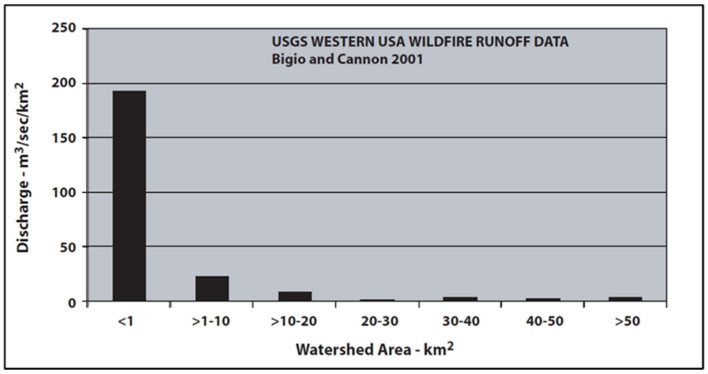


Figure 6 – Post-wildfire specific discharge and watershed area. (Adapted from Biggio and Cannon 2001).

Future Work: There have been some limited efforts to spatially identify the special soil features (e.g., rock, rubble, water, glaciers, etc.) and hydrophobic soils within the SBS feature layer. However, since SBS features are typically BAER products, cooperation in the future with BAER Teams will be needed to insure the inclusion of these features when applicable.

Lastly, additional work using the Gridded CN/ModClark Loss Model is needed to refine CNs by modeling historical storms and in comparison, with recorded flow data. This work will calibrate modeled flow to measured flow by refining CN values. The refinement of post-fire CNs is not likely possible using the SCS Curve Number Loss Model, or other Weighted CN models, due to the variability of the results.

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