TECHNICAL MEMORANDUM

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Date: March 6, 2026

Project: Wildfire Hazard Potential for River Restoration Projects

Re: Applied GIS Methodology

1 INTRODUCTION

This memo presents a GIS-based methodology for evaluating wildfire risks to river restoration projects during the early stages of site assessment and design. The objective is to provide a methodology that can be used by river restoration design practitioners to understand the potential risks to their projects from wildfire so that appropriate design decisions can be made. This effort builds off of a 2023 study supported by Reclamation on how wildfires affect river restoration projects in the Methow River Watershed (Rio ASE & Inter-Fluve, 2023). This document is a follow-up to a previous memo describing the draft GIS methodology (Inter-Fluve and Rio ASE, October 2024). The October 2024 memo details the conceptual framework and intended application of the GIS methods. This memo assumes an understanding of the content discussed in the October 2024 memo and provides an updated methodology and also includes descriptions of three case study applications of the methods: Phipps Meadow, Lookingglass Creek, and the Chiwawa River.

The Phipps Meadow Habitat Enhancement project area is located in the southern Blue Mountains in Oregon on a 279-acre property owned by the Blue Mountain Land Trust. The project goals are centered around raising the annual low water table, increasing activation of the valley's existing channels, and increasing habitat availability for riparian and wetland species. Additional goals include expanding suitable area for juvenile salmonid rearing and adult salmonid spawning. The project intends to increase complex habitat features and the proportion of the valley bottom available to active fluvial processes.

The Lookingglass Creek Restoration Project is located in the Grande Ronde River basin on a 666-acre property owned by the Confederate Tribes of the Umatilla Indian Reservation (CTUIR). The project's goals focus on restoration of First Foods through floodplain reconnection, restoration of channel morphology, enhanced instream habitat structure and complexity, and restoration of diverse and resilient native riparian and wetland plant communities.

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The Lower Chiwawa Assessment Unit (LCAU) spans the lower 13.9 miles of the Chiwawa River in Washington. The Chiwawa River supports populations of Endangered Species Act (ESA) listed Upper Columbia spring Chinook salmon (*Oncorhynchus tshawytscha*), Upper Columbia steelhead (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*). Project goals within this reach include adding structure in the channel to improve wood retention, increasing wood loading, improving access to off-channel floodplain and side channel habitat for summer rearing, winter rearing, and fry life stages, and improving pool quantity/quality and cover for adult holding and summer rearing life stages. The Lower Chiwawa River Area G Habitat Enhancement Project: Phase 1 has been completed in this reach, with several other projects anticipated in the future.

The GIS methods described in this memo evaluate indirect watershed scale impacts (potential sediment loading, wood loading, or runoff change). All methods utilize the Wildfire Hazard Potential (WHP) dataset along with other publicly available and user-sourced data described below.

The following methods make several assumptions that users should be aware of when interpreting the results and implementing any models:

1. The model outputs are not based on any current or predicted weather conditions.
2. Based on the available fuel loading, climate patterns, and physical landscape constraints, the analysis assumes that the impacts described are based on likelihood of fire intensity, assuming the highest intensity of all likely wildfire scenarios in each output.
3. As a result of being based on datasets such as the WHP, which represent a relative risk, the model outputs are not time bound and do not represent a forecast for a given amount of time in the future, and instead represent the most extreme of likely scenarios given the most recently modeled conditions based on available data.
4. Lastly, the models assume that additional fires which may have occurred in the study area after data updates have occurred will reduce fuel loading, and subsequent vegetative regrowth is not factored into any of the model results.

The GIS methods provide figures and summary statistics which can be used by practitioners to consider how wildfire impacts influence individual projects (Inter-Fluve and Rio ASE, October 2024). Wildfire impacts can be evaluated in the context of project goals (Figure 1). These evaluations can guide subsequent design modifications and adaptive management actions (Inter-Fluve and Rio ASE, October 2024).

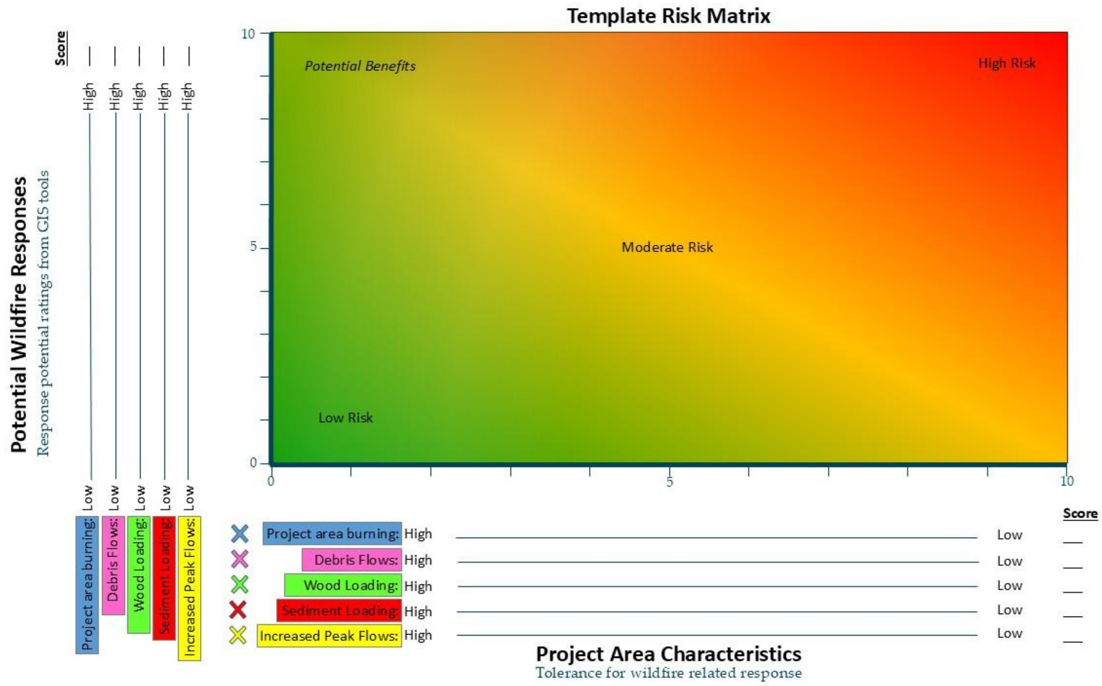

Figure 1: Framework for conceptualizing risk to project elements in relation overall project goals.

2 DATA

The GIS models presented below are intended to provide a user-friendly approach to assessing wildfire hazards and risks at a given river restoration project site. The GIS analysis in this study uses ArcGIS Pro v3.5 (ESRI, 2025), and the methodology is written with the assumption that the user would use the same software, although the conceptual framework could be applied with any GIS software capable of performing the analysis. The methods focus on leveraging existing wildfire hazard data products developed by fire scientists to apply spatially relevant elements to river restoration projects.

Datasets used to develop the models provide coverage for the United States. The GIS models presented are designed to provide flexibility so that users may utilize finer resolution data where available.

2.1 WILDFIRE HAZARD POTENTIAL

The primary dataset used in the following GIS models is the USDA Forest Service Fire Modeling Institute's Wildfire Hazard Potential (WHP) dataset (Scott et al., 2024). The WHP dataset depicts the relative potential for high-intensity wildfire for the U.S. at a 30-meter spatial resolution (Figure 2).

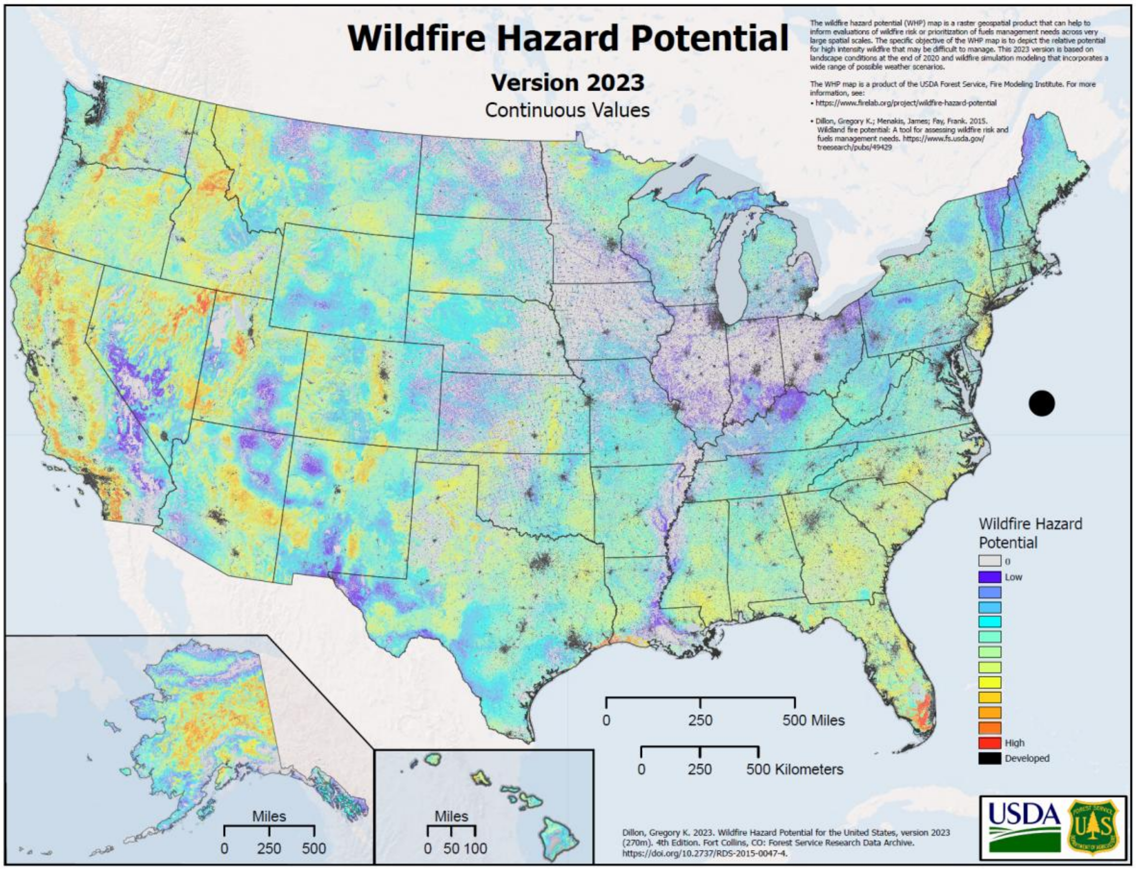

Figure 2: Wildfire Hazard Potential data displayed across the United States (Dillon et al., 2023).

In our model, we are using the continuous WHP dataset. This dataset was selected to map the relative risk of wildfire onto features of interest to river restoration practitioners and is employed in each GIS model presented below. The WHP dataset summarizes wildfire hazards by assessing burn likelihood and intensity by incorporating data from the Large Fire Simulator (spatial likelihood and intensity of wildfire), LANDFIRE 2020 data (spatial distribution of vegetation and fuel loading), and wildfire history, and does not include current or forecasted weather or fuel moisture conditions (Dillon et al., 2015). The LANDFIRE 2020 data was updated reflect fuel disturbances in 2021 and 2022. Therefore, the fire intensity used for modeling WHP reflects landscape conditions as of the end of 2022.

The primary input and outputs are burn probability (BP) and/or flame-length probabilities (FLPs) that are modeled with the geospatial Fire Simulation (FSim) system. FSim simulates the start and growth of wildfires that are likely to rapidly expand, which means it captures large fires but may neglect smaller ones. FLP is a conditional measure that represents the likelihood of burning at a certain intensity level with the assumption that a fire occurs. It is simulated with BP to determine if there is a fire, what intensity it will be and how high the flames will get. Together, BP and FLP determine not only the probability of fire but also its expected intensity. The core of this model is therefore based on vegetation and weather conditions that can lead to large fires. This system also accounts for fire suppression through probability of containment used in the statistical model based on spread rates, fuel types, and length of burning time.

[Wildfire Hazard Potential Dataset | Scott et al., 2024]

In the analysis described in this memo, wildfire risk is framed within the context of its potential impact on river restoration efforts. Risk is typically defined as the combination of likelihood and consequences, and the WHP framework reflects this concept while also incorporating fire intensity as a key factor (Figure 3). In this case, “susceptibility” refers to the consequences of wildfire damage to river restoration projects resulting from factors such as increased sediment and wood loading and increased flows, rather than to structures or timber values.

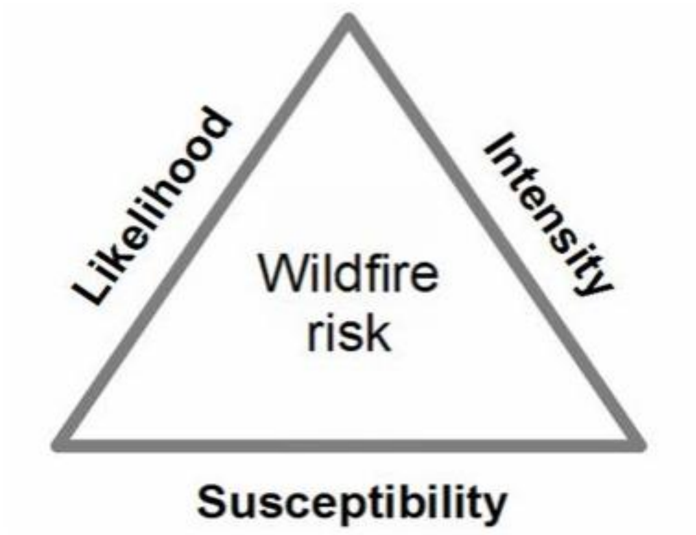

Figure 3: The wildfire risk triangle (Scott et al., 2013 and Dillon et al., 2015) is composed of likelihood and intensity of fire in relationship to the susceptibility of particular resources to fire.

2.2 LANDSLIDE SUSCEPTIBILITY DATABASE

The USGS landslide susceptibility database was created through analysis of a national landslide database to identify trends in topographic slope-relief thresholds for landslide-susceptible terrain. The database is the product of a model which aggregates landslide susceptibility zones using down-sampling results (Mirus et al., 2024). The landslide susceptibility database assesses the likelihood of occurrence rather than the risk to a given resource.

This dataset has a 90m resolution and uses USGS elevation data (3DEP) along with the locations of past landslides to model landslide susceptibility. Mirus et al. (2024) calculated slope and relief thresholds and used those thresholds to determine areas with greater landslide susceptibility. This dataset does not account for soil type/erodibility. This landslide susceptibility dataset spans from 0 - 81 with each number indicating an increased landslide susceptibility. This model has improved over previous landslide susceptibility modelling approaches by using an updated landslide inventory (Belair et al., 2022) and by using 10m DEMs to calculate the slope-relief threshold that cover the conterminous United States (CONUS) and Alaska, Hawaii, and Territory of Puerto Rico. Previous models used 90m DEMs that only covered CONUS. This layer does not account for frequency or magnitude of landslides as a landslide hazard map does, but rather it is determining landslide susceptibility based on topographical factors that have led to landslides in the past.

Debris Flow Map / Landslide Severity Map | USGS

2.3 SSURGO: SOIL ERODIBILITY AND HYDROLOGIC GROUP

Both soil erodibility and soil hydrologic group attributes from the Soil Survey Geographic Database (SSURGO) dataset are used in the below models. Soil hydrologic group refers to codes given to groups of soils that have similar runoff potential under similar storm and cover conditions.

Soil erodibility is measured through an erodibility factor which quantifies the susceptibility of soil particles to detachment and movement by water on a scale of 2 - 64. The soil erodibility index is composed of ratings of soil texture, organic matter content, soil structure, and soil permeability.

Both SSURGO hydro group and soil erodibility GIS layers were obtained through the Living Atlas in ArcGIS Pro. These datasets are derived from the USDA NRCS SSURGO dataset and cover the CONUS extent. They are updated by ESRI annually.

2.4 NATIONAL LAND COVER DATABASE (NLCD) LAND COVER

The NLCD is a database developed by the U.S. Geological Survey (USGS). The NLCD annually releases data products related to land cover and surface change across the U.S. These datasets are developed using Landsat data. Data is available for the U.S. from 1985 – 2024. 2024 NLCD land cover data was used in this analysis.

Land Cover (CONUS) | Multi-Resolution Land Characteristics (MRLC) Consortium

2.5 NLCD TREE CANOPY COVER

The NLCD Tree Canopy Cover dataset, developed by the USDA Forest Service, provides percent tree canopy cover for CONUS as well as Coastal Alaska, Hawaii, U.S. Virgin Islands and Puerto Rico. The dataset was developed in 2016 and last updated in 2023 and is available at a 30-meter spatial resolution. 2023 NLCD TCC data was used in this analysis.

The tree canopy cover (TCC) values are calculated based on baseline data that was averaged for each pixel. Each year the dataset has been updated (2011, 2013, 2016, 2019, 2021, 2023), the % TCC change is compared to the 2008 – 2010 baseline data. If an increase or decrease of 10% TCC occurred in the pixel, it is updated, and if not, it remains the same value as the prior release year. The pixel values range from 0 – 100 with values of 254 and 255 representing the non-processing area and the background, respectively.

TCC (CONUS) | Multi-Resolution Land Characteristics (MRLC) Consortium

2.6 VALLEY CONFINEMENT AND VALLEY BOTTOM DATASETS

Identification of confined (typically sediment transport dominated) and unconfined (typically sediment deposition dominated) reaches along a watershed’s valley bottom can help users interpret the landscape context of their findings. Multiple datasets delineating valley bottom and valley confinement can be used for this purpose.

The USFS Valley Confinement GIS layer identifies confined valleys across most of the Pacific Northwest in the United States. The layer was calculated by using the Valley Confinement Algorithm (VCA), USGS 30m DEM data, and NHDPlusV2 flowline data. The VCA was developed by Nagel et al. (2014), who also compared it to field data. They found that the VCA agreed with their valley confinement field findings 79% of the time, and that it could differentiate between unconfined and confined valleys with 89 – 91% accuracy. To determine the extent of the unconfined valley bottom, a flooding simulation was implemented that identified valley bottoms larger than 60 – 90m in width and flooded these valley bottoms to 5x the modelled bankfull depth. The concurrence of flooding and a minimum ground slope threshold was determined as the unconfined valley bottom. The USFS valley confinement dataset is limited to the Pacific Northwest of the United States.

The USFS Valley Confinement GIS layer can be accessed through the following link:

Valley Bottom Confinement | USFS

For users seeking to include valley confinement data outside of the Pacific Northwest, the Riverscapes Consortium Valley Bottom Extraction Tool (VBET) may be used. The tool identifies the geographic units of a valley bottom, including the channel, low-floodplain, and inactive floodplain. The user provides a DEM and channel area polygon to delineate the valley bottom using slope and the height above nearest drainage (Gilbert et al., 2016).

The Valley Botton Extraction Tool is available through the following link:

Valley Bottom Extraction Tool (VBET)

2.7 PROJECT WATERSHED

A watershed polygon is used in each of the methods presented below. The watershed should be defined with the most downstream point of the project area defined as the delineation point. Users may choose their own method for watershed delineation. Options include and are not limited to using the USGS's StreamStats tool or the Watershed Ready to Use tool in ArcGIS Pro.

StreamStats | USGS

Watershed Delineation Tool | ESRI

2.8 CURVE NUMBER PROCESSING

Curve numbers are a dimensionless parameter that measure runoff potential. They are calculated using a lookup table between hydrologic soil groups and land cover (USDA-SCS, 1972). There are many sources for local curve number values. A general curve number table produced by the U.S. Army Corps of Engineers (USACE) is linked below along with the general methodology used in this analysis for creating curve numbers from NLCD land cover.

TR-55 Curve Number Tables

Creating a Curve Number Grid and Computing Subbasin Average Curve Number Values

2.9 WILDLAND FIRE PERIMETER HISTORY

The Wildland Fire Perimeter History dataset is an inventory fire perimeters collected from multiple agencies. As of writing, the perimeters were updated through the 2024 fire season. This dataset is published by the National Interagency Fire Center (NIFC). This dataset is optional for use as a map overlay to the WHP dataset. Utilizing this dataset can identify fires that have occurred more recently than the fire history included in the most recent WHP dataset. Areas with more recent fire history not included in the WHP may have different actual values than those modeled in the output rasters.

Interagency Wildland Fire Perimeter History | NIFC

Table 1: Summary of datasets used in GIS methodology

Dataset	Spatial Resolution	Temporal Resolution	Publisher	Description
Wildfire Hazard Potential	30m	-	USDA Forest Service	Identifies areas with potential high intensity wildfires based on burn likelihood and intensity, vegetation, and wildfire history.
Landslide Susceptibility	90m	-	USGS	Identifies areas with high landslide potential by calculating a slope-relief threshold in conjunction with an inventory of past landslides.
SSURGO: Soil Erodibility and Hydrologic Group	30m	-	USDA Natural Resources Conservation Service	Soil information collected by the National Cooperative Soil Survey.
NLCD Land Cover	30m	2-3 years	USGS	Classifies land cover.
NLCD Tree Canopy Cover	30m	2-3 years	USDA Forest Service	Tree Canopy Cover (TCC) values averaged per pixel based on the 2008 – 2010 baseline data. Values are updated with each version released.
USFS Valley Confinement – Pacific Northwest	30m	-	USDA Forest Service	Identifies unconfined valleys based on the Valley Confinement Algorithm (VCA), USGS 30m DEM data, and NHDPlusV2 flowline data.
The Valley Bottom Extraction Tool – Outside of Pacific Northwest	10m	-	Riverscapes Consortium	A GIS tool used to identify valley bottoms within a landscape.

StreamStats or Watershed Ready to Use tool in ArcGIS Pro	-	-	USGS / ESRI	Delineates project area watershed
Curve Number Processing and TR-55 Curve Number Tables	-	-	Multiple sources	Curve number processing methods and TR-55 tables.
Wildland Fire Perimeter History	-	Annual	NIFC	Fire perimeter inventory accumulated from multiple agencies.

3 GIS METHODOLOGY

3.1 DIRECT PROJECT-SCALE IMPACTS

3.1.1 Data Exploration

This first step involves an initial exploration of the WHP dataset in relation to the project watershed and project area.

Data input

- Project watershed and project area polygon
- Wildfire Hazard Potential (WHP) continuous raster
- Valley confinement or valley bottom polygons
- Optional – Wildland Fire Perimeter History polygons

Geoprocessing

1. Import WHP raster.
2. Clip WHP dataset to project watershed and surrounding areas.
3. Right click the loaded WHP layer and open symbology.
4. Choose the ‘Classify’ symbology option:
    a. The Field is Value, Normalization is <None>, Method is Manual Interval, and Classes is 6
5. Manually enter the bin values as below in Table 2. The binned values and suggested symbology are from the supplemental materials provided with the Scott et al. (2024) WHP data publication.

Table 2. Bins for displaying the WHP layer. Values are from the supplemental materials provided by Scott et al. (2024).

Upper value	Label
0	NA
51	Very Low
137	Low
339	Moderate
1563	High
100000	Very High

6. Import project area polygon.
7. Overlay valley confinement / valley bottom dataset to provide geomorphic context.
8. Optional – Overlay the fire perimeter polygons over the WHP map and evaluate whether there have been recent fires that are not included in the WHP dataset. If there are more recent fires, these areas should be highlighted as likely having different values than those generated from the below result rasters.

Output

- The output map shows the project watershed and project area in spatial relationship to the Wildfire Hazard dataset.

3.2 INDIRECT WATERSHED-SCALE IMPACTS

3.2.1 Data Pre-Processing for All Rasters

The below analyses use national datasets that must undergo data transformations to create the final rasters used for the indirect watershed-scale analyses. Conducting these data transformations prior to the final calculated raster creation speeds up this process. Below are the necessary data transformation steps. The resulting rasters will be used in the result raster analyses. To prevent processing errors, ensure that the .tif extension is added to every output raster.

3.2.1.1 Clipping National Data to Watershed and Projection

1. Add the WHP, landslide susceptibility, NLCD 2023 TCC, NLCD 2024 land cover, SSURGO soil erodibility, and SSURGO hydrologic group rasters into your project.
2. Add in your watershed layer that your data will be clipped to.
3. Click on the Tools icon in the Analysis tab and in the search bar, type *Extract by Mask.*
    a. Right click on the resulting tool and select ‘Batch’. Select the next button on the following page.
    b. In the Batch Input Raster selection, input all rasters imported in step 1, except the SSURGO rasters.
        i. Keep the default parameters.

        ii. Hit Run.
    c. The resulting rasters should be clipped to your desired extent.
4. The coordinate systems differ between the national rasters. They will need to be reprojected into the same coordinate system.
    a. NAD 1983 Contiguous USA Albers is the recommended projection for all the rasters during this phase of analysis, given its default use in many of the national datasets. The final calculated rasters to be used in mapping can be converted to a more local projection.
    b. Click on Tools in the geoprocessing pane and type *Project Raster.*
        i. In the Input Raster pane, select the raster that needs to have the coordinate system changed. This step may have to be repeated multiple times if multiple rasters need to be reprojected.
        ii. Select the appropriate Output Coordinate System from the drop-down menu.
        iii. The correct geographic transformation should automatically fill in.
        iv. For the Resampling Technique, use these selections for each input dataset (if they are being reprojected):
            a. Bilinear Interpolation: WHP, landslide susceptibility, TCC, soil erodibility
            b. Nearest Neighbor: land cover, soil hydrologic group
        v. Keep the default output cell size.
        vi. Run the tool.
        vii. The resulting rasters are now ready to be resampled.
5. NOTE: Using the SSURGO data requires these additional processing steps because the layers for hydro group and soil erodibility are Living Atlas image layers that are too large to directly use in the *Extract by Mask* tool. These steps only need to be run once for each of the SSURGO rasters. The resulting rasters can be used in all subsequent steps where they are needed:
    a. Search for the *Clip Raster* tool in the geoprocessing pane.
    b. The Input Raster is the SSURGO layer for hydro group or soil erodibility.
    c. The Output Extent is your watershed.
    d. Name the Output Raster Dataset.
    e. Run the tool.
    f. Repeat for the other SSURGO raster.
    g. Run through steps 3 and 4 on the resulting clipped rasters, using the original *Extract by Mask* tool without the ‘Batch’ function.

3.2.1.2 Resampling Data to 30m Resolution

1. This step uses the clipped rasters from the previous step and creates 30m resolution datasets.
2. Click the Tools icon in the Analysis tab.
    a. Search for *Resample* in the geoprocessing pane.
    b. Right click the resulting tool and select ‘Batch’. Click next on the following page.
    c. In the Batch Resample tool:
        i. Input the landslide susceptibility and soil erodibility rasters.

ii. Manually enter the output cell size with X = 30m and Y = 30m.
    1. If using the NAD 1983 Contiguous USA Albers recommended projection, the cell sizes will be in meters by default. If using an alternative projection that measures cell sizes in feet, the X and Y units should be set to equal 98.425 ft.

iii. Select the Bilinear Interpolation Resampling Technique from the drop-down menu, since these are continuous datasets.
iv. In Environments, set Snap Raster to the clipped WHP dataset generated in Section 3.2.1.1. This ensures all rasters are aligned for calculations.
v. Run the tool.
vi. Right click the resulting rasters, go to Properties -> Source-> Raster Information and confirm that Cell Size x and Cell Size Y are 30 for all rasters.

d. Resample the clipped and reprojected hydro group raster using the Resample tool.
    i. Select the clipped hydro group raster for the Input Raster.
    ii. Manually enter the output cell size with X = 30 and Y = 30.
    iii. Select Nearest as the Resampling Technique, because this is categorical data.
    iv. In Environments, set Snap Raster to the clipped NLCD land cover dataset.
e. The resulting rasters are ready to be scaled.

3.2.1.3 Scaling Data from 0 – 10

This step scales each input dataset from 0 – 10 using the CONUS minimum and maximum in each input dataset. These rasters will be used in the next step to create the result rasters.

1. Wildfire Hazard Potential:
    a. The 2024 WHP CONUS ranges from 0 – 99853. Suggested bins were distributed in the supplemental materials alongside the Scott et al. (2024) WHP dataset publication. The bins were determined by log scaling the continuous WHP raster. These suggested bins were pared down from 12 to 10 for this analysis. Bins 1 and 2 were merged and bins 3 and 4 were merged. There were very few if any values in these low bins within the study watersheds. The other suggested bins remained the same as those suggested by the authors. The bins used in the *Reclassify* tool are shown below in Table 3.

Table 3. The bins used to scale the wildfire hazard potential dataset. Values are from the supplemental materials provided by Scott et al. (2024). The number of bins was modified from 12 to 10.

Start	End	New
0	0	0
0	7	1
7	46	2
46	121	3
121	316	4
316	825	5
825	2154	6
2154	5623	7
5623	14678	8
14678	38312	9
38312	100000	10
NODATA	NODATA	NODATA

b. Search for the *Reclassify* tool in the geoprocessing pane.
c. In the scaling boxes, set the values above.
d. Use the resulting scaled raster for WHP in all raster calculations.
e. The ArcGIS Pro ModelBuilder tool to generate the scaled Wildfire Hazard Potential dataset is shown below in Figure 4.

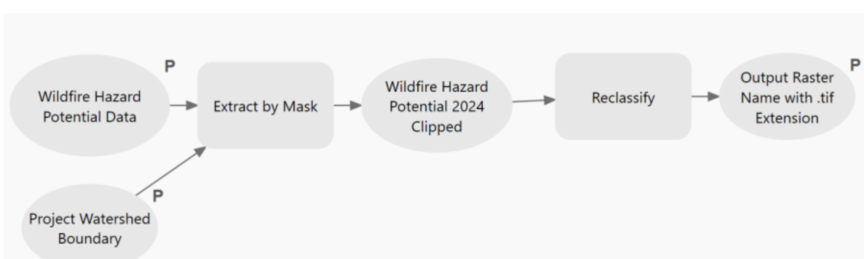

Figure 4. ModelBuilder tool in ArcGIS Pro to generate the scaled Wildfire Hazard Potential dataset.

2. Landslide Susceptibility:
   a. The CONUS landslide susceptibility raster ranges from 0 – 81.
   b. Search for the *Raster Calculator* in the geoprocessing pane.
   c. In the blank box, enter the equation below, filling in ‘Landslide’ with your clipped, resampled datasets:
      i. (“Landslide”/81)*10

d. The resulting scaled raster will be used in all raster calculations that require the landslide susceptibility dataset.
e. The ArcGIS Pro ModelBuilder tool to generate the scaled landslide susceptibility dataset is shown below in Figure 5.

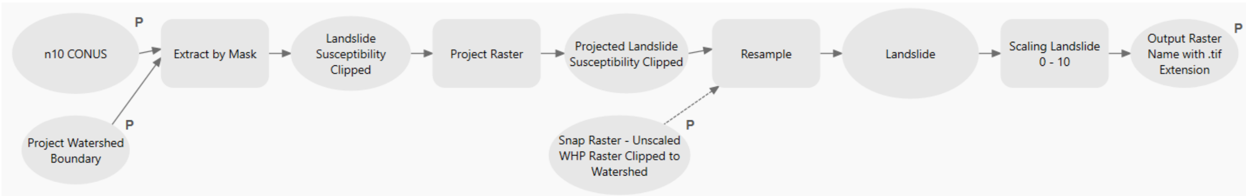

Figure 5. ModelBuilder tool in ArcGIS Pro to generate the scaled landslide susceptibility dataset. n10 is the model type used to generate the susceptibility layer.

3. NLCD Tree Canopy Cover:
   a. The NLCD 2023 Tree Canopy Cover dataset ranges from 0 – 255, with values above 100 indicating background data. Values above 100 need to be removed for proper scaling.
      i. Per the NLCD TCC 2023 metadata, the non-processing area is represented by the value 254 and the background is represented by the value 255. These cells need to be removed for proper scaling of this dataset.
   b. To fully remove these background values, open the 'Raster Calculator' and type this Con statement:
      i. Con("TCC Resampled" <= 100, "TCC Resampled")
   c. After this step, the max value in Properties > Statistics for the raster should show 100.
   d. Search for the *Raster Calculator* in the geoprocessing pane.
   e. In the blank box, enter the equation below, filling in 'TCC' with your cleaned and clipped dataset:
      i. ("Scaled TCC"/100)*10
   f. The resulting raster will be used in the wood loading likelihood raster calculation.
   g. The ArcGIS Pro ModelBuilder tool to generate the scaled NLCD TCC dataset is shown below in Figure 6.

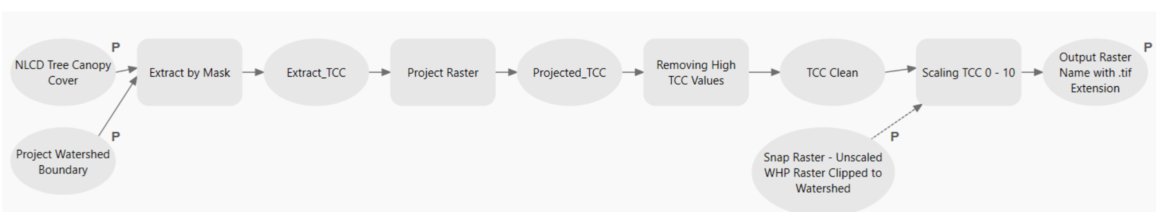

Figure 6. ModelBuilder tool in ArcGIS Pro to generate the scaled NLCD Tree Canopy Cover dataset.

4. SSURGO Soil Erodibility:
   a. The CONUS SSURGO soil erodibility raster ranges from 2 – 64.
      i. Search for the *Raster Calculator* in the geoprocessing pane.
      ii. In the blank box, enter the equation below, filling 'Soil_Erodibility' with your clipped dataset:
      iii. (('Soil_Erodibility' - 2)/62)*10

b. The resulting raster will be used in the sediment loading likelihood raster calculation.
c. The ArcGIS Pro ModelBuilder tool to generate the scaled soil erodibility dataset is shown below in Figure 7.

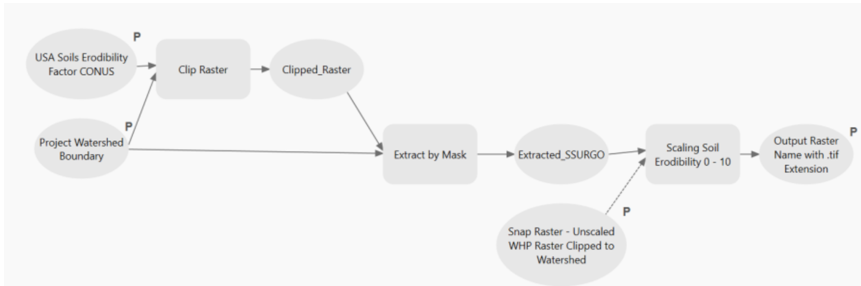

Figure 7. ModelBuilder tool in ArcGIS Pro to generate the scaled SSURGO soil erodibility dataset.

3.2.2 Debris Flow Potential Raster

This raster represents the potential for a debris flow accounting for wildfire hazard potential. This raster includes the landslide susceptibility raster and the WHP raster. High raster values indicate a higher likelihood of a debris flow within a watershed considering wildfire hazard potential (Figure 8, Figure 9, Figure 10).

Data input

- Scaled WHP raster from step 1 in Section 3.2.1.3
- Scaled landslide susceptibility raster from step 2 in Section 3.2.1.3

Geoprocessing

1. Create debris flow potential raster:
    a. Search for the *Raster Calculator* in the geoprocessing pane.
    b. In the blank box, enter the equation below, filling in ‘Landslide_scaled’ and ‘WHP_scaled’ with your scaled datasets:
        i. (“Landslide_scaled” + “WHP_scaled”)/2
        ii. The result is a debris flow potential raster, where values take into account the greater debris flow potential that may occur if there is greater wildfire potential.
2. Visualize data
    a. Users with data that is dense or difficult to interpret at the watershed scale may optionally choose to apply thresholds to their data to isolate high-risk areas using the *Con* tool. Alternatively, users with this type of data may choose to run the *Focal Statistics* tool to smooth their data.
    b. Outputs can be overlaid on hillshade or Relative Elevation Map surfaces.
    c. Optionally overlay the valley bottom / valley confinement dataset over outputs to visualize where depositional areas upstream of the project site may buffer downstream impacts.

Output

- Classified debris flow potential raster including increased risk considering wildfire hazard potential. Values represent potential increases in debris flow potential due to wildfire. Summary statistics can be calculated using *Focal Statistics* or *Zonal Statistics* (Table 4).
- This raster can be used to investigate areas adjacent to the project site or upstream to gauge the potential for an increase in debris flow likelihood given wildfire potential. This can help inform design and planning decisions such as:
    - Locating project elements such as log jams to avoid debris flow pathways
    - Anticipating potential sediment inputs into the project area
    - Assessing risks to infrastructure within and downstream of the project area

Table 4: Debris flow potential summary statistics within the case study watersheds. Statistics are shown with and without the WHP dataset for comparison.

WATERSHED	WHP	MIN	MAX	MEAN	MEDIAN	SD
Lookingglass Creek	Yes	0	9.5	5.4	5.2	2.1
	No	0	10	4.6	4.3	3.7
Phipps Meadow	Yes	0	9.5	4.9	4.8	1.9
	No	0	10	4.7	4.4	3.1
Chiwawa River	Yes	0	10	6.5	7	2.1
	No	0	10	7.7	9	2.9

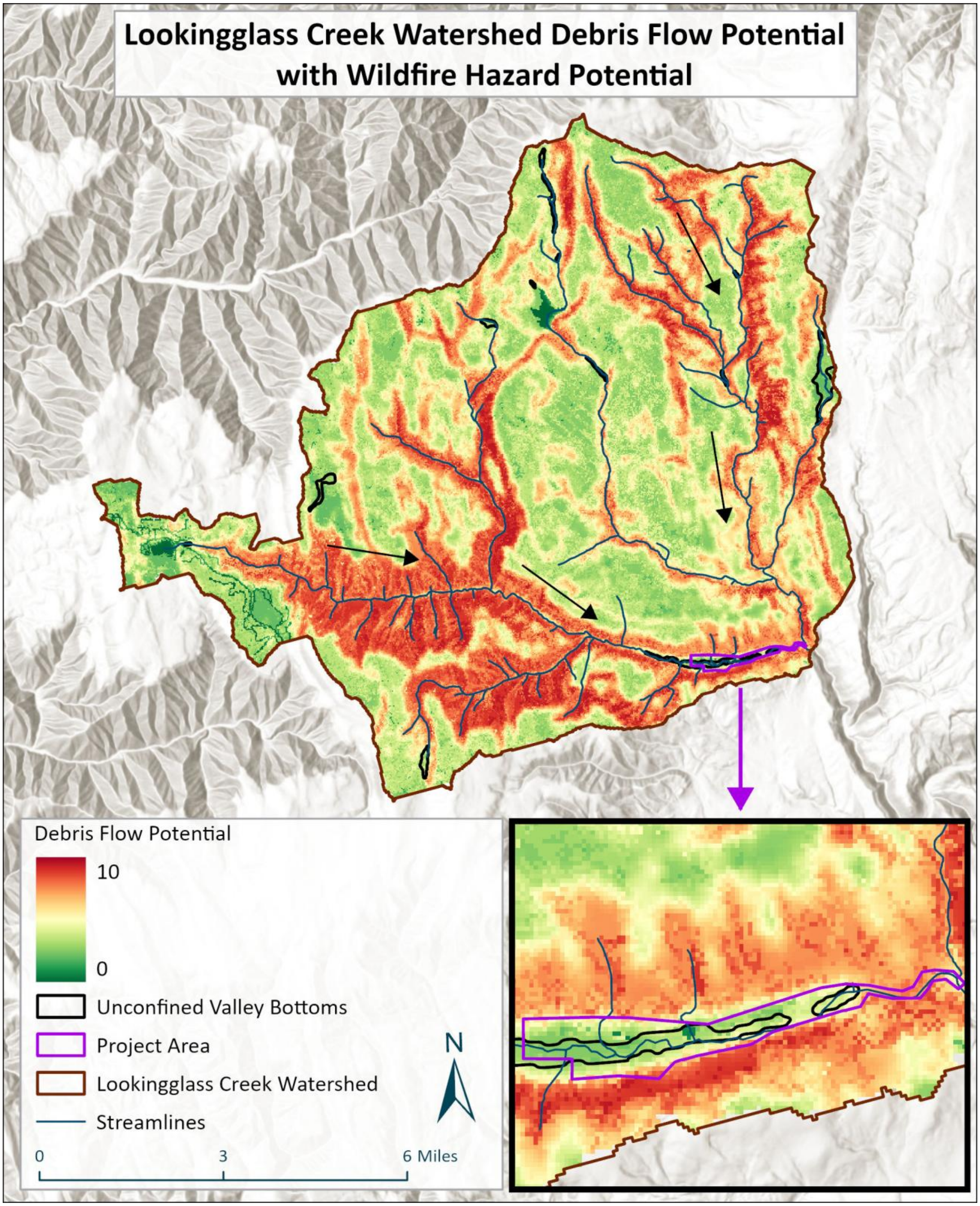

Figure 8: Debris flow potential with WHP in the Lookingglass Creek Watershed. Black arrows indicate general river flow direction.

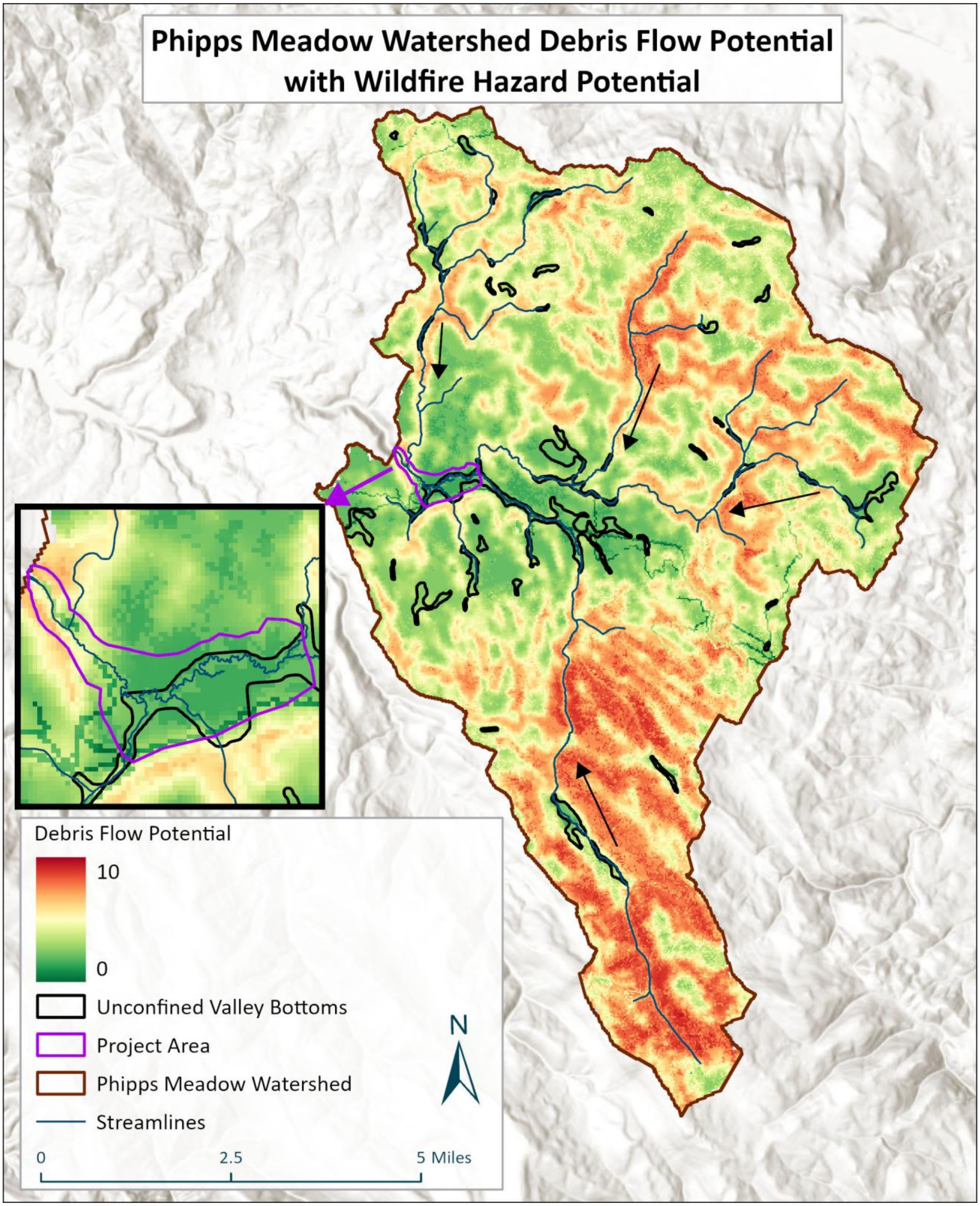

Figure 9: Debris flow potential with WHP in the Phipps Meadow Watershed. Black arrows indicate general river flow direction.

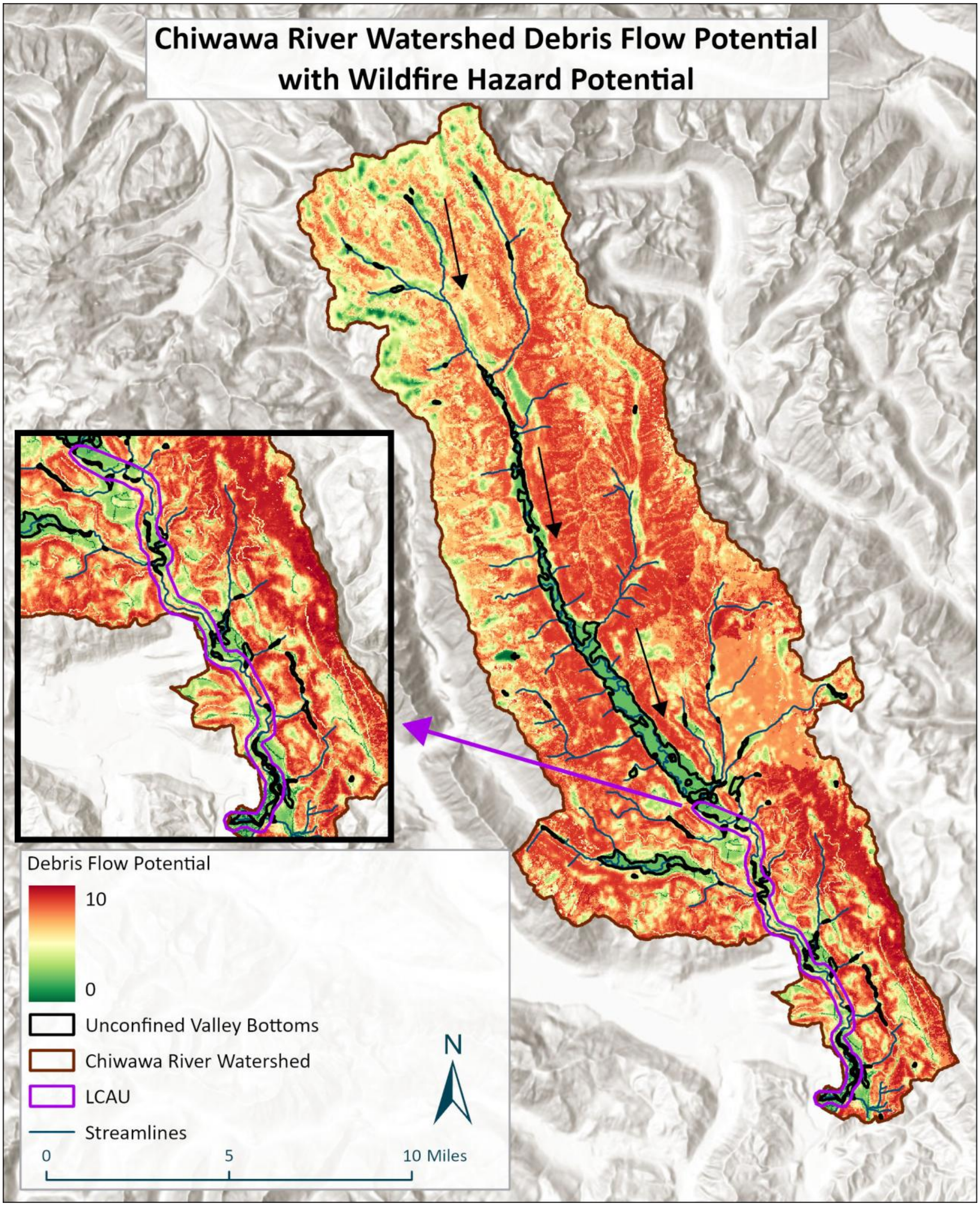

Figure 10: Debris flow potential with WHP in the Chiwawa River Watershed. Black arrows indicate general river flow direction.

3.2.3 Wood Loading Source Potential Raster

The wood loading source potential raster shows the location of increased wood loading with wildfire hazard potential. This raster does not show cumulative wood loading in the channel or transportation to the channel. The wood loading source is from the NLCD TCC raster, combined with the landslide susceptibility and WHP rasters. WHP accounts for half of the overall rating, which emphasizes potential wildfire impact in addition to current tree canopy cover and landslide susceptibility of the existing watershed (Figure 11, Figure 12, Figure 13).

Data input

- Scaled WHP raster from step 1 in Section 3.2.1.3
- Scaled landslide susceptibility raster from step 2 in Section 3.2.1.3
- Scaled NLCD 2023 Tree Canopy Cover raster from step 3 in Section 3.2.1.3

Geoprocessing

1. Create wood loading source raster:
    a. Search for the *Raster Calculator* in the geoprocessing pane.
    b. In the blank box, enter the equation below, filling in 'TCC_scaled', 'Landslide_scaled', and 'WHP_scaled' with your scaled datasets:
        i. (((“TCC_scaled” + “Landslide_scaled”)/2) + “WHP_scaled”)/2
    c. The resulting raster shows wood loading source potential with wildfire hazard potential.
2. Visualize data
    a. Users with data that is dense or difficult to interpret at the watershed scale may optionally choose to apply thresholds to their data to isolate high-risk areas using the *Con* tool. Alternatively, users with this type of data may choose to run the *Focal Statistics* tool to smooth their data.
    b. Outputs can be overlaid on hillshade or Relative Elevation Map surfaces.
    c. Optionally overlay the valley bottom / valley confinement dataset over outputs to visualize where depositional areas upstream of the project site may buffer downstream impacts.

Output

- Wood load increase source areas raster. Values represent a source of potential increased wood loading with wildfire hazard potential and existing wood loading conditions from tree canopy cover and landslide susceptibility.
- This wood loading raster only shows areas where additional wood loading is likely to be sourced from and does not show any information on the eventual transport of wood to a stream/project area.
- Summary statistics can be calculated using *Focal Statistics* or *Zonal Statistics* and plotted on Figure 1 for risk analysis in the context of project goals (Table 5).

- This raster can be used to investigate areas adjacent to the project site or upstream to gauge the potential for an increase in wood loading source given wildfire potential. This can help inform design and planning decisions such as:
    - Locating project elements such as log jams to accumulate wood in strategic locations
    - Locating depositional zones within the project to store wood on the floodplain
    - Assessing risks to infrastructure within and downstream of the project area

Table 5: Wood loading source potential summary statistics within the case study watersheds. Statistics are shown with and without the WHP dataset for comparison.

WATERSHED	WHP	MIN	MAX	MEAN	MEDIAN	SD
Lookingglass Creek	Yes	0	9.1	5.8	5.8	1.4
	No	0	9.4	5.4	5.3	2.1
Phipps Meadow	Yes	0	8.8	5	5	1.4
	No	0	9	4.8	4.9	2
Chiwawa River	Yes	0	9.6	6	6.3	1.9
	No	0	9.4	6.6	6.9	1.8

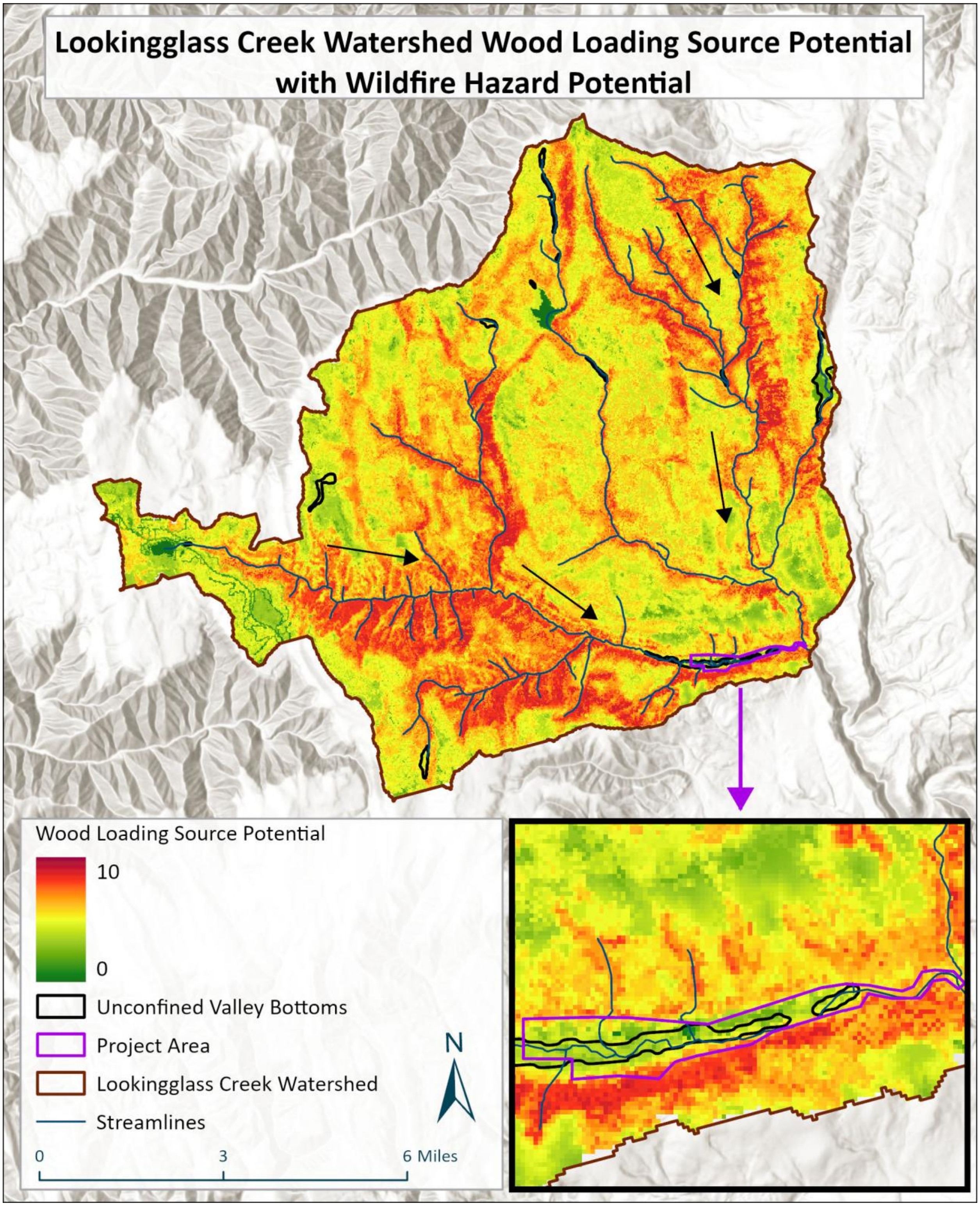

Figure 11: Wood loading source potential with WHP in the Lookingglass Creek Watershed. Black arrows indicate general river flow direction.

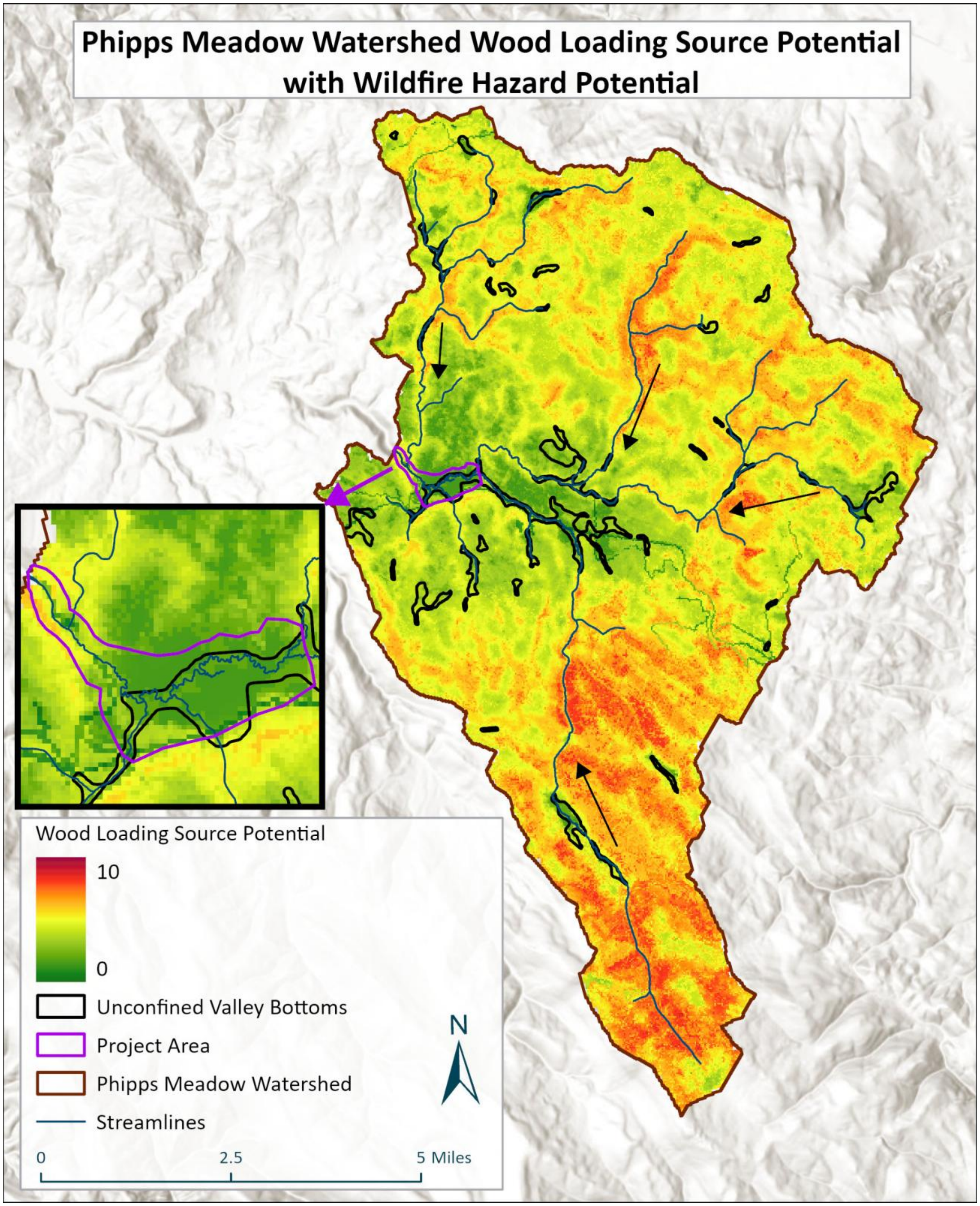

Figure 12: Wood loading source potential with WHP in the Phipps Meadow Watershed. Black arrows indicate general river flow direction.

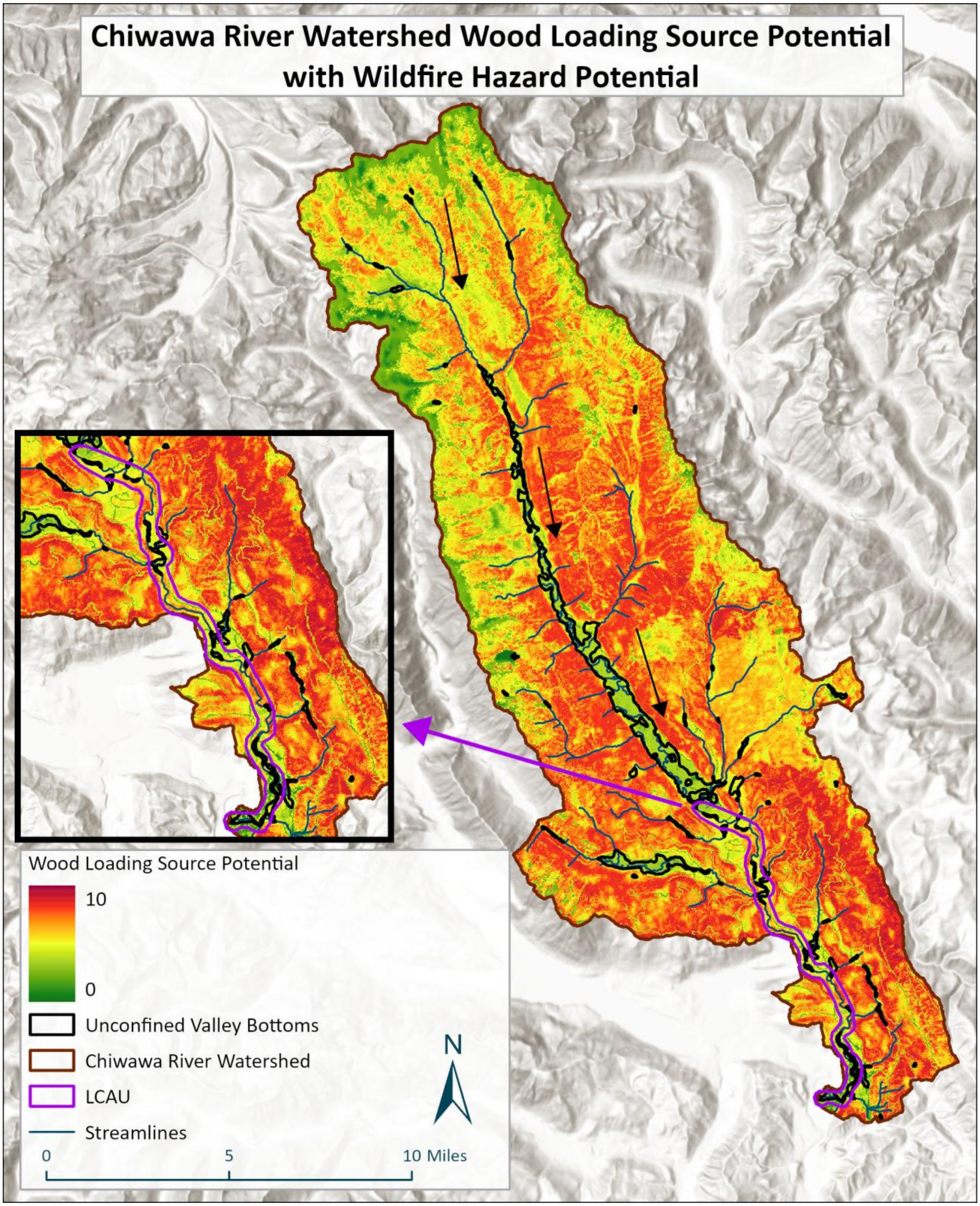

Figure 13: Wood loading source potential with WHP in the Chiwawa River Watershed. Black arrows indicate general river flow direction.

3.2.4 Sediment Loading Source Potential Raster

The sediment loading source potential raster represents the location of increased sediment loading with wildfire hazard potential. This raster does not consider cumulative sediment loading or transport of sediment to the channel. The SSURGO soil erodibility data is combined with landslide susceptibility and WHP. WHP accounts for half of the overall rating, which emphasizes potential wildfire impact on existing sediment loading due to current soil erodibility and landslide susceptibility conditions within a watershed (Figure 14, Figure 15, Figure 16).

Data input

- Scaled WHP raster from step 1 in Section 3.2.1.3
- Scaled landslide susceptibility raster from step 2 in Section 3.2.1.3
- Scaled SSURGO soil erodibility raster from step 4 in Section 3.2.1.3

Geoprocessing

1. Create the sediment loading source potential raster:
    a. Search for the *Raster Calculator* in the geoprocessing pane.
    b. In the blank box, enter the equation below, filling 'Soil_Erodibility_scaled', 'Landslide_scaled', and 'WHP_scaled' with your scaled datasets:
        i. ((('Soil_Erodibility_scaled' + 'Landslide_scaled')/2)+'WHP_scaled')/2
    c. The resulting raster is the sediment loading source potential raster, with values representing a potential source of increased sediment loading with wildfire hazard potential.
2. Visualize data
    a. Users with data that is dense or difficult to interpret at the watershed scale may optionally choose to apply thresholds to their data to isolate high-risk areas using the *Con* tool. Alternatively, users with this type of data may choose to run the *Focal Statistics* tool to smooth their data.
    a. Outputs can be overlaid on hillshade or Relative Elevation Map surfaces.
    b. Optionally overlay the valley bottom / valley confinement dataset over outputs to visualize where depositional areas upstream of the project site may buffer downstream impacts.

Output

- Values represent a potential increase in sediment contribution accounting for wildfire hazard potential.
- This sediment loading raster only shows areas where additional sediment loading is likely to be sourced from and does not show any information on the fate and transport of this sediment.
- Summary statistics can be calculated using *Focal Statistics* or *Zonal Statistics* and plotted on Figure 1 for risk analysis in the context of project goals (Table 6).
- This raster can be used to investigate areas upstream of the project site to gauge the potential for an increase in sediment inputs given wildfire potential. This can help inform design and planning decisions such as:

- Implementing project elements such as log jams and deep pools to store incoming sediment
- How to structure sediment depositional/transport zones within the project
- Assessing risks to infrastructure within and downstream of the project area

Table 6: Sediment loading source potential summary statistics within the case study watersheds. Statistics are shown with and without the WHP dataset for comparison.

WATERSHED	WHP	MIN	MAX	MEAN	MEDIAN	SD
Lookingglass Creek	Yes	0.7	8.9	6	5.9	1.2
	No	1	9.6	5.8	5.7	1.8
Phipps Meadow	Yes	1	8.6	5.7	5.7	0.9
	No	2.1	9.2	6	6	1.6
Chiwawa River	Yes	0.2	9.4	6	6.2	1.6
	No	0.3	8.8	6.1	6.7	1.8

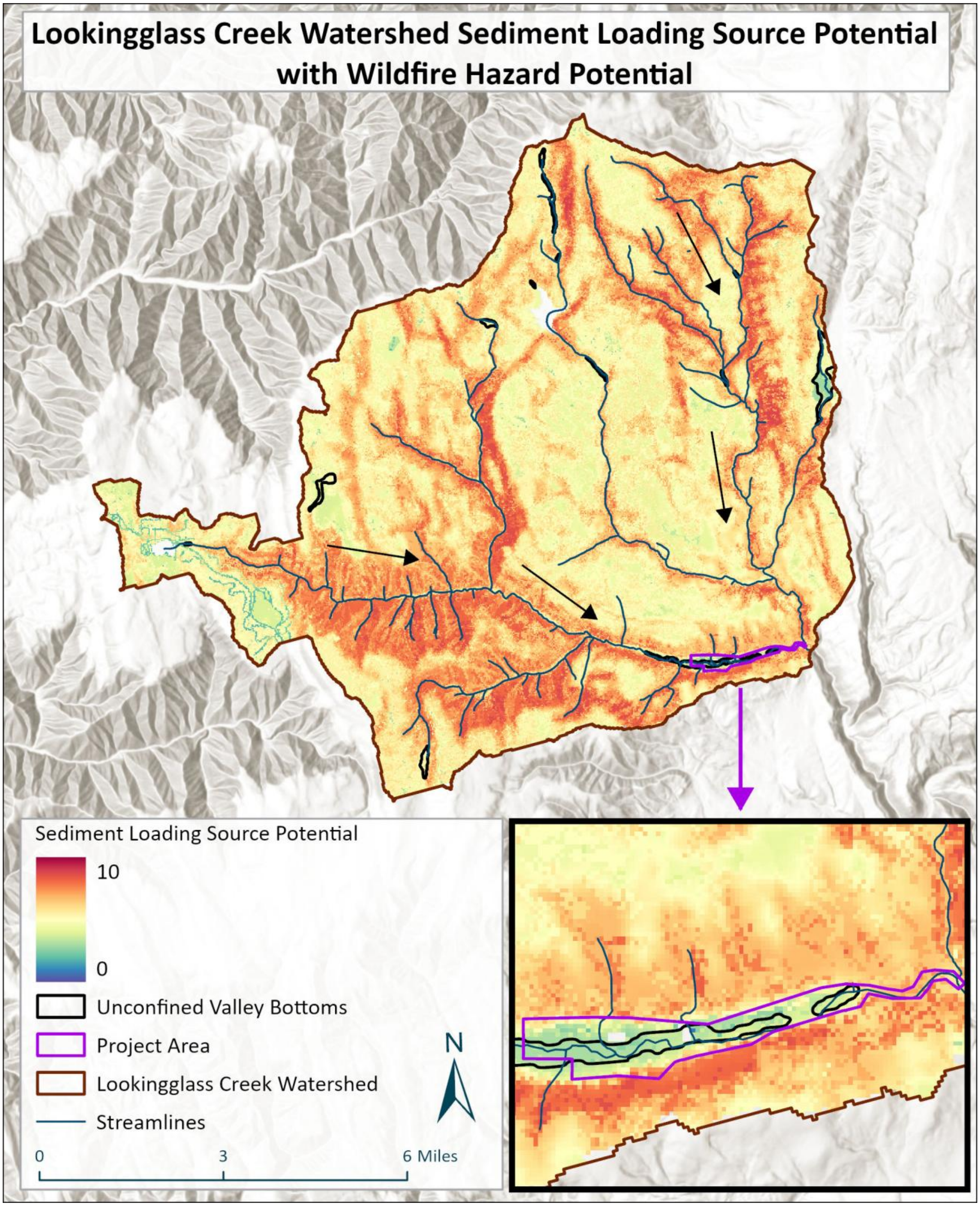

Figure 14: Sediment loading source potential with WHP in the Lookingglass Creek Watershed. Transparent holes in the result raster are missing data within the SSURGO dataset. Black arrows indicate general river flow direction.

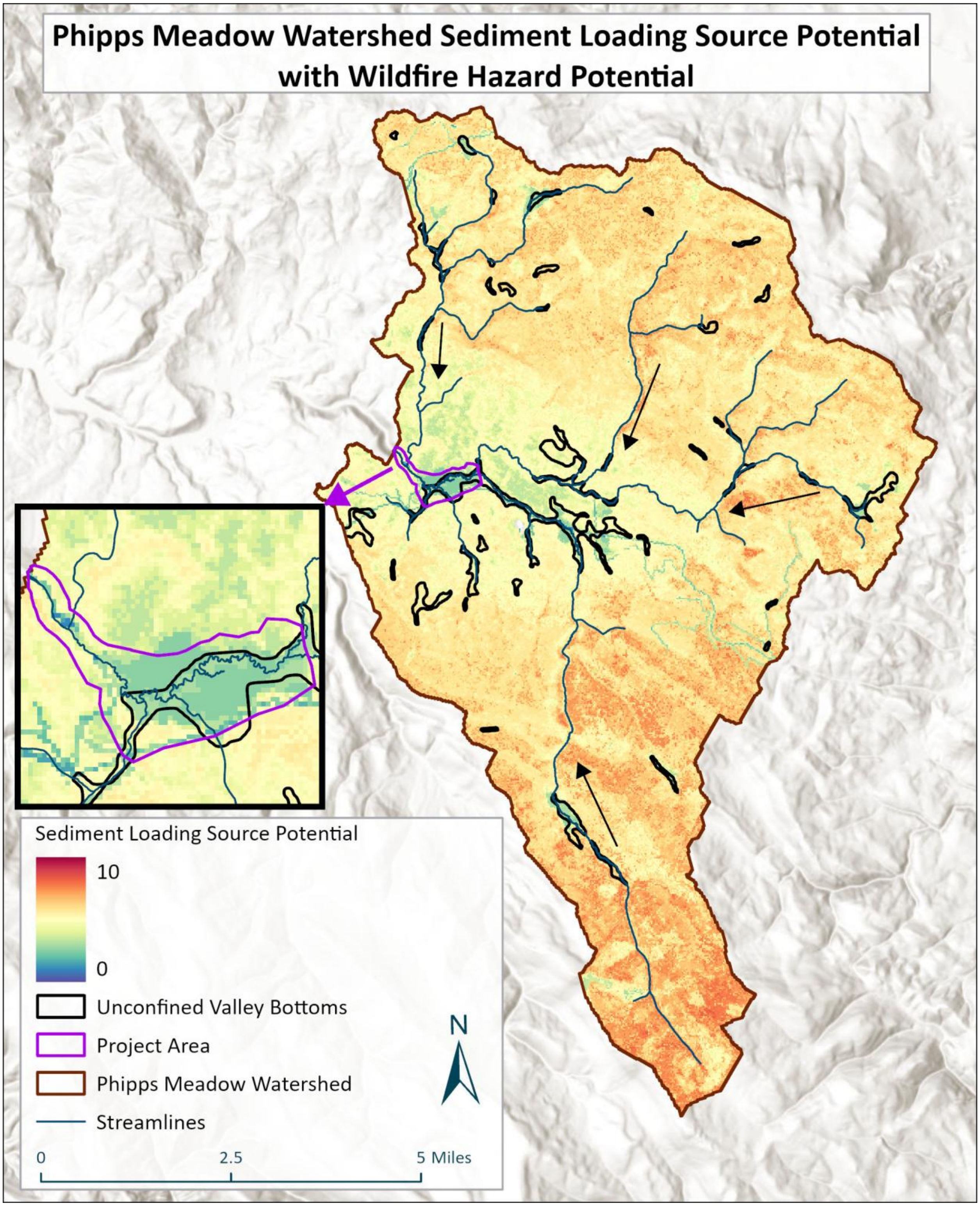

Figure 15: Sediment loading source potential with WHP in the Phipps Meadow Watershed. Transparent holes in the result raster are missing data within the SSURGO dataset. Black arrows indicate general river flow direction.

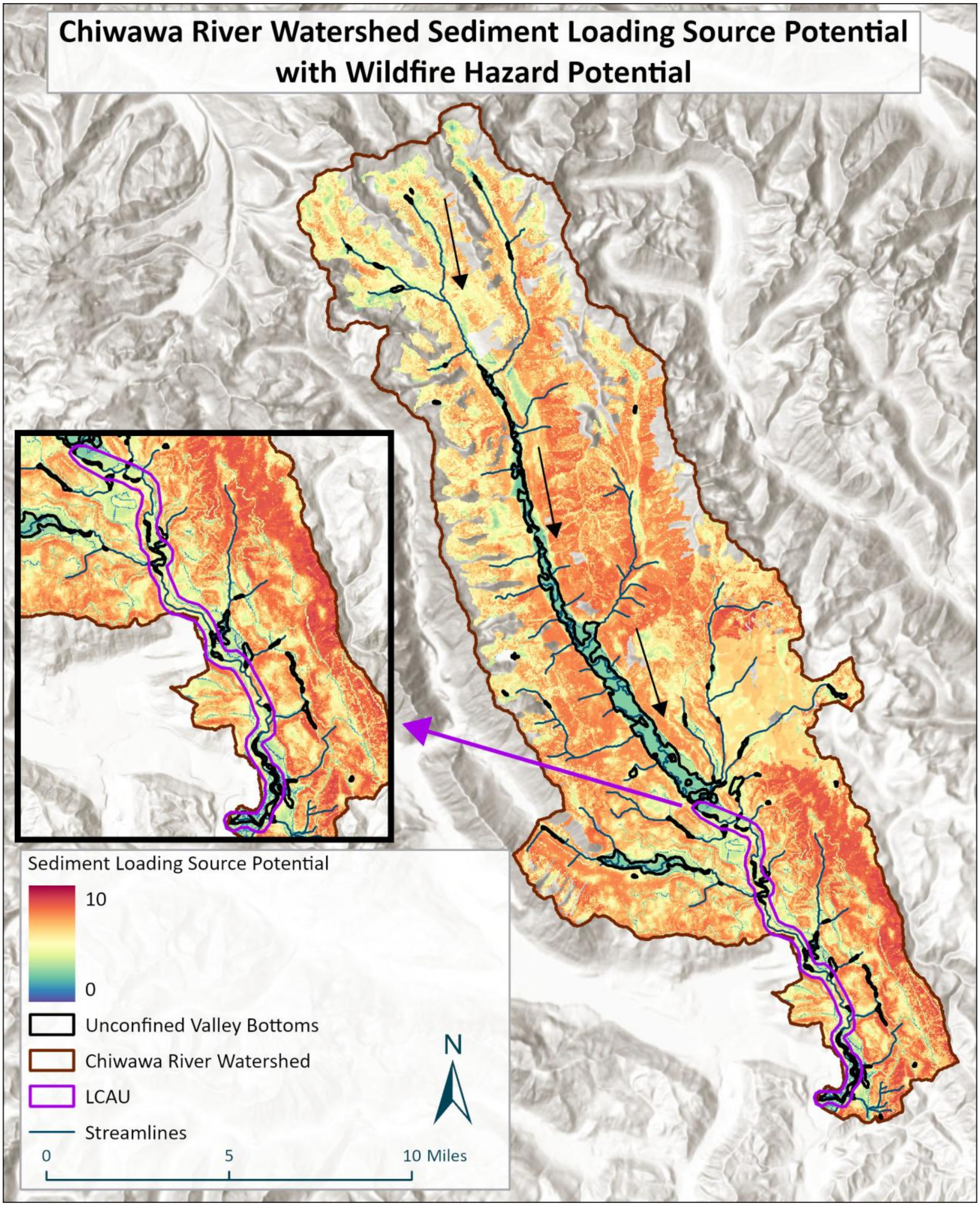

Figure 16: Sediment loading source potential with WHP in the Chiwawa River Watershed. Transparent holes in the result raster are missing data within the SSURGO dataset. Black arrows indicate general river flow direction.

3.2.5 Runoff Potential

Curve numbers are calculated using a lookup table between hydrologic soil groups and landcover (USDA-SCS, 1972). Studies on the impact of wildfire on curve numbers have developed recommendations for curve number modifications to account for the impacts of fire on runoff (Leopardi and Scorzini, 2014, Foltz et al., 2009). This analysis creates post-fire curve number maps for a given project watershed (Figure 17, Figure 18, Figure 19).

Data Input

- NLCD land cover
- SSURGO hydrologic group
- TR-55 curve number table (or regional substitute per user's discretion)
- Scaled WHP raster from step 1 in Section 3.2.1.3

Geoprocessing

1. Develop raster representing curve numbers for watershed current conditions (the below steps are adapted from the USACE Curve Number Calculation Methods).
    a. Process soils data
        i. Reclassify the values in the soil hydrologic group raster. Create an attribute table for the clipped SSURGO hydrologic group raster using the *Build Raster Attribute Table* tool. After the attribute table is created, create a new attribute titled "HSG_num" (make sure the class is numeric). Make an additional field named 'hydgrp' with Text data type.
        ii. The SSURGO hydro group data is numbered from 1 – 7. The numbers correspond to the following classes. Enter the group type in the new 'hydgrp' column based on the Value as shown below:
            1. 1 = A
            2. 2 = B
            3. 3 = C
            4. 4 = D
            5. 5 = A/D
            6. 6 = B/D
            7. 7= C/D
        iii. Use *Calculate Field* to reclassify, using the following code block as follows:
            1. HSG_num = reclass(!hydgrp!)
            2. Code Block:

```
def reclass(hydgrp):
  if hydgrp == "A":
    return "1"
  elif hydgrp == "B":
    return "2"
  elif hydgrp == "C":
```

```
        return "3"
    elif hydgrp == "D":
        return "4"
    elif hydgrp == "A/D":
        return "4"
    elif hydgrp == "B/D":
        return "4"
    elif hydgrp == "C/D":
        return "4"

    return hydgrp
```

iv. This is to follow the curve number classifications that only use values 1 – 4, as split soil hydro groups, such as A/D, are classified as the dominant soil type D.

v. Use *Reclassify* tool to convert raster values in SSURGO hydro group to their HSG numbers

vi. Use Value as reclass field, select Unique and then manually change the new values to reflect their identified HSG number

a. Create Curve Number raster
   i. Use *Raster Calculator* to classify soils and land use data combinations into curve numbers. See **Appendix B** for the recommended .txt values (adapted from USACE). If using curve numbers based on a source other than TR-55, the .txt file will require an update based on those values.
   ii. Save new raster as “CurrentCond_CN”

2. Calculate watershed curve number for watershed under likely burn conditions
   a. Use the *Raster Calculator* to modify “Current_cond_CN” values using guidance developed by BAER burn severity (Foltz et al., 2009):

```
Con("WHP_scaled"> 9, "CurrentCond_CN" + 20,Con("WHP_scaled" > 8, "CurrentCond_CN" + 18,Con("WHP_scaled” > 7, "CurrentCond_CN" + 16,Con("WHP_scaled" > 6, "CurrentCond_CN" + 14,Con("WHP_scaled" > 5, "CurrentCond_CN" + 12,Con("WHP_scaled" > 4, "CurrentCond_CN" + 10,Con("WHP_scaled"> 3, "CurrentCond_CN" + 8,Con("WHP_scaled" > 2, "CurrentCond_CN" + 6,Con("WHP_scaled" > 1, "CurrentCond_CN" + 4,Con("WHP_scaled" > 0, "CurrentCond_CN" + 2,Con("WHP_scaled" == 0, "CurrentCond_CN" + 0, "CurrentCond_CN")))))))))))
```

   b. Save new raster as “CN_adjusted”.

3. Modify the adjusted post-fire curve numbers considering wildfire hazard potential to cap values at 100, the maximum curve number. Use the *Raster Calculator*:

```
Con("CN_adjusted" > 100, 100, "CN_adjusted")
```

   a. Save new raster as "PostFire_CN". This raster shows high and low curve number areas with wildfire hazard potential.

4. Optional: Import Current Conditions and Post Fire rasters into HEC-HMS to further quantify runoff differences between evaluated conditions across a range of runoff events.
5. Visualize Data
   a. Outputs can be overlaid on hillshade or Relative Elevation Map surfaces
   b. Optionally overlay the valley bottom / valley confinement dataset over outputs to visualize where depositional areas upstream of the project site may buffer downstream impacts.

Output

- A map showing areas with the greatest change can be created by subtracting the runoff map with the influence of the wildfire hazard potential data from that without.
- The rasters can also be imported into HEC-HMS for further processing to compute average curve numbers with and without the impact of the Wildfire Hazard Potential data.
- Further case study analysis of curve number changes with wildfires can be conducted using the Automated Geospatial Watershed Analysis tool, developed by the USDA-ARS
  - This is a hydrologic modeling tool that conducts runoff assessments using the Kinematic Runoff and Erosion (KINEROS2) hydrologic model and the Soil and Water Assessment Tool (SWAT)
  - This model can run to model curve number changes in areas that have had past fire activity with land cover change captured between NLCD datasets
- Summary statistics can be calculated using *Focal Statistics* or *Zonal Statistics* and plotted on Figure 1 for risk analysis in the context of project goals (Table 7).

Table 7: Runoff potential with wildfire hazard potential summary statistics within the case study watersheds. Statistics are shown with and without the WHP dataset for comparison.

WATERSHED	WHP	MIN	MAX	MEAN	MEDIAN	SD
Lookingglass Creek	Yes	40	100	83.3	82	4.9
	No	30	100	70.9	70	4.9
Phipps Meadow	Yes	34	100	75.1	78	8.4
	No	30	87	64.7	70	9.2
Chiwawa River	Yes	1	100	71.2	71	12.2
	No	1	100	59.5	55	12.7

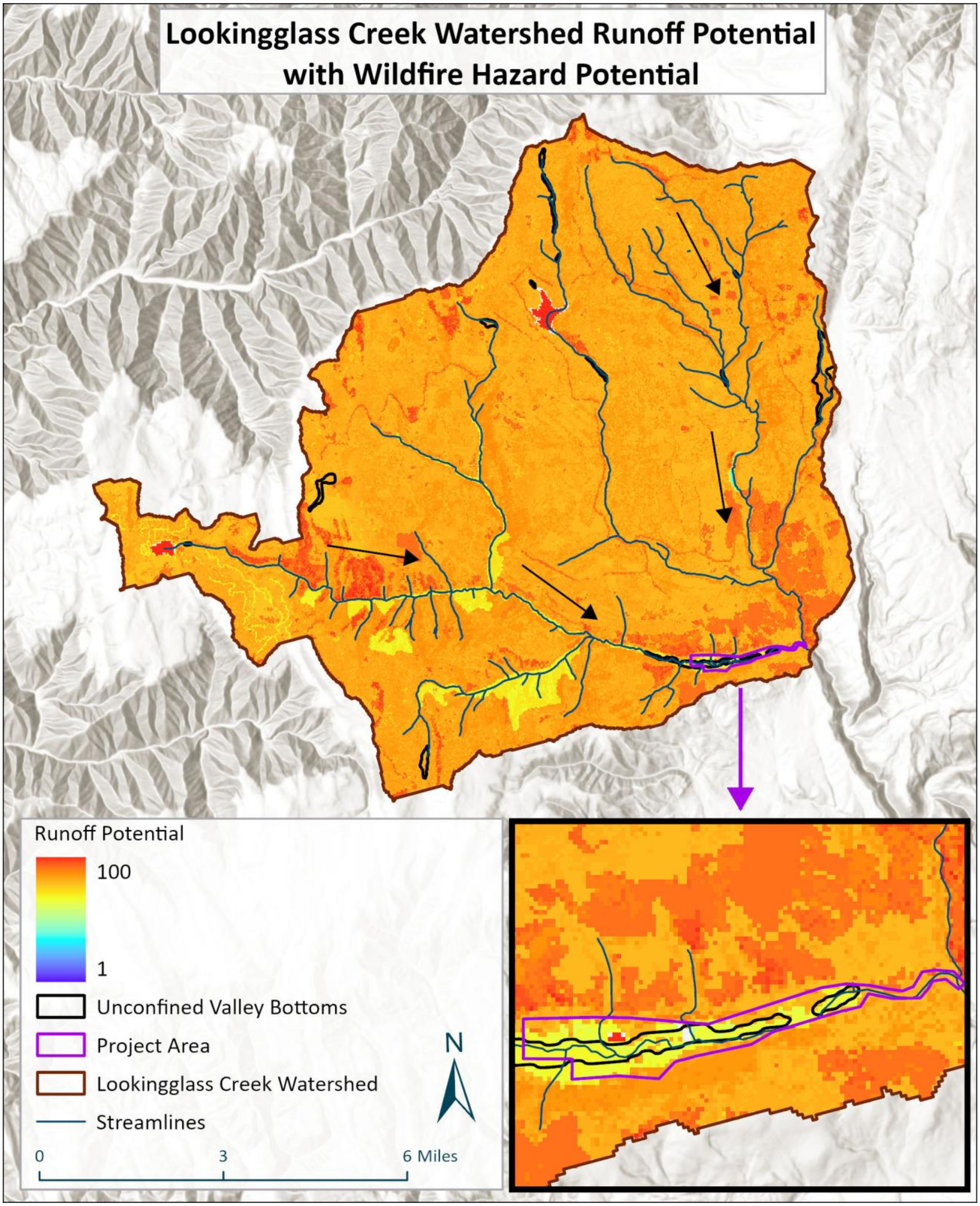

Figure 17: Runoff potential with WHP at the Lookingglass Creek Watershed. Black arrows indicate general river flow direction.

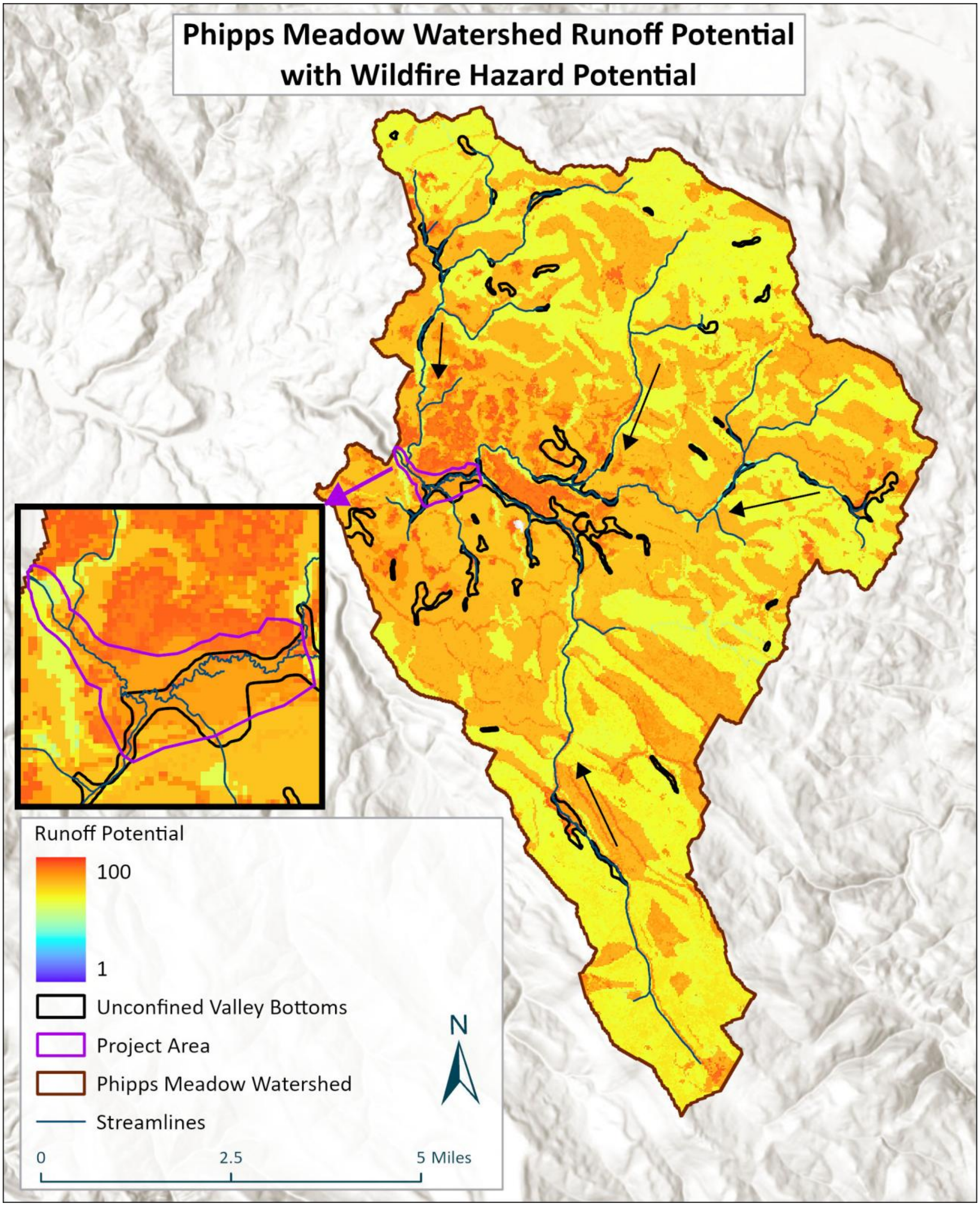

Figure 18: Runoff potential with WHP in the Phipps Meadow Watershed. Black arrows indicate general river flow direction.

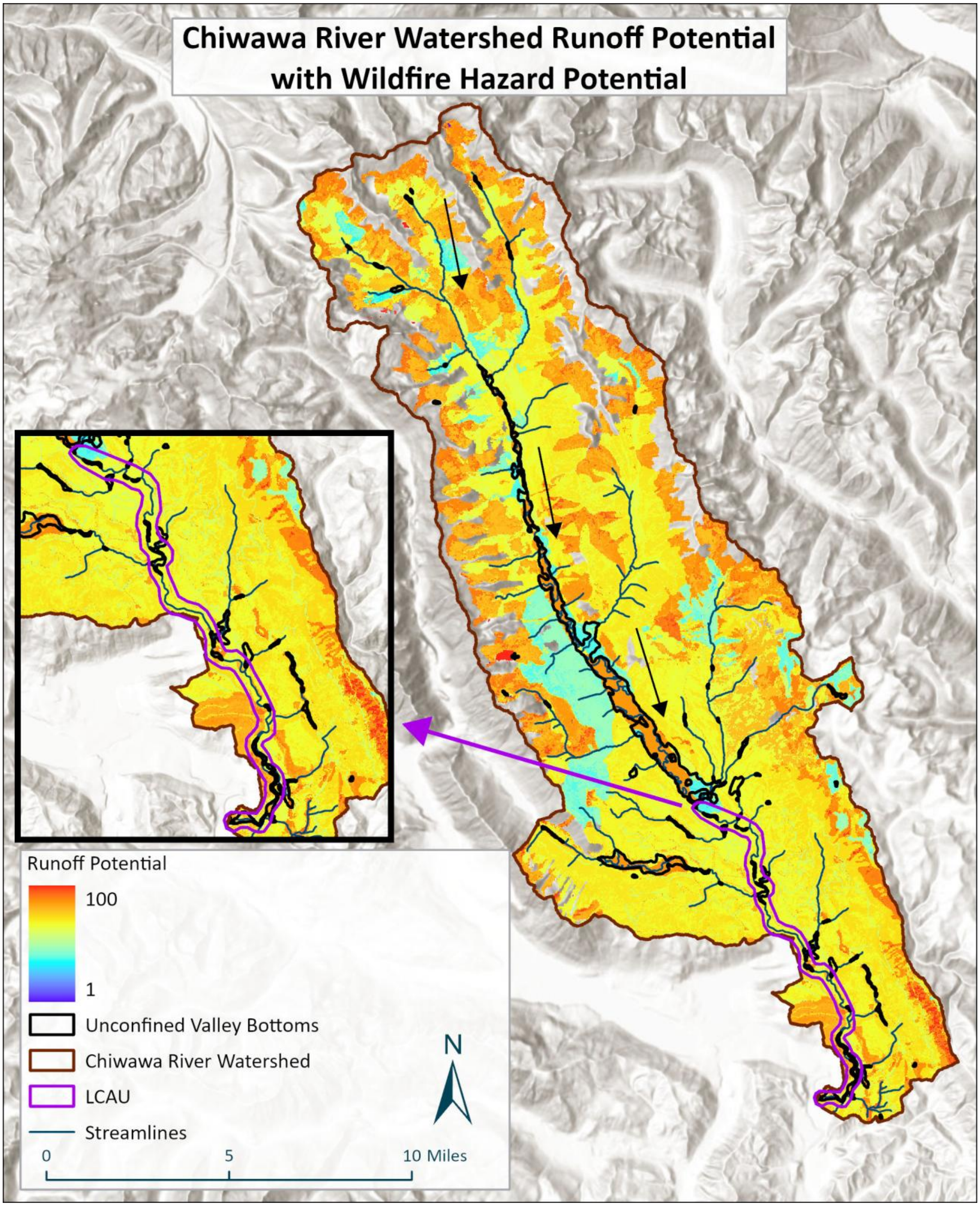

Figure 19: Runoff potential with WHP in the Chiwawa River Watershed. Black arrows indicate general river flow direction.

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APPENDIX A – DATA SOURCES

- Wildfire Hazard Potential
  - Wildfire Hazard Potential Dataset | Scott et al., 2024
- USGS Debris Flow Map / Landslide Severity Map
  - Debris Flow Map / Landslide Severity Map | USGS
- SSURGO Soil Erodibility and Hydrologic Group
  - Living Atlas on ArcGIS Pro
- National Land Cover Database
  - Land Cover (CONUS) | Multi-Resolution Land Characteristics (MRLC) Consortium
- Tree Canopy Cover
  - TCC (CONUS) | Multi-Resolution Land Characteristics (MRLC) Consortium
- StreamStats Watershed Delineation
  - StreamStats | USGS
- ArcGIS Pro Watershed Delineation Tool
  - Watershed Delineation Tool | ESRI
  - Curve Number Analysis
  - Creating a Curve Number Grid and Computing Subbasin Average Curve Number Values
- TR-55
  - TR-55 Curve Number Tables
- Historical Wildfire Boundaries
  - Interagency Wildland Fire Perimeter History | NIFC
- Valley Confinement Shapefile
  - Valley Bottom Confinement | USFS

APPENDIX B - CURVE NUMBER RECLASSIFICATION

Curve Number Reclassification Adapted from the US Army Corps Hydrologic Engineering Center. Values were modified based on Oregon and Washington CN tables.

Creating a Curve Number Grid and Computing Subbasin Average Curve Number Values

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Con(("nlcd_2024.tif"==95)&("HydroSoilGroup.tif"==2),58,Con(("nlcd_2024.tif"==95)&("HydroSoilGroup.tif"

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==3),71,Con(("nlcd_2024.tif"==95)&("HydroSoilGroup.tif"==4),78,1)))))))))))))))))))))))))))))))))))))))))))))))))))))))))
```