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Ashleigh Boyd

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Modeling Debris Flow Hazard Risk Post Wildfire in Northern Colorado:

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Ashleigh Boyd

University of Denver

Department of Geography and the Environment

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Acronyms and Program Abbreviations

3DEP: 3D Elevation Program

BAER: Burned Area Emergency Response

CN: Curve Number

HUC: Hydrologic Unit Code

LANDSAT 8: Satellite which carries Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) remote sensing instruments. Resolution is 1-arc-second multispectral spatial resolution.

MRLC: Multi-Resolution Land Characteristics

NGS: National Geodetic Survey

NHD: National Hydrography Dataset

NLCD: National Land Cover Database

RAVG: Rapid Assessment of Vegetation Condition After Wildfire

SSURGO: Soil Survey Geographic Database

USGS: United States Geological Survey

Abstract

The 2020 Cameron Peak Fire, the largest in Colorado's History, impacted over 200,000 acres of land, including vital watersheds close to population centers in Colorado, such as the towns of Estes Park and Loveland. Runoff and debris flows are a continuous hazard for approximately five years post-fire. This study takes a spatial approach to modeling runoff potential of the Big Thompson Subbasin Watershed, using curve number methodology to approximate runoff potential by combining land cover, soil data, slope, and burn severity. Field work indicated possible uncertainty in the model due to discrepancies with field sample soil hydro groups compared to soil dataset. Flow Accumulation model informs areas of highest risk within the curve number model output, with the aim to inform hazard mitigation and disaster management decision-makers how best to proactively lessen runoff risk.

Introduction

The years between 2000 and 2021 were the driest period in recorded history in the mountainous region of the western United States since the year 800 (Williams et al. 2022). These conditions, labeled “an exceptional Megadrought” by researchers, are predicted to extend the wildfire season in the affected region by approximately three to four months (Williams et al. 2022). Combined with decreased snowpack, expansion of urban areas, and greater availability of wildfire fuel, wildfire risk will continue to increase in the future with climate change (McKenzie 2011)(NASA 2021). Although wildfires are a crucial component to ecosystem cycles, and have occurred naturally and critically for millennia, current anthropogenic influences are modifying fire regimes globally (Bento-Gonçalves, 2012). In Colorado, twenty of the largest wildfires in recorded history have occurred since 2001, with four of the top five largest wildfires occurring since 2018 (Colorado DFPC 2021). With hundreds of thousands of acres of burn scar from these major wildfires, there is a need to model potential runoff and debris flow hazards.

After a wildfire, it can take up to five years for vegetation to be restored, greatly increasing the risk for flash flooding and subsequent runoff hazards (FEMA 2021). Post-wildfire mud slides and debris flows following flood events contribute to tens of deaths and up to $2 billion in damages each year, including critical infrastructure (Colorado Geological Survey 2021). By using GIS datasets combined with spatial and image analysis, creating a model of greatest runoff risk would be a helpful tool to inform emergency and disaster relief planners.

This project examines the debris flow hazard from the 2020 Cameron Peak and East Troublesome Fires in Larimer County, Colorado, with a pilot project focusing on the Big

Thompson Watershed. The debris flow model is based on the Curve Number methodology, which produces a unitless number between 0 and 100, indicating the runoff potential for different soil groups, land use, slopes (McCuen 2017). Other features such as fires can be added using burn severity indices (McCuen 2017). The soils data, which determines water infiltration in the model, is susceptible to uncertainty. Field work was performed to assess the validity of the soils data contribution to infiltration in the model. Upon validity, models and risk assessment will be translated to other fires in the Rocky Mountain Region. It seeks to identify debris flow risk through terrain and hydrogeographic analysis in the aftermath of a wildfire. With a greater potential for wildfires impacting urban areas with the increase of wildfires in the Western U.S, debris flow hazard maps would allow local emergency management teams focus mitigation efforts in critical areas, such as those with a high population density or potential to damage infrastructure.

Background

The year 2020 brought to Colorado three of the largest wildfires in recorded history, including the record-breaking Cameron Peak Fire (Colorado Division of Fire Prevention & Control, 2021). This wildfire burned 208,913 acres, leaving behind a burn scar which already has caused debris flows, and will likely continue to do so for the next several years (Coalition for the Poudre River Watershed 2021). This project examines a vital watershed affected by the Cameron Peak Fire, with the proximity of the city of Loveland taken into consideration for determining the study area for the pilot project (Fig 1)(Fig2).

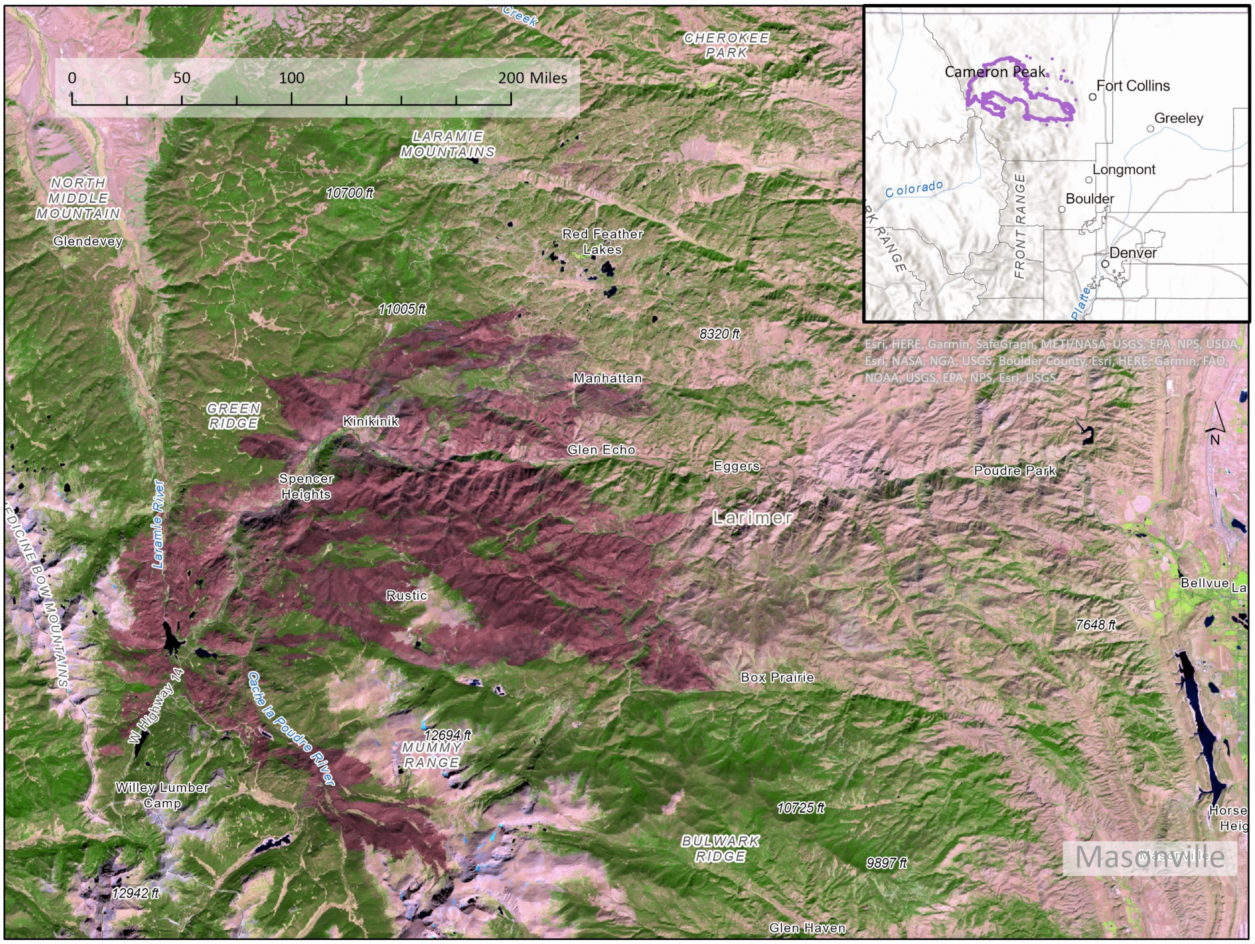

Fig 1. Landsat 8 satellite imagery from October 2020, mid Cameron Peak Fire - false color image for vegetation analysis.

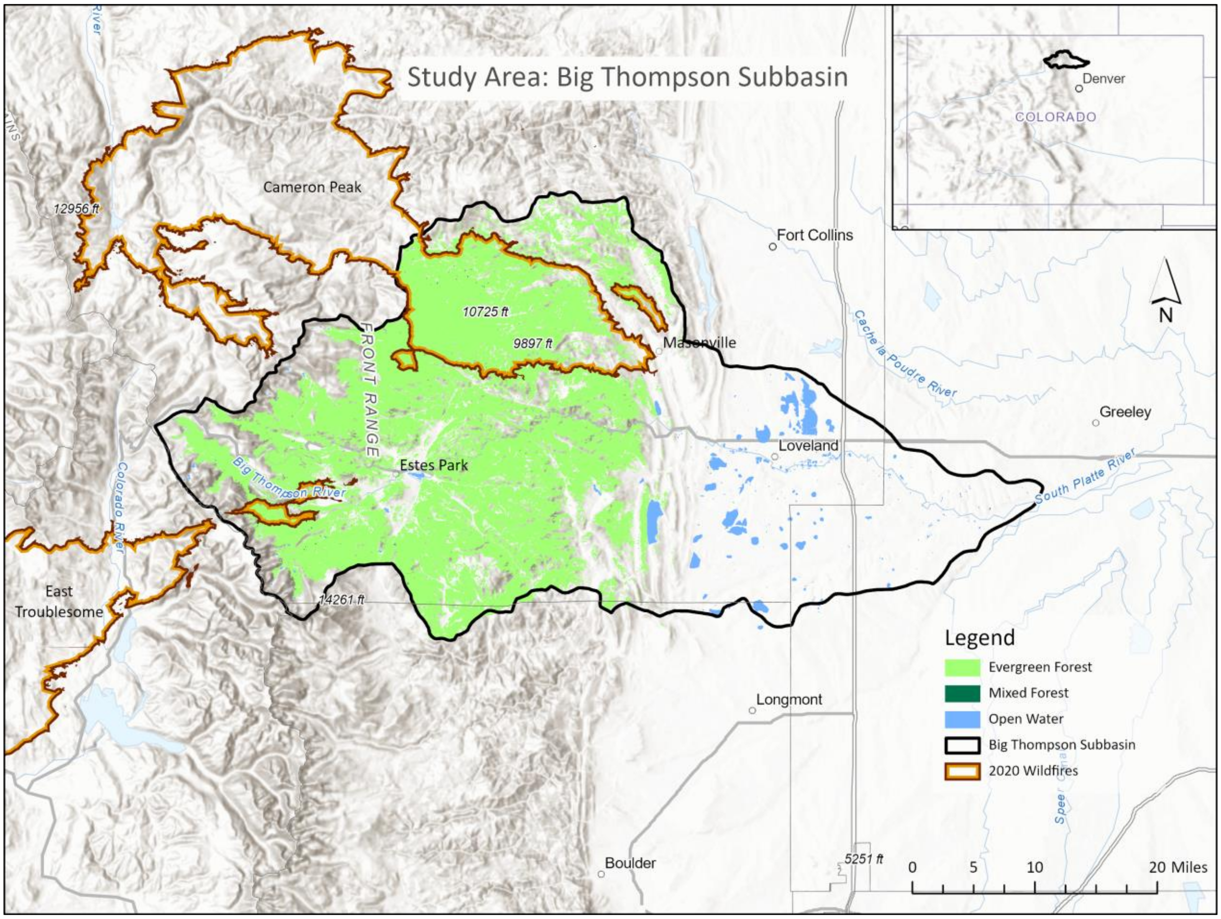

Fig 2. Study Area of the Big Thompson Subbasin, including 2019 forest land cover, and 2020 fire boundaries.

Human lives and critical infrastructure are vulnerable to debris flows post-wildfire, due to lack of integrity of soils, causing rapid erosion events during periods of heavy rainfall (MENA Report 2021). Damages from these debris flows are costly in dollars as well, with one example of a budget for critical infrastructure repair estimating $11.6 million in emergency relief funding when a debris flow damaged I-70.

Examining debris flow hazard of the Cameron Peak Fire can allow local decision-makers, emergency planners, disaster budgeters, and locals the tools to mitigate and plan for likely debris flows at precipitation thresholds. Knowing where to place new stream gauges empowers local communities for runoff risk. Assessing erosion combined with runoff potential has the power to inform these decision-makers about debris flow hazards.

Literature Review

Often after a wildfire in typical dry months, local governments and land management must act quickly to implement soil erosion safety measures before fall and winter rains. This is where GIS modeling is most powerful, to assess probabilities of debris flow, runoff events, and flooding in affected areas, and to assist the hazard teams in where to direct mitigating resources. One model which is available to the public is the POSTFIRE model, which was developed by Fox et al. (2016). This model quantifies fire impacts on the land and calculates soil erosion rates as related to rainfall probabilities, terrain (using DEM), land cover, and sedimentation values. They assessed their model against indices, sensors, and field measurements of erosion. They claim it is adaptable to local conditions and provides a realistic model of burn scar, discharge, and soil erosion post forest wildfire.

USGS (2018) has developed a model for Emergency Assessment of Post-Fire Debris-Flow Hazards which is based upon rainfall conditions, terrain, soil, historical debris flows, and normalized burn ratio images (dNBR). The USGS uses ground-truthing to validate soil burn severity. The model generates a debris-flow probability on a range from 0 to 1, which are then assigned a 1 – 5 interval class represented as a percentage likelihood. The USGS doesn't publicly publish the results of their assessment study in interactive map form, but does publish the probabilities in hazard assessment in publications of study areas. The calculations for this model are available in raw form via USGS.

Since debris flow and runoff hazard models rely heavily on soil erosion properties following a wildfire, it is important to understand the methodology for assessing soil erosion following a wildfire. Argentiero et al. (2021) combined methods such as the Monitoring Trends in Burn Severity (MTBS) method, the Soil Conservation Service Curve Number (SCS-CN) method, Normalized Burn Index (NDVI), and Relative differenced Normalized Burn Index (RdNBR) from raster imagery to model post-fire erosion. Their study was focused on wildfires in Southern Europe, and they found that transitional areas are particularly vulnerable to erosion following a fire event. The Front Range of Colorado is a classic transitional area, from high elevation short-grass prairie to mountainous. This study was able to assess a more accurate representation of soil erosion using satellite imagery and was able to assess areas of high erosion post-fire in order to prioritize burned area restoration, such as soil bioengineering or physical protective actions in a burn scar.

Although these models are used by governments and hazard mitigation teams, they are not without their caveats. Lopes et al. (2020) noted that the impact of climate change on wildfires is predicted to have higher occurrence in the future, and therefore the models examining post-fire hazards should be examined closely for weaknesses and field validation. They performed a meta-analysis on post-fire soil erosion modeling, including methodologies and applications. They concluded that models critically need to address burn severity, burn conditions, mitigation measures, uncertainties, and must be validated in the field. They also noted that models are distributed unevenly to the US and Europe, despite having lower percentage of burned area per continent than Africa, Australia, or South America. Although my study will be within the US, it is important to note the researcher's conclusions about critical methodology and the importance of ground-truthing local variances in soil erosion.

Although there are models for initial debris-flow hazard following a wildfire, the change in probability of debris flows as the habitat recovers from the wildfire is not as well-understood or modeled. Thomas et al. (2021) examined this problem closely, concluding that creating an additional model for rainfall thresholds helps to create more realistic models of debris flow hazard in the years after a wildfire. The researchers looked at a variety of physical and biological properties of a burn-scarred mountain range in Southern California. They noted an increase in sedimentation in the three years following a wildfire, as erosion increased, but did note that the model might not be accurate in other regions of the Mountain West.

Post-wildfire debris flow hazard has been documented extensively in Europe, California, and other areas of the Mountain West, but Colorado has few publications involving this risk. Ebel (2020) is a researcher with USGS working in the Colorado Front Range specializing in hydrologic hazards. He produced an extensive look at seven years' worth of soil-hydraulic properties near Boulder, CO with regards to water infiltration, quantifying when soil erosion properties recover post-wildfire. He concludes that the greatest risk for hydrologic hazards in the Colorado front range exist for two years post-wildfire. After the two-year mark, the mechanism for hydrologic hazards transitions to subsurface mechanisms, which are not easily remedied by human intervention. He suggests immediate assessment of hazards post-wildfire, with hillslope and soil erosion recovery efforts concentrated on recent wildfires. Within the parameters of the study, the researcher included the 2013 "extreme" rainfall storm which contributed to peak discharge measurements. He noted that in the instance of such a storm, even slopes which show substantial recovery still produce hydrological hazards such as flash flooding, surface runoff, and debris flows. Ebel shares his “Green-Ampt” hydrological infiltration model for the Colorado Front Range in this publication as well. The advantage to Ebel’s publication is that it accounts for Front Range conditions, including previous drought and dry conditions, land cover data, and similar soil properties. His research suggests that five years post-wildfire, only the most extreme rainfall events will produce substantial erosion-related hazards.

Design and Implementation

Data was obtained from US government sources (Table 1) and processed using Esri ArcPro 3.1 and ERDAS IMAGINE 16.7.0. Watershed Boundary HU8 Big Thompson was selected for data extraction. Relevant data layers include: SSURGO soil data, NLCD land cover, NHD watershed boundaries and flowlines, 3DEP elevation raster datasets, GPS Benchmarks, Colorado county boundary and demographic data, USGS stream gauges, and Landsat 8 raster image data.

Table 1. Data Sources

Product	Layer	Source
Runoff Model	3DEP (DEMs)	Nationalmap.gov
Runoff Model	HUC (Watershed)	Nationalmap.gov
Runoff Model	National Hydrography Dataset	Nationalmap.gov
Runoff Model	Soils (SSURGO)	websoilsurvey.nrcs.usda.gov
Runoff Model	Burn polygon	Data-nifc.opendata.arcgis.com
Runoff Model	Land Cover	NLCD (usgs.gov)
Runoff Model	Burn Severity	USGS RAVG https://burnseverity.cr.usgs.gov/products/ravg
Map Data	Precipitation	Mrlc.gov
Map Data	County Population Centers	Mrlc.gov
Map Data	State counties	Data.colorado.gov
Map Data	Stream gauges	streamstats.usgs.gov/ss
Remote Sensing Analysis	Landsat 8 Images	https://earthexplorer.usgs.gov/
Vertical Accuracy Assessment	GPS Benchmarks	National Geodetic Survey https://geodesy.noaa.gov/NGSDataExplorer/

Data manipulation:

- Projected data into NAD 1983 State Plane Colorado North FIPS 0501 (US Feet).
- Reclassified land cover categories into water, forest, developed land, barren/grassland/agriculture, and snow/ice (Fig 3).

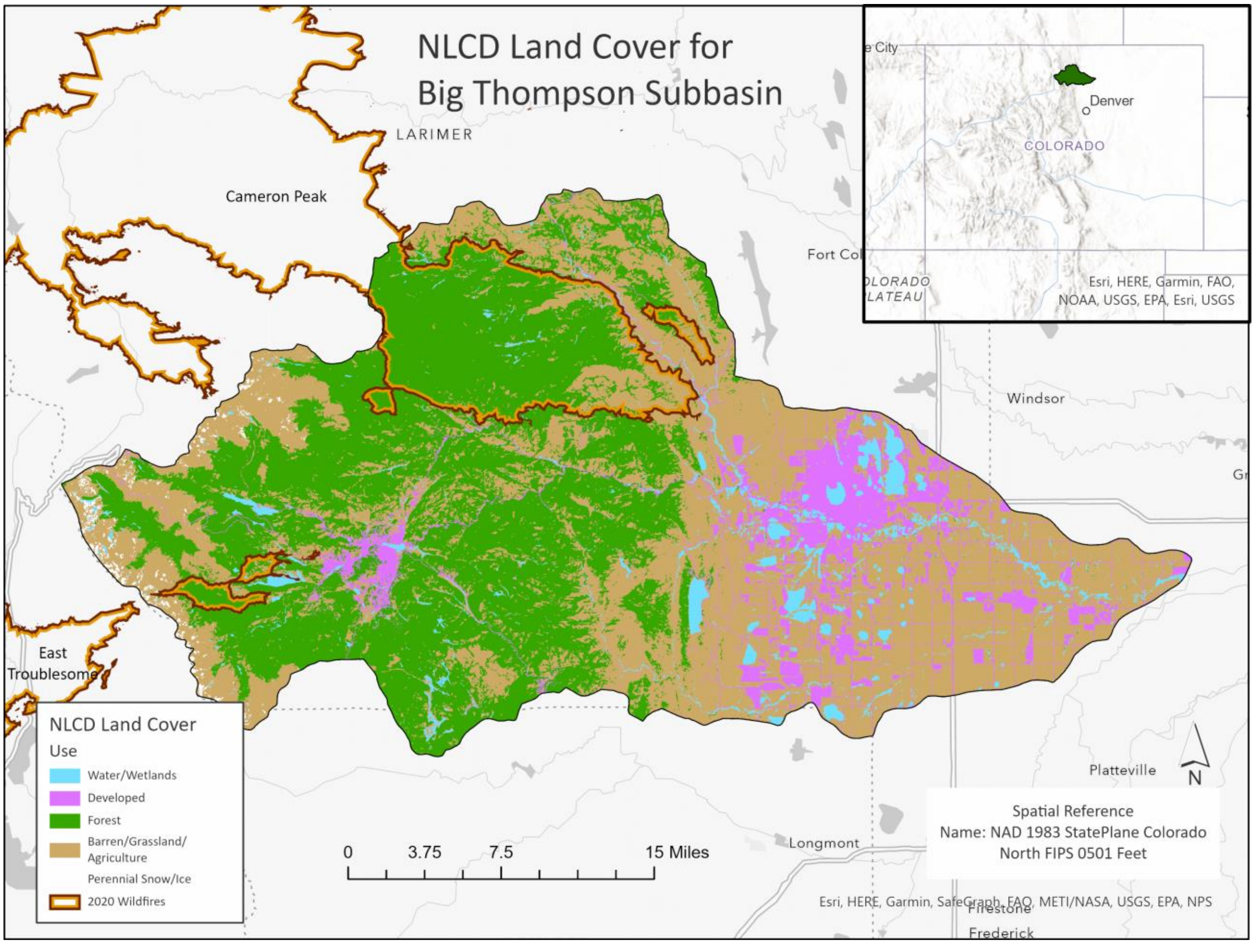

Fig 3. NLCD Land Cover reclassified map of the Big Thompson Subbasin. Watershed is divided where the front range of the Rocky Mountains meets the short grass prairie habitat.

- Manually corrected null values in SSURGO data, combined soil groups into A, B, C, D hydrogroup runoff potential (Table 2.)(Fig 4.)

Table 2. SSURGO soil hydrologic groups.

Group A	Low runoff potential when thoroughly wet, water is transmitted freely through soil.	Typically less than 10% clay and more than 90% sand or gravel.
Group B	Moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded.	Typically between 10%-20% clay.
Group C	Moderately high runoff potential when thoroughly wet. Water transmission is somewhat restricted.	Typically between 20 and 40% clay.
Group D	High runoff potential when thoroughly wet. Water is restricted or very restricted.	Typically greater than 40% clay, may also have high shrink-swell potential.

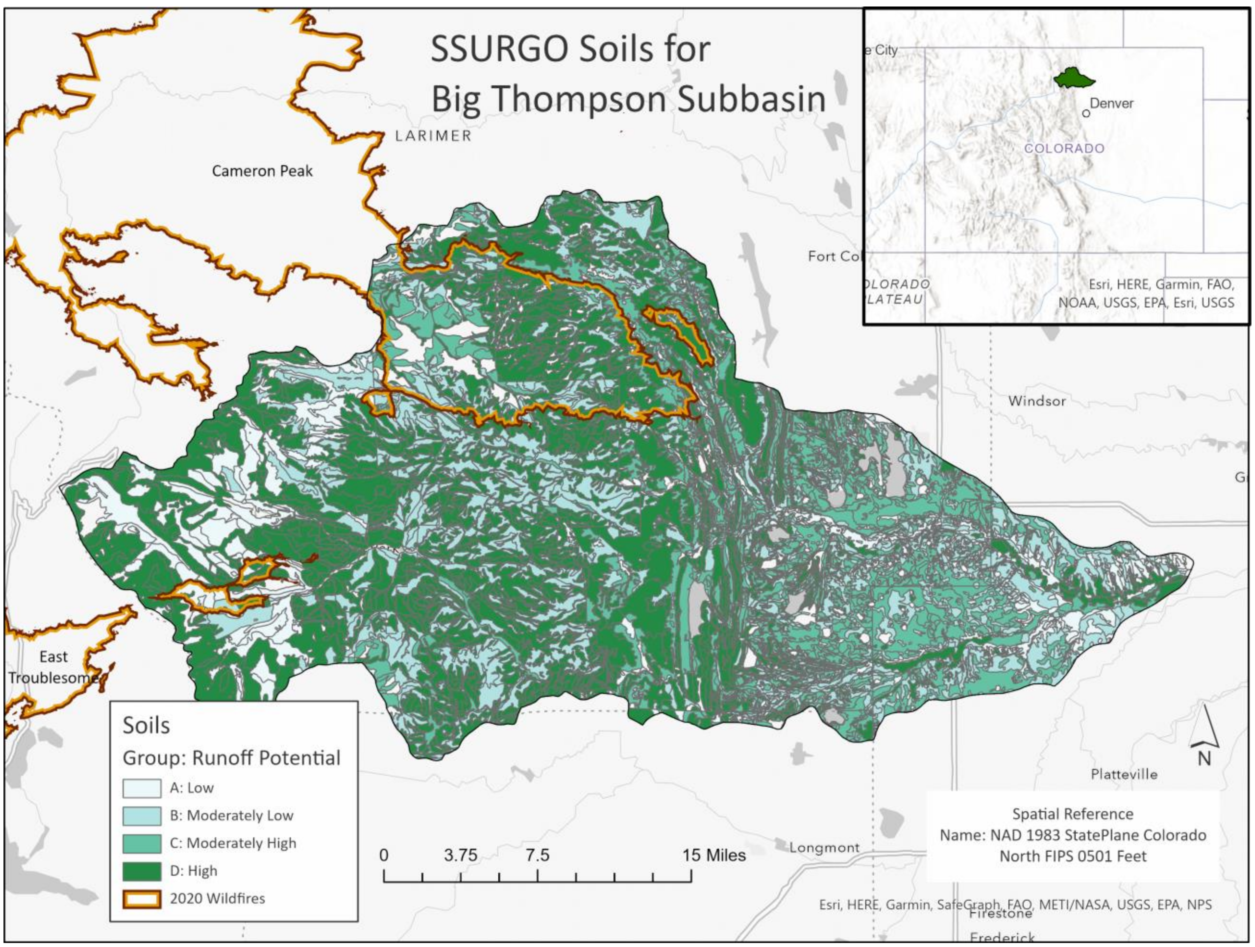

Fig 4. SSURGO soils map for the Big Thompson Subbasin.

- Used 10km buffer for data layers around watershed to ensure no data loss at boundaries.
- Used 1 arc-second (~30m) 3DEP elevation models for watershed stream modeling (fill sinks, flow direction, flow accumulation).
- Generated Curve Number Grid via Union geoprocessing of soil and land cover datasets. Curve number was calculated from McCuen, 2017, at precipitation recurrence intervals less than 25 years (Table 3).

Table 3. Curve Numbers for land use and soil groups.

Land Cover	**Soil Group A**	**Soil Group B**	**Soil Group C**	**Soil Group D**
Water	100	100	100	100
Developed	31	35	38	42
Forest	11	14	16	20
Barren/Agriculture/ Meadow	25	30	36	40
Perennial Snow/Ice	0	0	0	0

- Polygon of Normalized Burn Index of wildfire burn areas added from RAVG database (created from Normalized Burn Index raster data), scaled from 0-3 unburned to severe burn (Table 4).
- Post-Wildfire Curve Number modified using methodology from Leopardi and Scorzini BAER model (2015)(Table 4).

Table 4. Curve Number Adjustments for Post-Wildfire modeling

Normalized Burn Index	**Runoff Adjustment**
3: High Burn Severity	$CN_{post} = CN_{pre} + 15$
2: Moderate Burn Severity	$CN_{post} = CN_{pre} + 10$
1: Low Burn Severity	$CN_{post} = CN_{pre} + 5$
0: Unburned	$CN_{post} = CN_{pre}$

- Slope dataset created from 3DEP Digital Elevation Model, combined with runoff model via increasing or decreasing the curve numbers (Table 5). Curve numbers adjusted to be above or below the range of 0-100 were corrected for the lowest or highest curve number (0 or 100). Slope adjustments for the runoff model were estimated based off of curve number runoff modeling of McCuen (2017).

Table 5. Curve Number Adjustments for Runoff Modeling Accounting for Slopes

Slope grade	Runoff Adjustment
Shallow: 0%-3%	$CN_{runoff} - 10$
Average: 4%-9%	$CN_{runoff} + 0$
Steep: 10% and above	$CN_{runoff} + 10$

- Data validity performed using vertical accuracy assessment, using GPS Surveyed benchmarks (National Geodetic Survey) to validate the digital elevation model from 1-arc second dataset. Root mean squared error: 3.0m, within the 7m accuracy standards of USGS.
- Data validity performed using field-validated soil samples (Appendix A).
- Field sampling done along Buckhorn Creek, along W Co Rd 44H (Buckhorn Rd) in the Arapahoe/Roosevelt National Forest (Figure 10).
- Sampling performed using a soil core sampler, taking top 5 inches of soil in two locations for each soil hydro group, except A which only had one location on public land.
- Soil groups analyzed for type using the Soil Texture Flow Chart from Feel from NRCS, USDA (n.d).

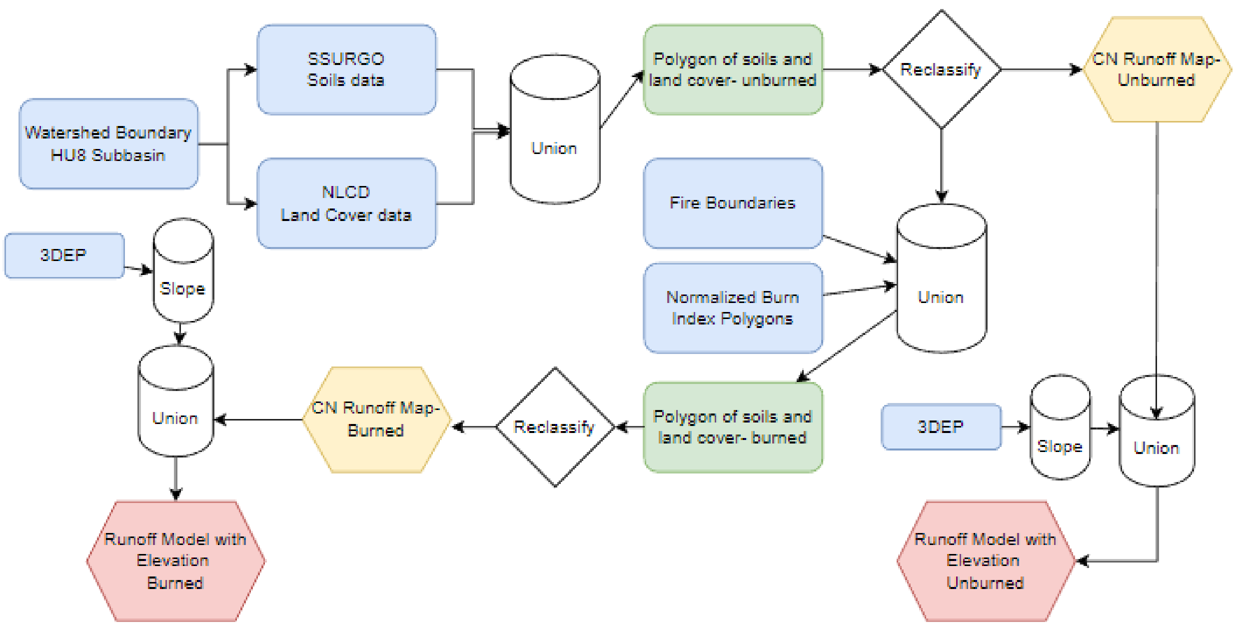

Fig 5. Flowchart of runoff model- burned and unburned products.

Results

The curve number model for the Big Thompson watershed pre-fire (2019) shows a healthy forested western segment of the watershed, with very low runoff in areas of lower slope and forested (Fig 6). The short-grass prairie habitat combined with development indicates moderate runoff potential when elevation and slope are not factored in. Areas of normal concern include steep mountain slopes in the Arapahoe/Roosevelt National Forest, and front range valleys.

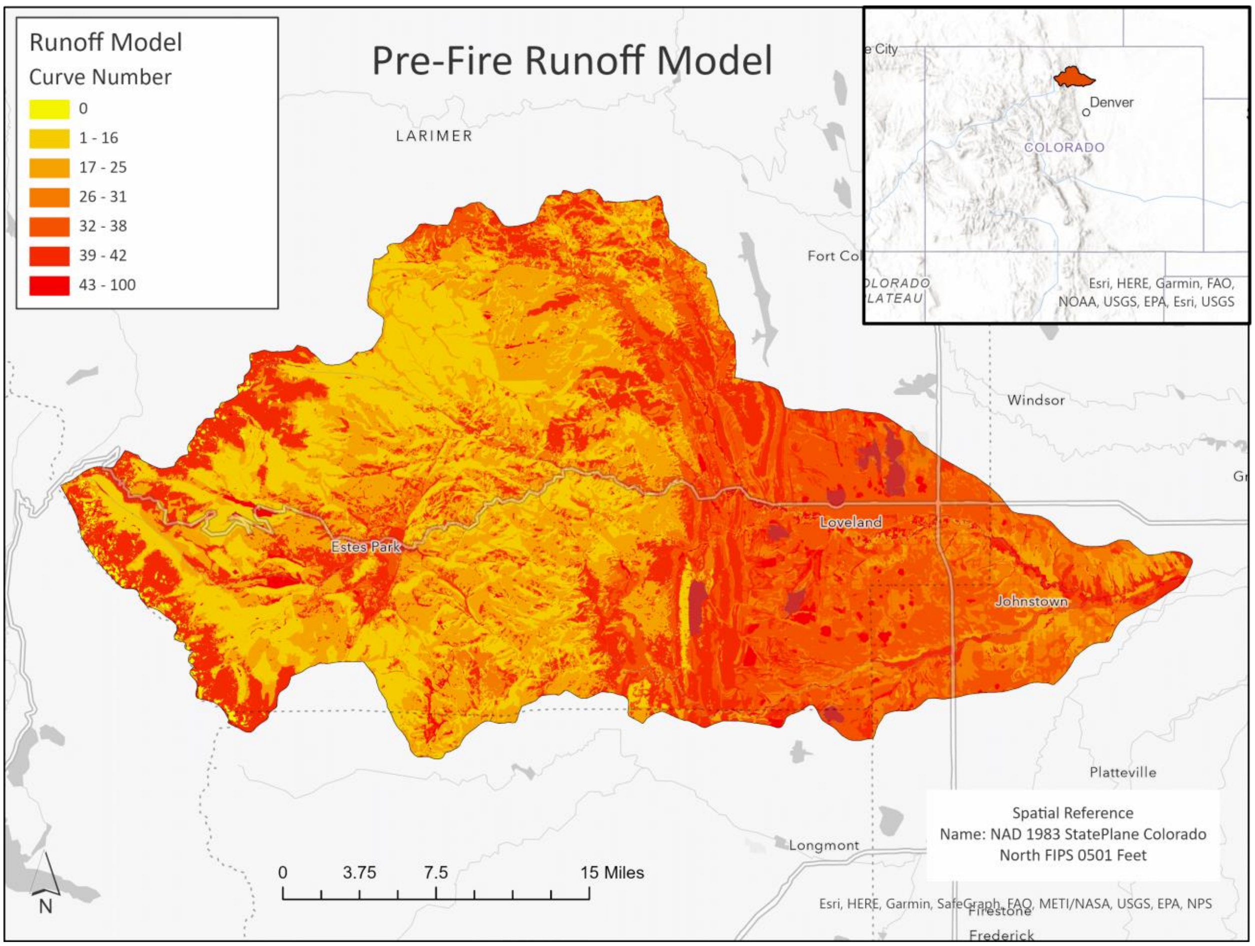

Fig 6. Curve number runoff model (0-100 unitless runoff potential) for post-fire Big Thompson Subbasin.

The post-fire runoff model shows the entire region of the Cameron Peak and East Troublesome Fires increasing in runoff potential from low to moderate and moderately high (Fig 7). Areas of concern include the valley to the north and east of the Cameron Peak Fire, which contains Buckhorn Creek and passes through Masonville, Colorado, as well as Big Thompson River downstream of the East Troublesome Fire which runs through Estes Park (Fig 8). Both of these spots have high flow accumulation rivers and streams, with the potential for debris flows and flooding (Fig 9).

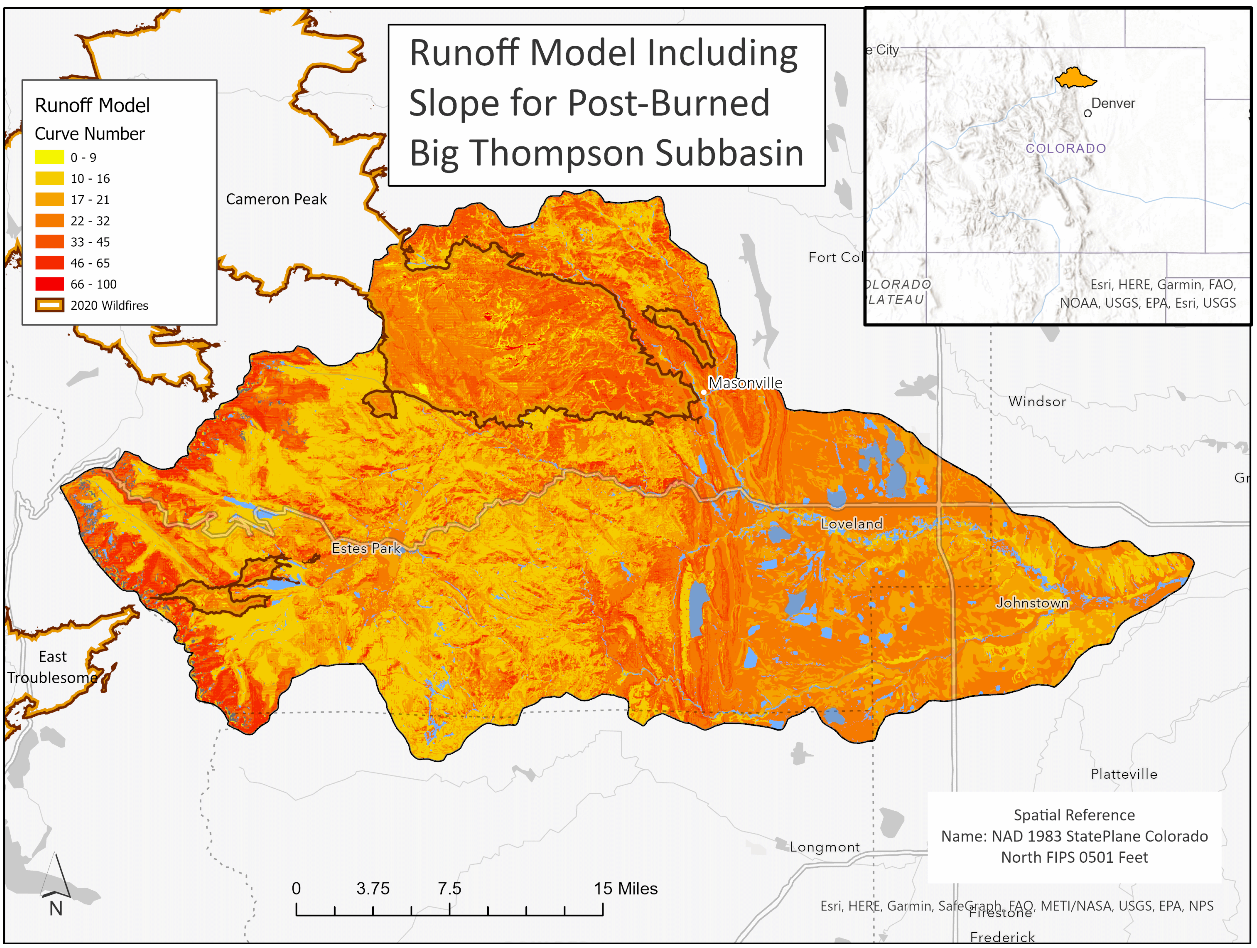

Fig 7. Runoff model including land cover, soils, slope, and fire severity for the Big Thompson Subbasin.

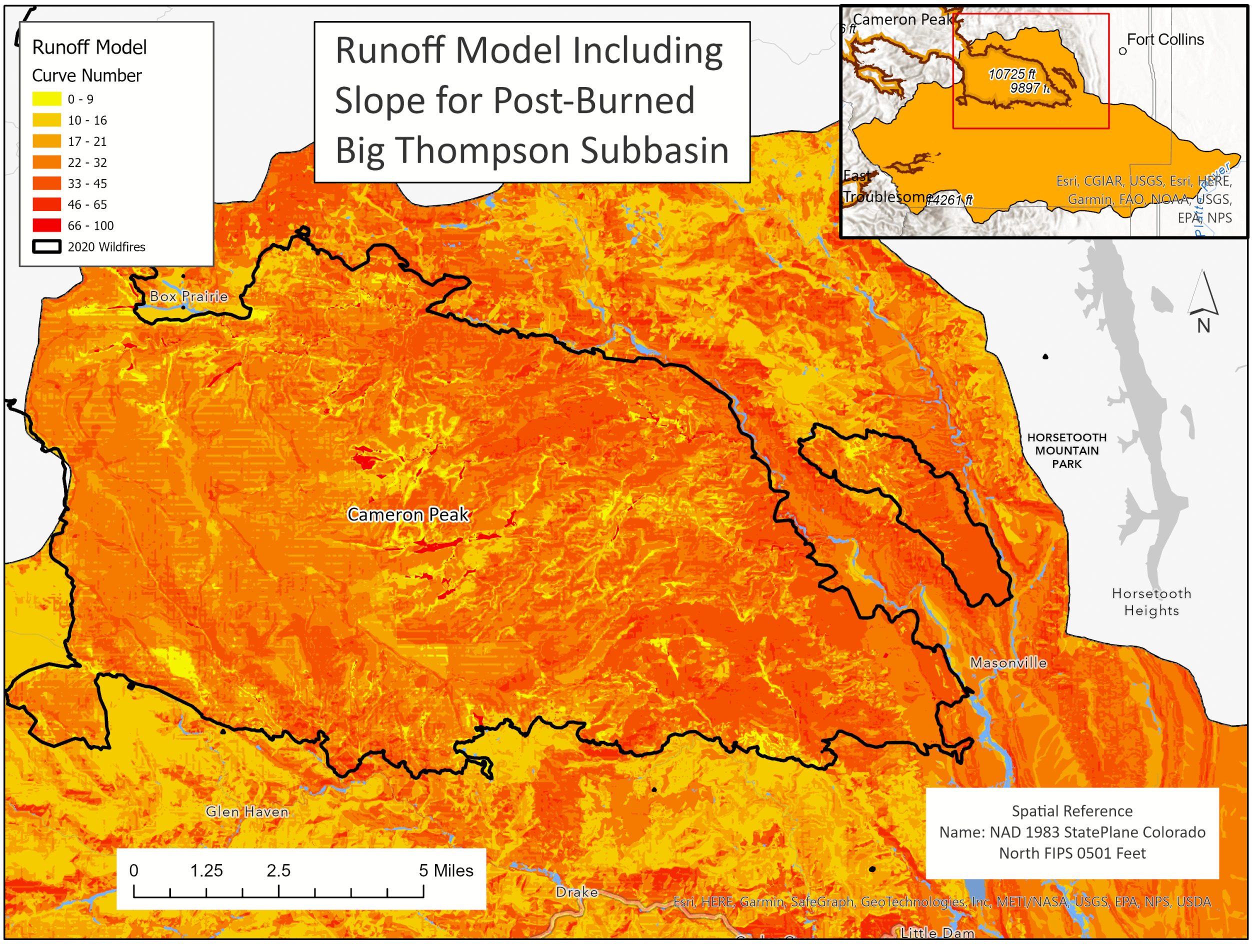

Fig 8. Runoff model accounting for low and high slope values, focusing on Buckhorn Creek which flows through Masonville, CO.

When slope is added to the model to strengthen or decrease the curve numbers for very high and very low values (less than 4% grade or higher than 10% grade), helps alleviate some of the runoff potential in the more remote sections of the Cameron Peak fire, but leaves the steep valley along the Buckhorn Creek and Big Thompson River as areas of high concern (Fig 8). Within the Cameron Peak fire boundary, the highest runoff potential fortunately hits remote National Forest, with no critical infrastructure, although an inventory of private parcels should be assessed, as there is potential of risk to human life and property along Buckhorn Creek.

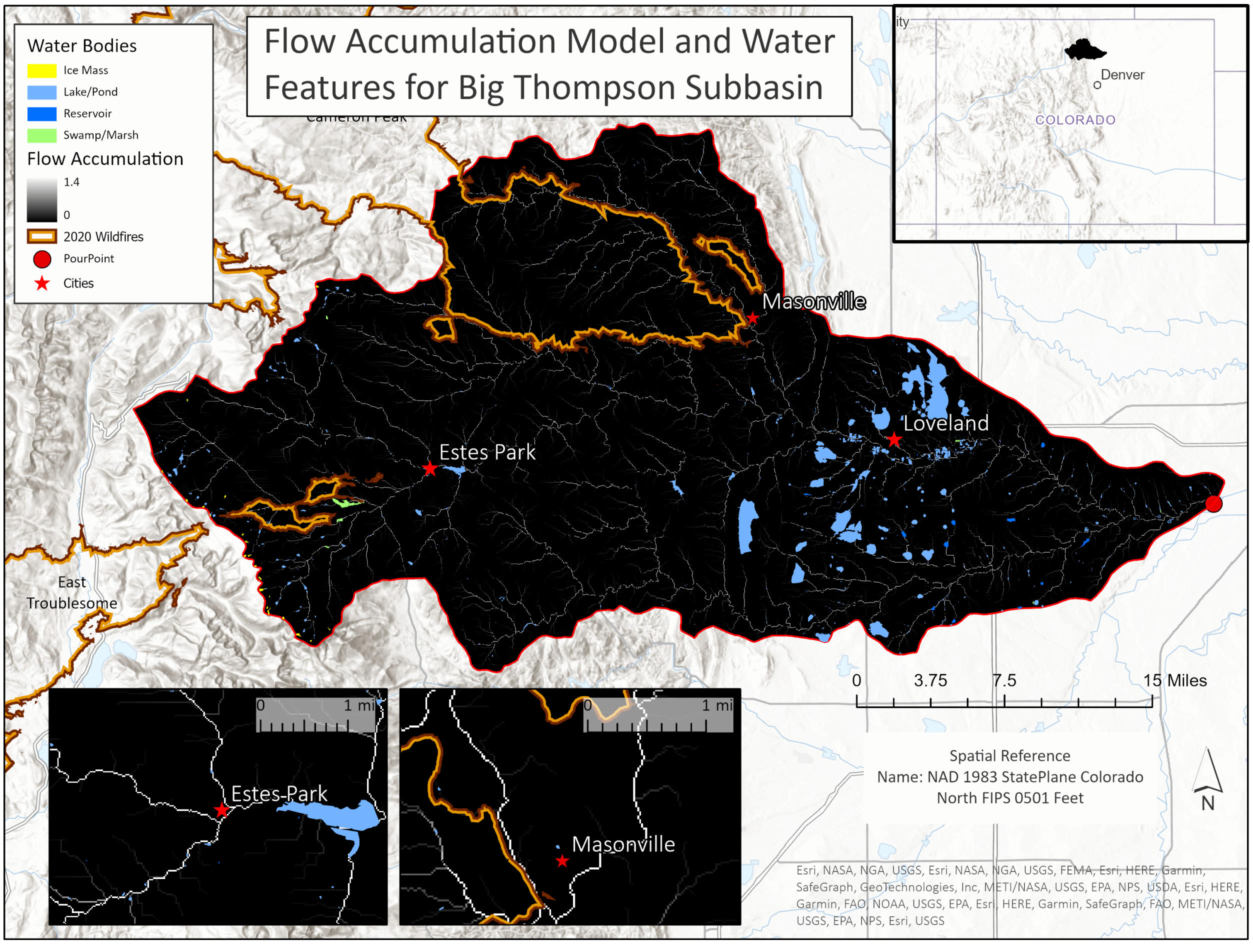

Fig 9. Flow accumulation model of the watershed, highlighting Estes Park and Masonville.

The raster flow accumulation, generated from a flow direction raster created from the filled digital elevation model, shows that the Big Thompson River and Buckhorn Creek accumulate water from both normally high CN values from the pre-burned model, as well as the burned areas of concern in the post-fire model (Fig 9).

The field component to ground-truth the soils infiltration data yielded mixed results for validity of the hydrogroups (Fig 10). This aspect of the model is sensitive to uncertainty, and further examination of a section is recommended for a action plans such as mulching or debris-flow nets at a higher resolution.

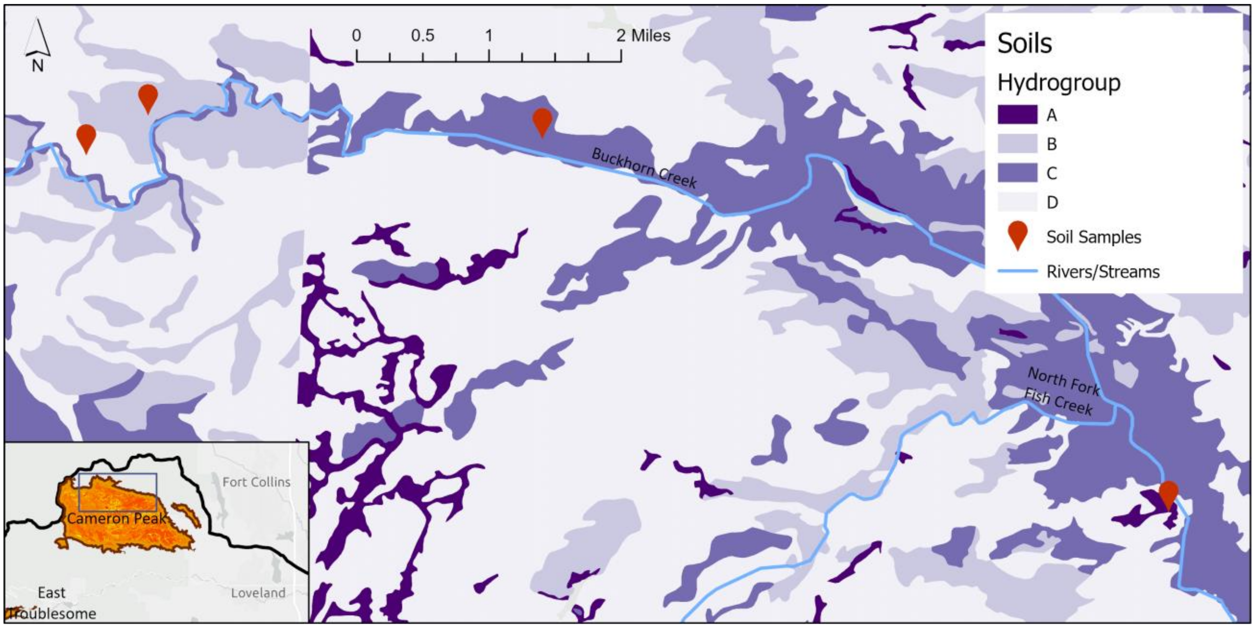

Figure 10. Field soil sample sites along Buckhorn Creek in Larimer County, CO.

Results were expected for A and B, but C and D showed the opposite result, with C having the highest clay content of ~40%, which would place it in Hydro Group D. The field sample for D showed sandy clay loam, which has a clay percentage of 20%-40%, indicating that it would belong to Hydro Group C. This could indicate the need for a higher resolution soil dataset, especially for locations of precise mulching or other mitigative measures.

Discussion

Although the runoff models of the post-burned areas of the Big Thompson Subbasin show an increase in runoff potential, most of the immediate burned area is National Forest which lacks critical infrastructure and few population centers. However, along the eastern boundary of the Cameron Peak fire lies Buckhorn Creek, an area of concern of high runoff and debris flow potential, with steep slopes of the valley adding to the increase in runoff potential. In addition to the private parcels along this area of concern, Buckhorn Creek flows through Masonville, Colorado, potentially impacting the 3,593 lives in that region (2020 Census). Another area of increased risk revealed by the modeling includes the high flow regions near the East Troublesome boundary near Estes Park, including the Big Thompson River. Disaster mitigation budgets should focus on these two population centers, with mulching, replanting understory, debris flow nets or other physical barriers, and focused efforts to implement early warning signs of runoff hazard, such as emergency notification of stream gauge thresholds during high precipitation events.

Stream Gauge station number 402114105350101, which measures the Big Thompson River about three miles upstream of Estes Park, is a critical gauge to monitor during periods of heavy precipitation, as the models account for precipitation at less than a 25-year recurrence interval, which for this gauge is 60 ft^3/s (USGS, n.d). Another stream gauge to monitor would be station number 06739500, which lies approximately two miles south of Masonville, CO. As of May 2023, this gauge is inactive (Fig 11).

In light of the Cameron Peak fire size and devastation, the model suggests the need to add stream gauges upstream of Masonville along Buckhorn Creek closer to the burn scar, as well as another one or two gauges closer in proximity to the Masonville population center, including along the Redstone Creek, which is also impacted by the Cameron Peak Fire (Fig 11). In addition, the model suggests another stream gauge along the Fall River upstream of Estes Park, as well as one more stream gauge in Rocky Mountain National Park, along the Big Thompson River near the Fern Lake Trailhead (Fig 11).

In addition to stream gauges, the models also recommend rainfall gauges, as remote mountain rainfall is not always accurately measured by radar (Germann 2022). Future wildfire debris flow hazard mitigation should include placement of new gauges and monitoring streams and rivers which are an early indication of debris flow hazard risk (Fig 11).

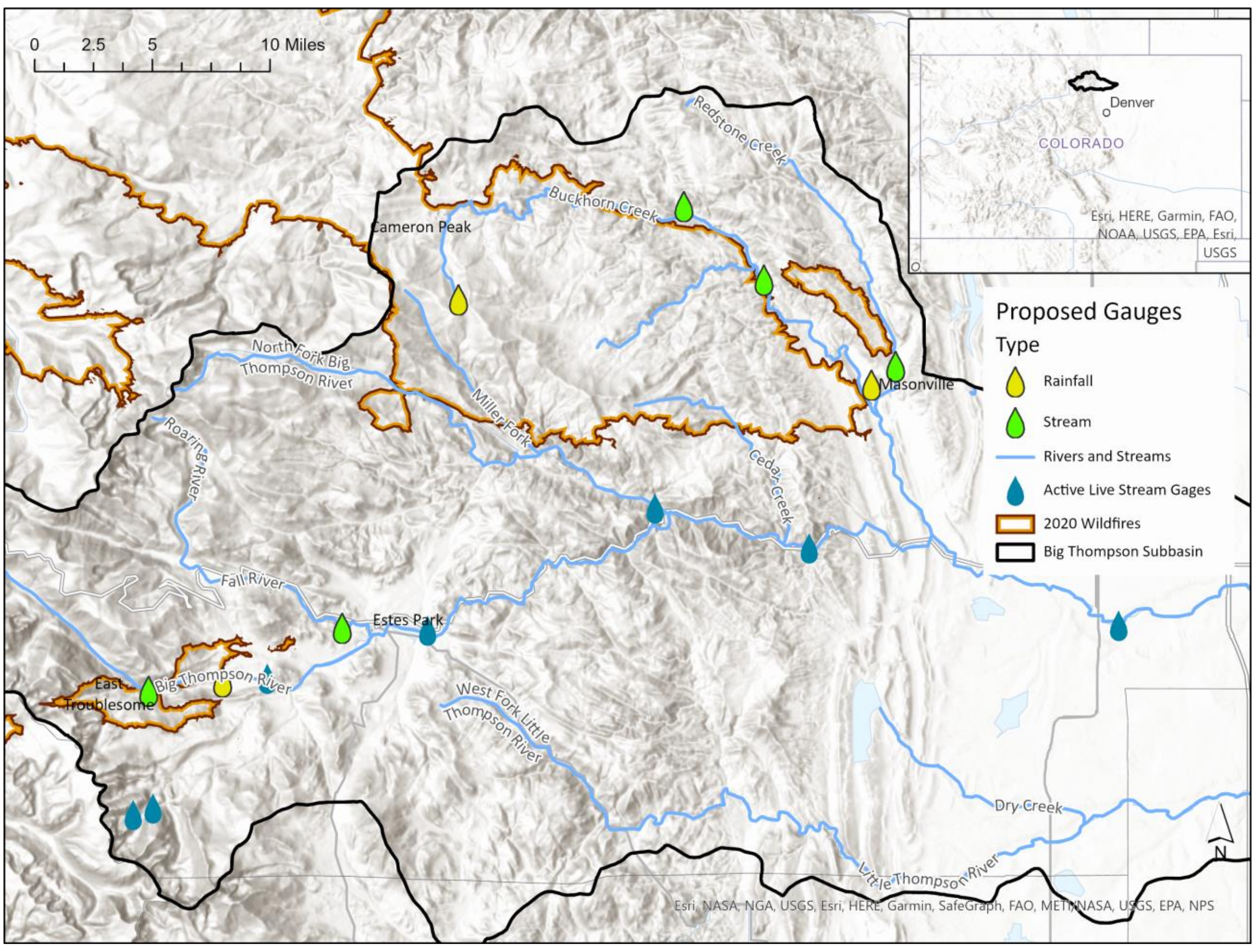

Figure 11. Proposed and current stream gauges of the Big Thompson Subbasin.

Further Research

Although it has been nearly three years since the Cameron Peak and East Troublesome Fires of 2020, with the scientific prediction of the extension of wildfire season in the Rocky Mountain Region, the need to model debris flow hazard risk post-wildfire in Colorado will continue. Loss of human life from the Black Hollow Mudslide in the neighboring Poudre River Canyon in 2021 shows a need to continue to monitor the watersheds affected by the historic wildfires of 2020. With detailed data modeling soil properties in the region, future debris flow models will reduce uncertainty and provide decision-makers with useful data on which to plan hazard mitigation. This pilot project can be translated to other watersheds in the front range, with ground-truthing of soil properties. Proactive post-fire hazard modeling may help budget risk mitigation dollars effectively, save critical infrastructure, and even help save lives.

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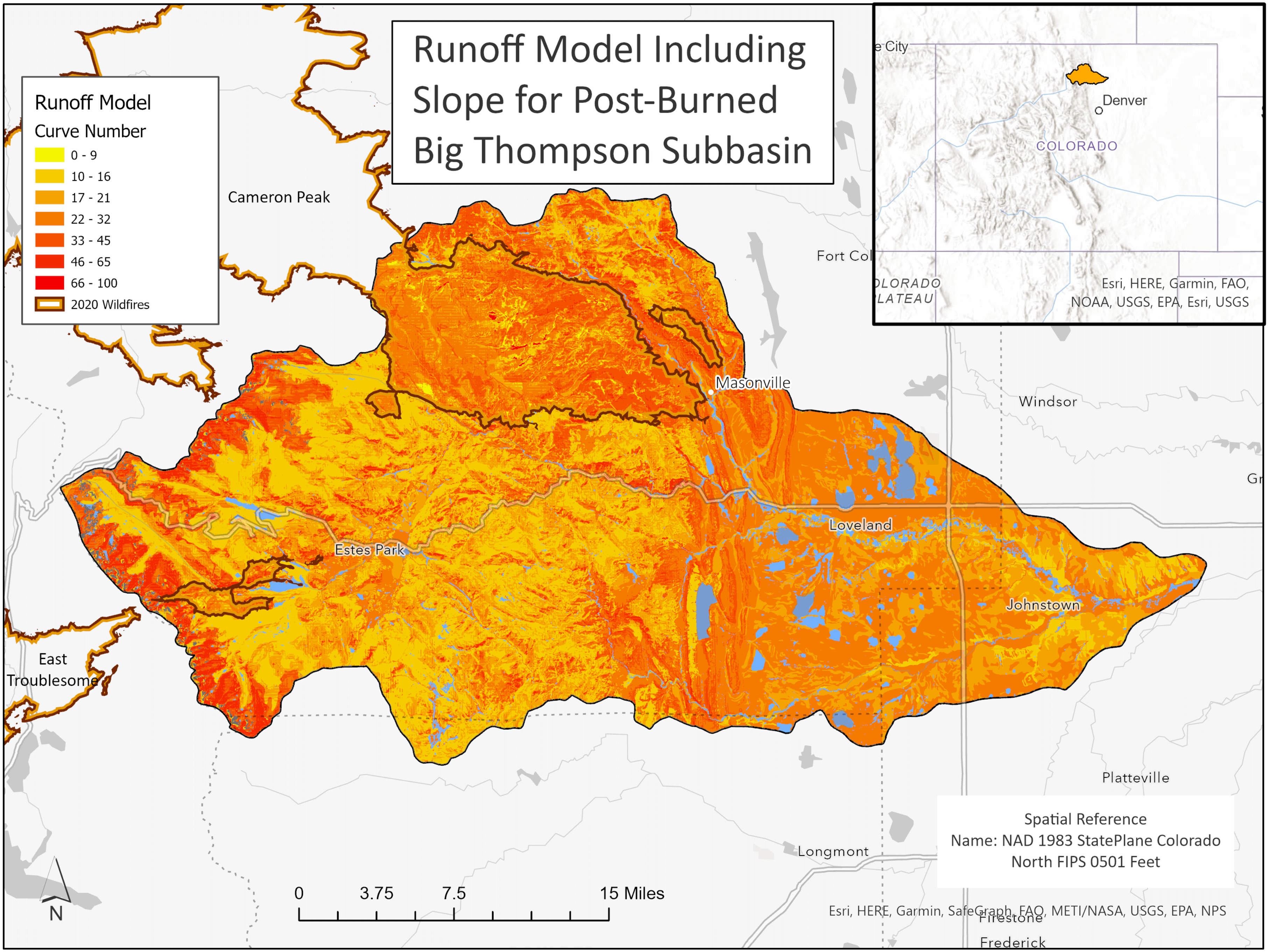
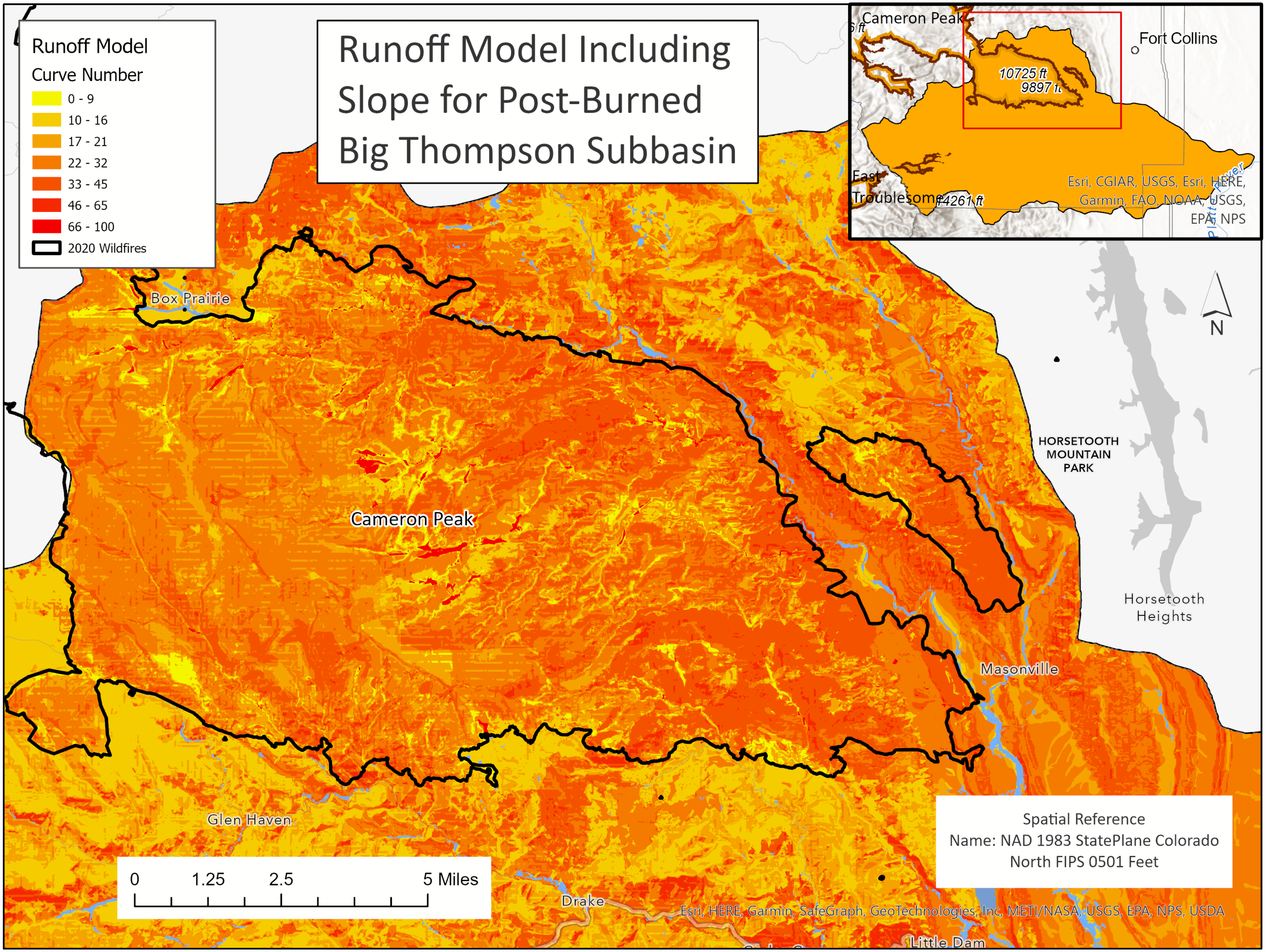
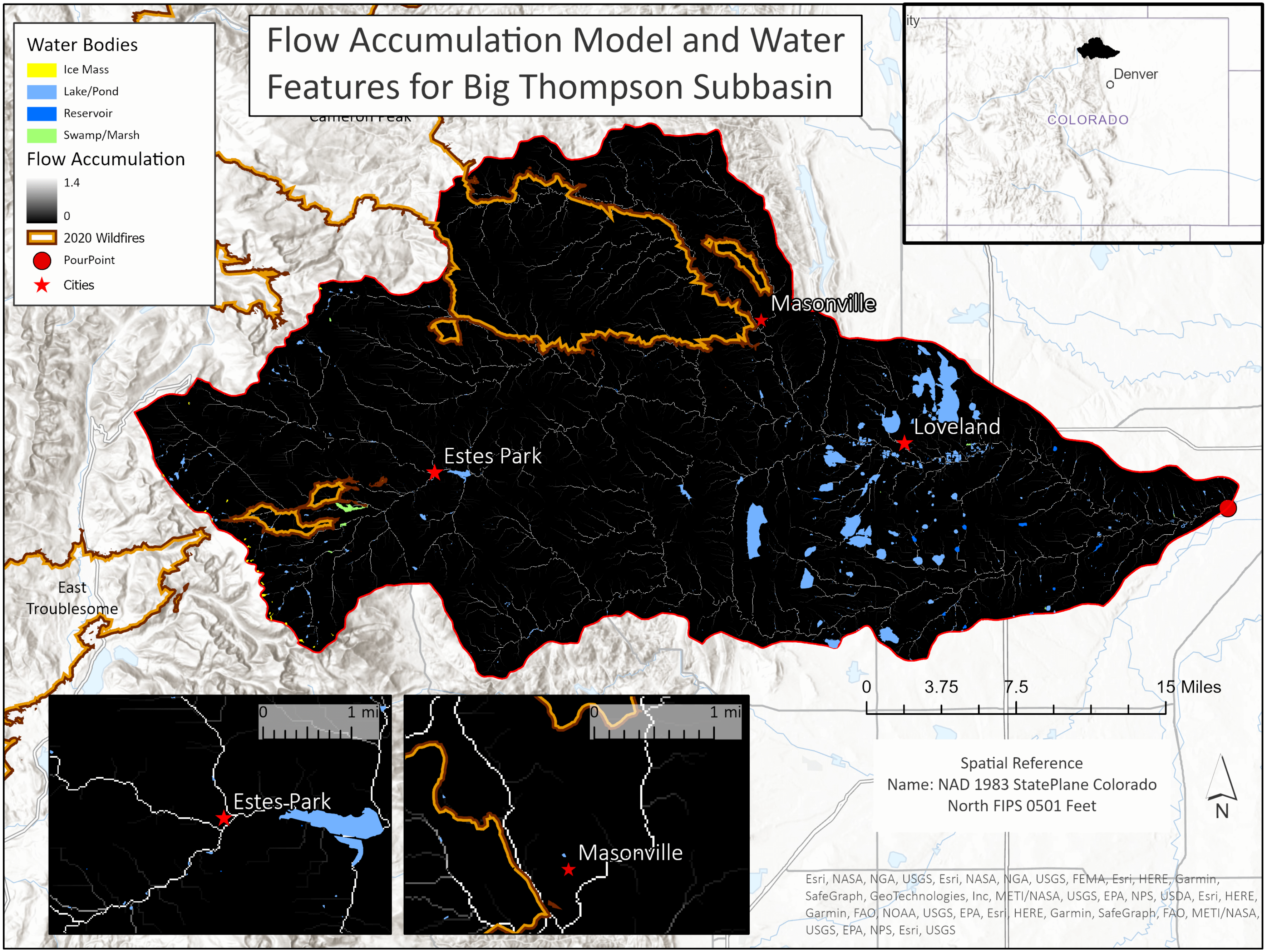
Appendix and Larger Maps

Table A. Field soil sample hydrogroups location and results. A * indicates disparate result from SSURGO soils data hydrogroup.

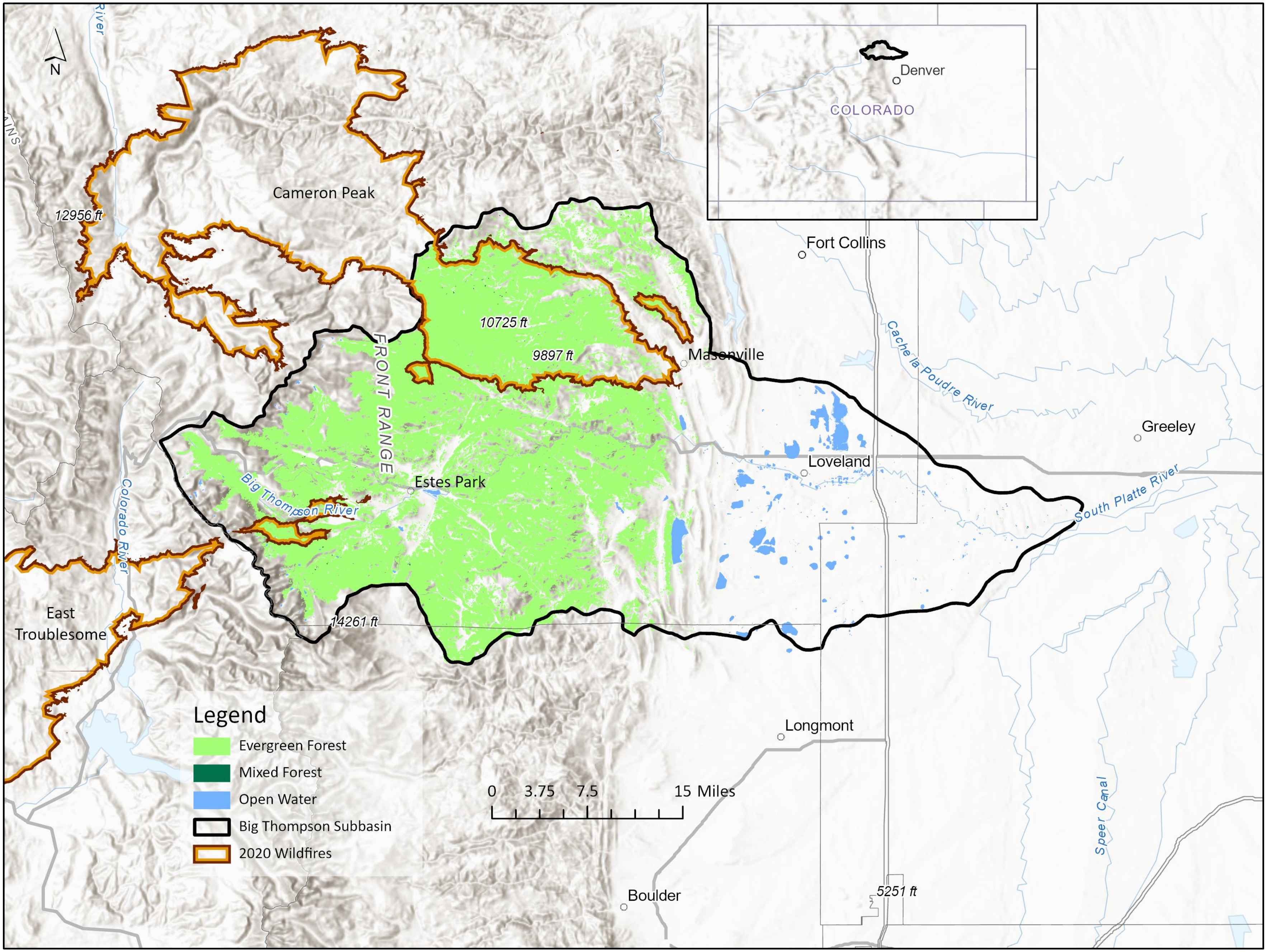
Soil Hydrogroup	**Coordinates**	**Field Samples Results**
A (Low runoff potential)	N 40.571565° W 105.322262°	Sandy Loam
B (Moderately low runoff potential)	N 40.575320° W 105.423399°, N 40.578616° W 105.462917°	Loam
C (Moderately high runoff potential)	N 40.55415° W 105.373645°, N 40.575955° W 105.395936°	Silty clay loam*
D (High runoff potential)	N 40.569371° W 105.427516°, N 40.573265° W 105.444807°	Sandy clay loam*


Runoff Model Including Slope for Post-Burned Big Thompson Subbasin
Runoff Model
Curve Number
0 - 9
10 - 16
17 - 21
22 - 32
33 - 45
46 - 65
66 - 100
2020 Wildfires
Cameron Peak
Fort Col
Masonville
Windsor
Loveland
Estes Park
Johnstown
East Troublesome
Platteville
Longmont
Firestone
Frederick
Denver
COLORADO
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, USGS
0 3.75 7.5 15 Miles
N
Spatial Reference
Name: NAD 1983 StatePlane Colorado North FIPS 0501 Feet
Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

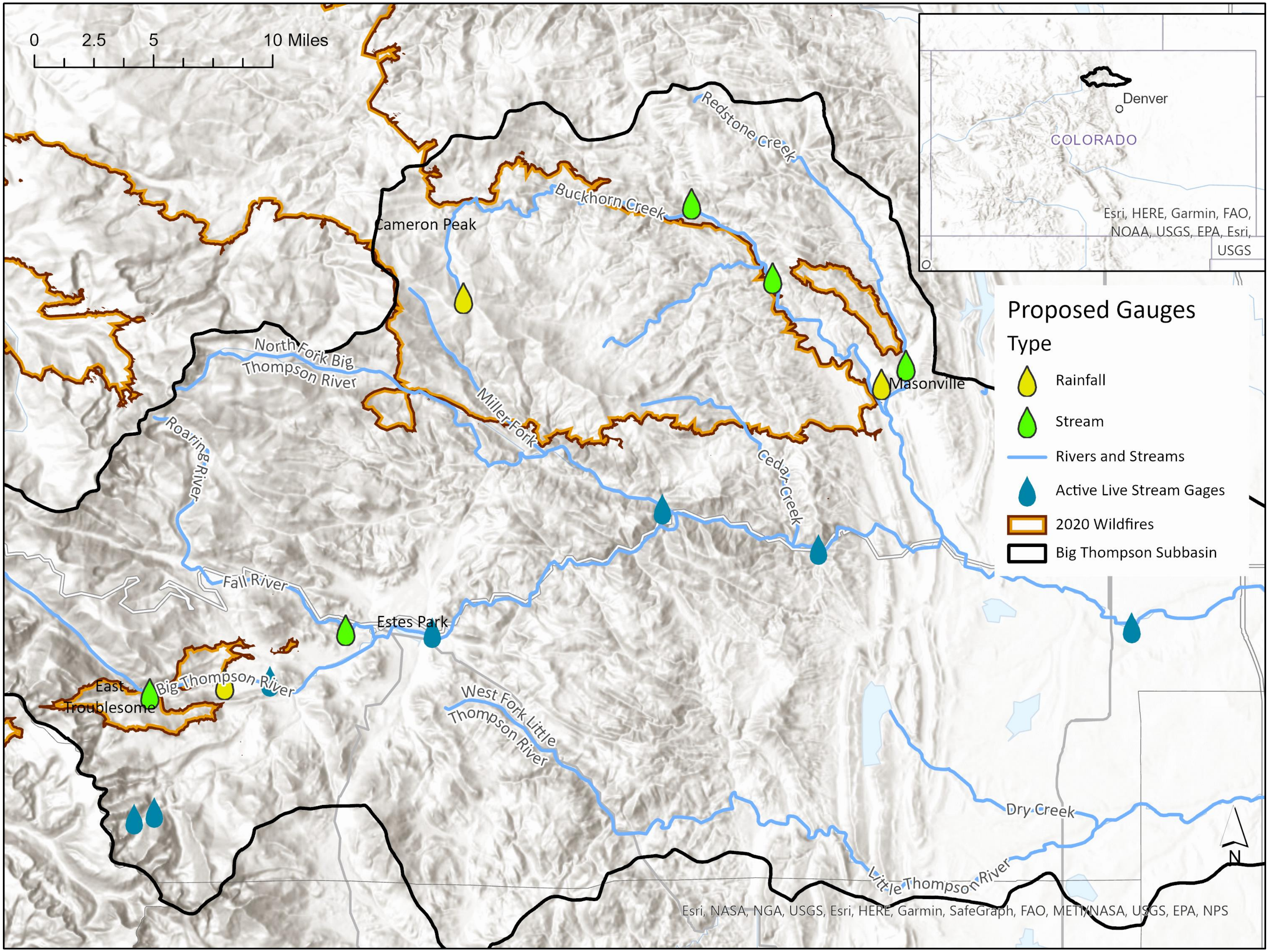

Runoff Model Including Slope for Post-Burned Big Thompson Subbasin
Runoff Model
Curve Number
0 - 9
10 - 16
17 - 21
22 - 32
33 - 45
46 - 65
66 - 100
2020 Wildfires
Cameron Peak
Fort Collins
10725 ft
9897 ft
East Troublesome
14261 ft
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS
Box Prairie
Cameron Peak
N
HORSETOOTH MOUNTAIN PARK
Horsetooth Heights
Masonville
Glen Haven
0
1.25
2.5
5 Miles
Drake
Spatial Reference
Name: NAD 1983 StatePlane Colorado North FIPS 0501 Feet
Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA
Little Dam



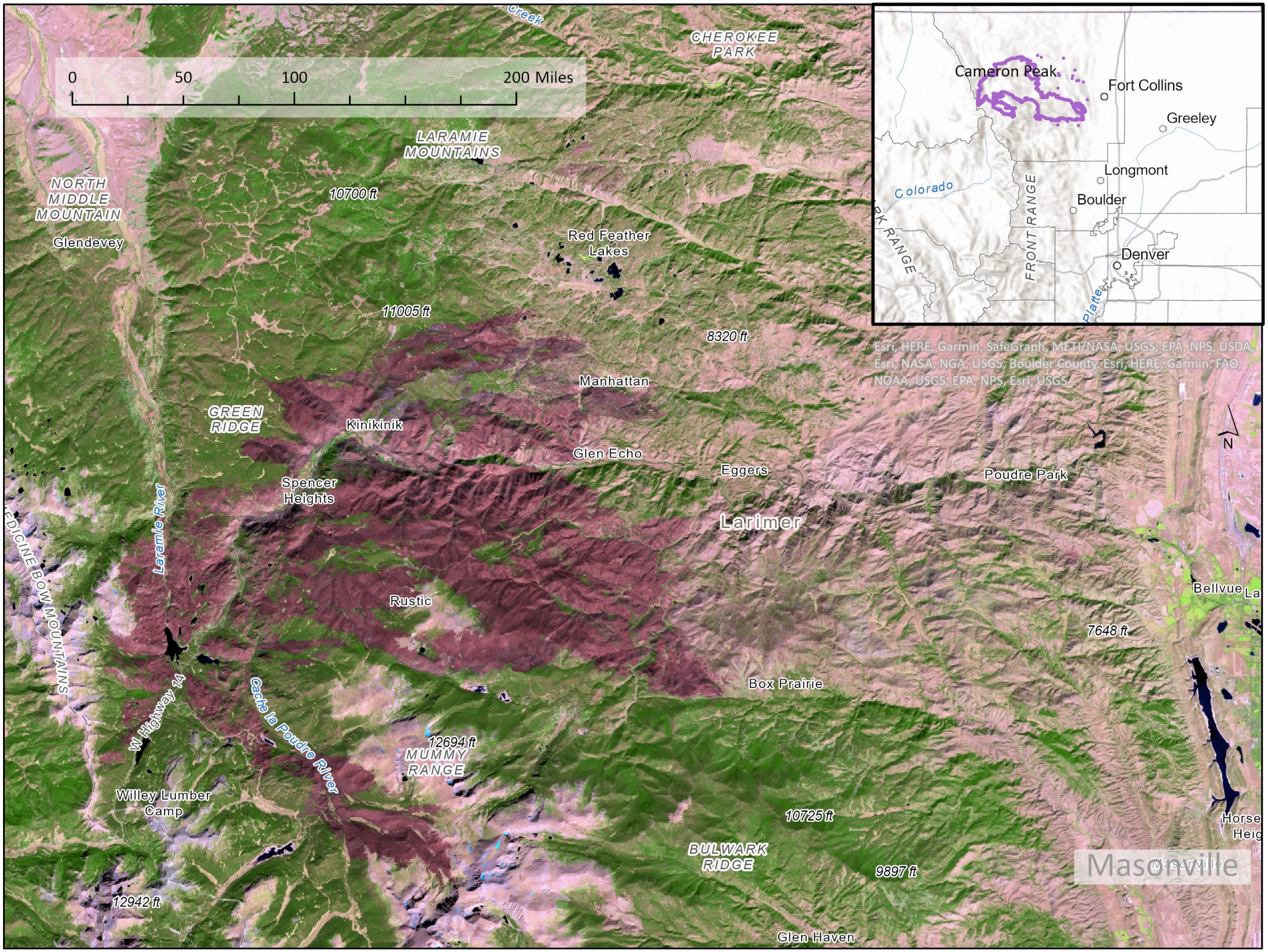
Flow Accumulation Model and Water Features for Big Thompson Subbasin
Water Bodies
Ice Mass
Lake/Pond
Reservoir
Swamp/Marsh
Flow Accumulation
1.4
0
2020 Wildfires
PourPoint
Cities
Masonville
Loveland
Estes Park
East Troublesome
Denver
COLORADO
0
3.75
7.5
15 Miles
0
1 mi
Estes Park
0
1 mi
Masonville
Spatial Reference
Name: NAD 1983 StatePlane Colorado North FIPS 0501 Feet
N
Esri, NASA, NGA, USGS, Esri, NASA, NGA, USGS, FEMA, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS



N
Cameron Peak
12956 ft
10725 ft
9897 ft
Masonville
Fort Collins
Denver
COLORADO
Cache la Poudre River
Greeley
Loveland
FRONT RANGE
Estes Park
Big Thompson River
South Platte River
Colorado River
East
Troublesome
14261 ft
Legend
Evergreen Forest
Mixed Forest
Open Water
Big Thompson Subbasin
2020 Wildfires
0 3.75 7.5 15 Miles
Longmont
Speer Canal
Boulder
5251 ft



0
2.5
5
10 Miles
Denver
COLORADO
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, USGS
Proposed Gauges
Type
Rainfall
Stream
Rivers and Streams
Active Live Stream Gages
2020 Wildfires
Big Thompson Subbasin
Redstone Creek
Buckhorn Creek
Cameron Peak
North Fork Big Thompson River
Miller Fork
Masonville
Roaring River
Cedar Creek
Fall River
Estes Park
East Troublesome
Big Thompson River
West Fork Little Thompson River
Dry Creek
Little Thompson River
N
Esri, NASA, NGA, USGS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS



0
50
100
200 Miles
CHEROKEE PARK
LARAMIE MOUNTAINS
NORTH MIDDLE MOUNTAIN
Glendevey
10700 ft
Red Feather Lakes
11005 ft
8320 ft
Manhattan
GREEN RIDGE
Kinikinik
Glen Echo
Eggers
Poudre Park
Spencer Heights
Larimer
Laramie River
Rustic
Bellvue
7648 ft
Box Prairie
W Highway 14
Cache la Poudre River
12694 ft
MUMMY RANGE
Willey Lumber Camp
10725 ft
BULWARK RIDGE
9897 ft
Masonville
12942 ft
Glen Haven
Horse
N
Cameron Peak
Fort Collins
Greeley
Longmont
Boulder
Denver
Colorado
FRONT RANGE
Platte
Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA, Esri, NASA, NGA, USGS, Boulder County, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, USGS