TEHAMA COUNTY TRANSPORTATION COMMISSION

Board Chambers
Tehama County Board of Supervisors Chambers
727 Oak Street, Red Bluff, CA 96080
https://tehamacounty.legistar.com/Calendar.aspx

AGENDA FOR MONDAY, JANUARY 26, 2026

Chairman: Jim Bacquet Vice-Chairman: Patrick Hurton
Commissioners: Robert Burroughs, Matt Hansen, Tom Walker, Dave Demo

Tom Provine, Interim Executive Director
Jessica Riske-Gomez, Deputy Director

This meeting conforms to the Brown Act Open Meeting Requirements, in that actions and deliberations of the TCTC created to conduct the people’s business are taken openly; and that the people remain fully informed about the conduct of its business. Any written materials related to an open session item on this agenda that are submitted to the Deputy County Clerk less than 72 hours prior to this meeting, and that are not exempt from disclosure under the Public Records Act, will promptly be made available for public inspection at Tehama County Transportation Commission, 1509 Schwab St., Red Bluff, CA 96080.

Standing Items

1. Call to Order / Pledge of Allegiance / Introductions

Moment of Silence - Chair's Announcement **26-0077**

Before we proceed with today's agenda, I would like to acknowledge the tragic transit incident involving TRAX that resulted in the loss of six lives and left one individual seriously injured.

We extend our deepest condolences to the families and loved ones affected, and we honor the life and service of TRAX driver Kelly Langstaff, whose loss is profoundly felt by her colleagues and this community.

We also wish to recognize and thank the first responders and emergency personnel who responded to this horrific incident under extraordinarily difficult circumstances. Their professionalism, care, and dedication in the face of such tragedy are deeply appreciated.

Out of respect for those who were lost, those who are injured, those who are grieving, and those who responded, I ask that we pause for a moment of silence.

Thank you.

2. Public Comment

This time is set aside for citizens to address this Board on any item of interest to the public that is within the subject matter jurisdiction of this Board provided the matter is not on the agenda or pending before this Board. The Chair reserves the right to limit each speaker to three (3) minutes. Disclosure of the speaker's identity is purely voluntary during the public comment period.

3. Announcement of Agenda Corrections

4. Announcements

a. In accordance with AB23, it is hereby announced, the Transportation Commissioners and Transit Directors in attendance at today's meeting shall receive a stipend of $100, per the adopted Bylaws.

b. The next scheduled Tehama County Transportation Commission and Tehama County Transit Agency Board regular meetings are scheduled for 2/23/2026, at 8:30 AM and 8:45 AM respectively.

Regular Items

5. Approval of Minutes - Associate Transportation Planner Houghtby **25-2078**

Waive the reading and approve the minutes from the October 27, 2025 Tehama County Transportation Commission regular meeting.

Attachments: 10.27.2025 TCTC Minutes

6. Approval of Claims - Accountant Jensen **25-2072**

Approve Tehama County Transportation Commission claims for October, November, and December 2025, in the amount of $108,489.79.

Attachments: TCTC Oct - Dec Claims

7. Monthly Staff Report - Deputy Director Riske Gomez **25-2100**

Monthly update on active projects and topics within Tehama County. This item is informational only, no Commission action is required.

8. 2026 Meeting Schedule - Associate Transportation Planner Houghtby **25-2073**

Adopt the TCTC regular meeting dates for 2026 including a consolidation of the November and December 2026 meetings to Monday, December 7, 2026, 8:30 AM.

The 2026 meeting dates, if approved, will be as follows:

- January 26, 2026 8:30 AM
- February 23, 2026 8:30 AM
- March 23, 2026 8:30 AM
- April 27, 2026 8:30 AM
- May 18, 2026 8:30 AM
- June 22, 2026 8:30 AM
- July 27, 2026 8:30 AM
- August 24, 2026 8:30 AM
- Sept 28, 2026 8:30 AM
- Oct 26, 2026 8:30 AM
- Dec 7, 2026 8:30 AM

9. Interagency Agreement with Redding Area Bus Authority - Deputy Director Riske-Gomez **26-0059**

Authorize the Interim Executive Director to execute the Fund Transfer Agreement between the Tehama County Transportation Commission (TCTC) and the Redding Area Bus Authority (RABA) for the transfer of Congestion Mitigation and Air Quality (CMAQ) funds to support expanded intercity transit connectivity benefiting Tehama County residents.

Attachments: TCTC-RABA Draft Agreement V4

AATF

10. Environmental Systems Research Institute, Inc. (ESRI) Master Agreement - Deputy Director Riske-Gomez **26-0061**

a.) Approve a three-year Master Product and Services (Enterprise) Agreement with Environmental Systems Research Institute, Inc. (ESRI) for geographic information system (GIS) software, licensing, and support services.
b.) Find that ESRI constitutes a sole-source provider and that waiving the formal competitive bidding process is in the best interest of the public, consistent with County and Commission procurement policies.
c.) Authorize the Interim Executive Director to execute all necessary agreements and related documents.

Attachments: ESRI Quotation #Q-554397 Signed 09.30.25
J-8933-SGEA (1)
Bid Waiver
ICE and Summary
AATF

11. BUILD Grant Application Support - Deputy Director Riske-Gomez **26-0076**

Informational item regarding the use of the Interim Executive Director's signature authority to retain grant writing services to assist staff with preparation of a FY 2026 USDOT BUILD grant application for the Lake California Drive Reconstruction Project.

12. Informational Presentation on Self-Help Counties - Deputy Director Riske-Gomez **25-2108**

Informational presentation on the Self-Help Counties Coalition and statewide transportation planning practices and provide direction to staff on any future educational topics the Commission would like brought forward.

Attachments: Tehama PCI
What is a Self-Help County
SHCC_Fact_Sheet_20160322
1938A-Agrawal-California-Local-Transportation-Funding

13. Public Hearing: Unmet Transit Needs - Deputy Director Riske-Gomez **26-0016**

a) Overview of Annual Unmet Transit Needs process

This step of today's agenda item is to provide a brief overview of the process and invite public comment regarding unmet transit needs. The Unmet Transit Needs process specifically excludes:

- Primary and secondary school transportation.
- Minor operational improvement or changes involving issues such as bus stops, schedules and minor route changes.
- Improvements funded or scheduled for implementation in the following fiscal year.

b) Open Unmet Transit Needs public hearing

This step of today's agenda item is to officially open the public hearing on unmet transit needs, providing an opportunity for stakeholders and community members to voice their concerns and suggestions related to local transit services.

c) Invite public comment on unmet transit needs

This step of today's agenda item invites members of the public to provide input regarding unmet transit needs. Comments should focus on gaps or deficiencies in the current transit system that prevent residents from accessing essential services or activities.

d) Close the public hearing and refer comments to the Social Services Transportation Advisory Council (SSTAC) for review

This step of today's agenda item is to formally close the public hearing on unmet transit needs. All comments received will be forwarded to the SSTAC for thorough review and consideration as part of the decision-making process.

Attachments: Flow Chart
UNMET TRANSIT NEEDS PROCESS
Adopted Definitions 2013
Unmet Needs Matrix
Unmet Needs - Legal Notice (English) 2025
Unmet Needs - Legal Notice (Spanish) 2025
Legal Notice
Receipt Printed from Order 00304266_2024-11-21-15-48-15

14. Watershed, Flood-Risk, and Infrastructure Assessment Coordination - Deputy Director Riske-Gomez 25-2115

Informational presentation on TCTC's ongoing coordination with Public Works - Flood Administration, the Resource Conservation District (RCD), and State and federal partners regarding watershed-driven transportation impacts and the development of a countywide infrastructure risk assessment.

Attachments: Justification Map
Park Fire
Dixie
August Complex
McFarland
WF24225_Final Manuscript
CALTRANS-final-report-regional-sediment-bulking-methods-a11y (1)
Silver Jacket Toolkit

15. Lake California Drive - Informational Presentation 26-0055

Informational presentation from staff providing a status update on the Lake California Drive Reconstruction Project, including current scope development, programming, funding strategy, conceptual design work, and the anticipated path forward.

16. Items for Future Agenda

17. Closing Comments

18. Adjourn

The County of Tehama does not discriminate on the basis of disability in admission to, access to, or operation of its buildings, facilities, programs, services, or activities. Questions, complaints, or requests for additional information regarding the Americans with Disabilities Act (ADA) may be forwarded to the County's ADA Coordinator: Tom Provine, County of Tehama, 727 Oak St., Red Bluff, CA 96080, Phone: (530) 527-4655. Individuals with disabilities who need auxiliary aids and/or services or other accommodations for effective communication in the County's programs and services are invited to make their needs and preferences known to the affected department or the ADA Coordinator. For aids or services needed for effective communication during Tehama County Transportation Commission meetings, please contact the ADA Coordinator prior to the day of the meeting. This notice is available in accessible alternate formats from the affected department or the ADA Coordinator.

File #: 26-0077 **Agenda Date:** 1/26/2026 **Agenda #:**

Moment of Silence - Chair's Announcement

Announcement
Before we proceed with today's agenda, I would like to acknowledge the tragic transit incident involving TRAX that resulted in the loss of six lives and left one individual seriously injured.

We extend our deepest condolences to the families and loved ones affected, and we honor the life and service of TRAX driver Kelly Langstaff, whose loss is profoundly felt by her colleagues and this community.

We also wish to recognize and thank the first responders and emergency personnel who responded to this horrific incident under extraordinarily difficult circumstances. Their professionalism, care, and dedication in the face of such tragedy are deeply appreciated.

Out of respect for those who were lost, those who are injured, those who are grieving, and those who responded, I ask that we pause for a moment of silence.

Thank you.

Tehama County

Agenda Request Form

File #: 25-2078 **Agenda Date:** 1/26/2026 **Agenda #:** 5.

Approval of Minutes - Associate Transportation Planner Houghtby

Requested Action(s)
Waive the reading and approve the minutes from the October 27, 2025 Tehama County Transportation Commission regular meeting.

Financial Impact:
None.

Background Information:
See attached minutes.

Tehama County

Tehama County Board of Supervisors Chambers
727 Oak Street, Red Bluff, CA 96080
https://tehamacounty.legistar.com/Calendar.aspx

Meeting Minutes

Monday, October 27, 2025

8:30 AM

Board Chambers

Transportation Commission

Chairman: Jim Bacquet Vice-Chairman: Patrick Hurton
Commissioners: Pati Nolen, Matt Hansen, Tom Walker, Dave Demo

Tom Provine, Interim Executive Director
Jessica Riske-Gomez, Deputy Director

This meeting conforms to the Brown Act Open Meeting Requirements, in that actions and deliberations of the TCTC created to conduct the people's business are taken openly; and that the people remain fully informed about the conduct of its business. Any written materials related to an open session item on this agenda that are submitted to the Deputy County Clerk less than 72 hours prior to this meeting, and that are not exempt from
disclosure under the Public Records Act, will promptly be made available for public inspection at Tehama County Transportation Commission, 1509 Schwab St., Red Bluff, CA 96080.

Standing Items

1. Call to Order / Pledge of Allegiance / Introductions

The Tehama County Transportation Commission Regular meeting was called to order at 8:30 AM.

Present:	Commissioner Matt Hansen, Vice Chair Patrick Hurton, Commissioner Pati Nolen, Commissioner Dave Demo, and Commissioner Tom Walker
ABSENT:	Chairperson Jim Bacquet

2. Public Comment

This time is set aside for citizens to address this Board on any item of interest to the public that is within the subject matter jurisdiction of this Board provided the matter is not on the agenda or pending before this Board. The Chair reserves the right to limit each speaker to three (3) minutes. Disclosure of the speaker's identity is purely voluntary during the public comment period.

There was no public comment.

3. Announcement of Agenda Corrections

There were no agenda corrections.

4. Announcements

a. In accordance with AB23, it is hereby announced, the Transportation Commissioners and Transit Directors in attendance at today's meeting shall receive a stipend of $100, per the adopted Bylaws.

b. The next scheduled Tehama County Transportation Commission and Tehama County Transit Agency Board regular meetings are scheduled for December 8th, 2025 at 8:30 AM and 8:45 AM respectively.

The announcements were read by Vice-chair Hurton.

Regular Items

5. Approval of Minutes - Associate Transportation Planner Houghtby

Waive the reading and approve the minutes from the September 22nd, 2025 Tehama County Transportation Commission regular meeting.

RESULT: APPROVE
MOVER: Tom Walker
SECONDER: Dave Demo

AYES: Commissioner Hansen, Vice Chair Hurton, Commissioner Nolen, Commissioner Demo, and Commissioner Walker

ABSENT: Chairperson Bacquet

6. Approval of Claims - Accountant Jensen

Approve Tehama County Transportation Commission claims for September 2025, in the amount of $48,038.35.

RESULT: APPROVE
MOVER: Dave Demo
SECONDER: Matt Hansen

AYES: Commissioner Hansen, Vice Chair Hurton, Commissioner Nolen, Commissioner Demo, and Commissioner Walker

ABSENT: Chairperson Bacquet

7. 2026 Regional Transportation Improvement Program (RTIP) - Deputy Director Riske-Gomez

a. Informational presentation on the 2026 Regional Transportation Improvement Program (RTIP).

b. Receive the Technical Advisory Committee (TAC) recommendation as presented by staff.

c. Adopt Resolution No. 08-2025 approving the 2026 Regional Transportation Improvement Program (RTIP) for submission to the California Transportation Commission (CTC).

or

d. Return the Draft 2026 RTIP to the Technical Advisory Committee (TAC) for further review and modification.

An informational presentation was provided by Deputy Director Riske-Gomez.

Commissioner Demo asked if the possibility of waste management contributing to the baker road project had been considered. Deputy Director Riske-Gomez advised that it would be unlikely that they would contribute as this project is aimed at long term fixes to this road way. However there would be no downside to inquiring.

Commissioner Walker expressed that he is pleased that many of the different municipalities within the county are being represented in the RTIP.

A motion was made by Vice Chair Hurton, seconded by Commissioner Walker, to:

c. Adopt Resolution No. 08-2025 approving the 2026 Regional Transportation Improvement Program (RTIP) for submission to the California Transportation Commission (CTC).

RESULT:	ADOPT
MOVER:	Patrick Hurton
SECONDER:	Tom Walker
AYES:	Commissioner Hansen, Vice Chair Hurton, Commissioner Nolen, Commissioner Demo, and Commissioner Walker
ABSENT:	Chairperson Bacquet

8. Commission Working Session: Understanding the Governance Structure and Future Direction of the Tehama County Transportation Commission (TCTC)

a. Receive and discuss the organization of the Tehama County Transportation Commission (TCTC).

b. Review outcomes from prior Commission discussions and Question Log for transitioning the Commission from the County organization.

c. Authorize staff to coordinate with County Personnel, CalPERS, and other relevant agencies to gather information regarding employee classifications, benefits continuity, and transition processes for presentation at future Commission meetings.

d. Review and discuss the transition timeline and identify the point at which the Commission would feel comfortable moving forward with the formal presentation to the Board of Supervisors with staff.

Informational presentation provided by Deputy Director Riske-Gomez.

Commissioner Hansen inquired regarding the creation of new positions in the new structure. Deputy Director Riske-Gomez provided insight and recommended seeking advise from individuals who are trained in personnel and HR.

Interim Deputy Director Provine added that there is a general consensus and approval for the transition from stakeholders.

A motion was made by Commissioner Hansen, seconded by Commissioner Walker, to:
c. Authorize staff to coordinate with County Personnel, CalPERS, and other relevant agencies to gather information regarding employee classifications, benefits continuity, and transition processes for presentation at future Commission meetings.

RESULT:	APPROVE
MOVER:	Matt Hansen
SECONDER:	Tom Walker
AYES:	Commissioner Hansen, Vice Chair Hurton, Commissioner Nolen, Commissioner Demo, and Commissioner Walker
ABSENT:	Chairperson Bacquet

9. Items for Future Agenda

There were no items for future agenda.

10. Closing Comments

Commissioner Walker thanked Deputy Director Riske-Gomez's for her hard work on her informational presentation.

11. Adjourn

With no further business, the meeting was adjourned at 9:05 AM.

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Tehama County

Agenda Request Form

File #: 25-2072 **Agenda Date:** 1/26/2026 **Agenda #:** 6.

Approval of Claims - Accountant Jensen

Requested Action(s)
Approve Tehama County Transportation Commission claims for October, November, and December 2025, in the amount of $108,489.79.

Financial Impact:
Click here to enter Financial Impact.

Background Information:
See attached claims summary for October, November, and December 2025.

Tehama County Transportation Commission Claims

Meeting Date: 1/26/26

Claimant	Invoice Description	Amount
CLAIMS PAID IN OCTOBER 2025		
Cal-Card	APA CA 2025 Conference	966.25
Chico State Enterprises	GIS Services 07/01-09/30/25	16,900.00
Ashley Fox	2025 BCAG/CTC Town Hall Meeting	119.48
Ashley Fox	CALACT 2025 Fall Conference	421.10
Jessica Riske-Gomez	2025 BCAG/CTC Town Hall Meeting	174.92
Tiffany Jensen	CALACT 2025 Fall Conference	1,332.18
Obsidian IT	IT Support Services October	1,842.37
Optimize Worldwide	Web Development	25.00
Red Bluff Chamber of Commerce	Annual Membership Nov '25 - Oct '26	195.00
Stipends: Hansen, Nolen, Hurton, Walker, Demo	Meeting Stipends 09/22/25	500.00
Stipends: Hansen, Nolen, Hurton, Walker, Demo	Meeting Stipends 10/27/25	500.00
Time Warner Cable	Fiber Internet October '25	719.00
UBEO	TCTC Lease Agreement 10/01-10/31/25	275.78
Verizon Wireless	12 iPad Pro 11 inch - Park Fire	456.12
Verizon Wireless	Communications 08/24-09/23/25	185.52
Walker Printing	Business Cards - A. Fox	51.48
Wave Technologies	Phone Service - November	327.34
	GRAND TOTAL:	**$ 24,991.54**

Claimant	Invoice Description	Amount
CLAIMS PAID IN NOVEMBER 2025		
Green DOT	Professional Services - October	27,442.60
Mike's Heating and Air	HVAC Repair	781.67
Obsidian IT	IT Support Services November	1,842.37
Optimize Worldwide	Web Development	125.00
Time Warner Cable	Fiber Internet November '25	719.00
UBEO	TCTC Lease Agreement 11/01-11/30/25	269.91
Verizon Wireless	12 iPad Pro 11 inch - Park Fire	456.12
Verizon Wireless	Communications 08/24-09/23/25	185.56
World Telecom & Surveillance	New Files Backed Up and Installed	375.00
Wave Technologies	Phone Service - December	327.43
	GRAND TOTAL:	**$ 32,524.66**

mw:\\T:\TCTC\Packet\2026\01-January\TCTC\TCTC Oct - Nov Claims

Tehama County Transportation Commission Claims

Meeting Date: 1/26/26

CLAIMS PAID IN DECEMBER 2025		
Daily News	Public Hearing - Unmet Transit Needs	$651.19
Corniong Observer	Legal Notice - Unmet Transit Needs	$761.58
Green DOT	Professional Services - November	12,695.20
Mccuen Construction	Bus Maintenance Project	31,686.04
Obsidian IT	IT Support Services December	1,842.37
Optimize Worldwide	Web Development	100.00
Time Warner Cable	Fiber Internet December '25	719.00
UBEO	TCTC Lease Agreement 12/01-12/31/25	269.91
Verizon Wireless	12 iPad Pro 11 inch - Park Fire	456.12
Verizon Wireless	Communications 10/24-11/23/25	185.56
Zoom Video Communications, Inc.	Annual Subscription	1,279.19
Wave Technologies	Phone Service - January	327.43
	GRAND TOTAL:	**$50,973.59**

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Tehama County

Agenda Request Form

File #: 25-2100 **Agenda Date:** 1/26/2026 **Agenda #:** 7.

Monthly Staff Report - Deputy Director Riske Gomez

Requested Action(s)
Monthly update on active projects and topics within Tehama County. This item is informational only, no Commission action is required.

Financial Impact:

None.

Background Information:

TCTC staff provides monthly updates to keep the Commission informed about ongoing projects, funding activities, and coordination with local, state, and federal partners. This report summarizes recent work, key developments, and any items that may require follow-up or direction.

At-a-Glance - Active Projects & Topics

Woodson Bridge / Woodson Bridge Park Embankment Stabilization & Bridge Improvement / Replacement Project

South County 99W Corridor Study and Gap Closure Project/ EDA “Readiness Path” Application (South County Corridor)

Mineral Project: Design, Crosswalk Location & Bid Submission

Lake California Drive Roadway Improvement Project

VMT & Carbon Reduction Program (CRP) Project Update

Regional Flooding & Post-Fire Resiliency Technical Assistance Request

Hazard Tree Removal Project - Phases I & II

TRAX Request for Proposals

Arts Council: Roundabout Art Proposal and Potential Tribal Partnership

Tehama County

Agenda Request Form

File #: 25-2073 **Agenda Date:** 1/26/2026 **Agenda #:** 8.

2026 Meeting Schedule - Associate Transportation Planner Houghtby

Requested Action(s)
Adopt the TCTC regular meeting dates for 2026 including a consolidation of the November and December 2026 meetings to Monday, December 7, 2026, 8:30 AM.

The 2026 meeting dates, if approved, will be as follows:

January 26, 2026	8:30 AM
February 23, 2026	8:30 AM
March 23, 2026	8:30 AM
April 27, 2026	8:30 AM
May 18, 2026	8:30 AM
June 22, 2026	8:30 AM
July 27, 2026	8:30 AM
August 24, 2026	8:30 AM
Sept 28, 2026	8:30 AM
Oct 26, 2026	8:30 AM
Dec 7, 2026	8:30 AM

Financial Impact:
None.

Background Information:
None.

Tehama County

Agenda Request Form

File #: 26-0059 **Agenda Date:** 1/26/2026 **Agenda #:** 9.

Interagency Agreement with Redding Area Bus Authority - Deputy Director Riske-Gomez

Requested Action(s)
Authorize the Interim Executive Director to execute the Fund Transfer Agreement between the Tehama County Transportation Commission (TCTC) and the Redding Area Bus Authority (RABA) for the transfer of Congestion Mitigation and Air Quality (CMAQ) funds to support expanded intercity transit connectivity benefiting Tehama County residents.

Financial Impact:

Approval of this item authorizes the transfer of up to $200,000 in CMAQ funds in the first year, and up to $100,000 annually thereafter, subject to funding availability and continued eligibility. No additional local funds are required beyond those already programmed. TCTC's financial obligation shall not exceed the amounts authorized by the Commission.

Background Information:

The foundation for this intercity transit initiative was established by the Shasta Regional Transportation Agency (SRTA) through a federally funded Intercity Bus Feasibility Study and Action Plan conducted between 2015 and 2016. That study, supported by Federal Transit Administration Section 5311(f) planning funds and accepted by the SRTA Board in December 2016, evaluated market demand and service feasibility for expanded interregional bus service along the Interstate 5 corridor and identified the need for improved north-south connectivity to Sacramento and statewide rail services .

Building on that early planning work, the Redding Area Bus Authority (RABA) assumed the lead role in advancing intercity transit implementation, including service development, coordination with Amtrak and the San Joaquin Joint Powers Authority, and operation of intercity bus services serving Redding and Red Bluff with connections to regional and statewide transit networks.

Throughout this multi-year effort, TCTC has supported SRTA's and RABA's leadership through regional coordination, planning collaboration, and identification of eligible federal funding opportunities. With the service concept now fully developed and operationally ready, RABA is prepared to execute expanded intercity service connecting Redding, Red Bluff, and Sacramento.

This Fund Transfer Agreement represents TCTC's first formal stage of participation in implementation, establishing a compliant framework to transfer CMAQ funds to support eligible operating and administrative costs while affirming RABA as the sole operator and project lead. Approval of this item positions TCTC to directly support expanded intercity transit connectivity for Tehama County residents consistent with long-standing regional planning efforts.

FUND TRANSFER AGREEMENT
BY AND BETWEEN THE
TEHAMA COUNTY TRANSPORTATION COMMISSION AND
REDDING AREA BUS AUTHORITY

FOR THE PURPOSE OF SUPPORTING EXPANDED INTERCITY TRANSIT CONNECTIVITY BENEFITING TEHAMA COUNTY RESIDENTS AND TRAVELERS ALONG THE INTERSTATE 5 CORRIDOR AND AMTRAK COAST STARLIGHT, GOLD RUNNER AND CAPITOL CORRIDOR ROUTES.

This Fund Transfer Agreement, hereinafter referred to as the "Agreement," is made and entered into between TEHAMA COUNTY TRANSPORTATION COMMISSION, a Regional Transportation Planning Agency, hereinafter referred to as "TCTC," and the REDDING AREA BUS AUTHORITY (RABA). TCTC and RABA are hereinafter collectively referred to as the "Parties" or individually as a "Party."

This Agreement establishes the terms under which TCTC will transfer Congestion Mitigation and Air Quality (CMAQ) funds to RABA to support expansion of RABA's intercity bus services that enhance mobility for Tehama County residents, Shasta County residents, and other travelers on I-5, including connections to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other regional and statewide transit providers.

This Agreement shall become effective upon execution upon the signature of RABA as shown on the signature page.

WITNESSES THAT:

WHEREAS, RABA is a public transportation operator that provides services in Shasta County, and is eligible to apply for and receive State, Federal Transit Administration (FTA) and Federal Highway Administration (FHWA) transit funding for capital, operating and planning assistance for the delivery of public mass transportation; and

WHEREAS, TCTC is the Regional Transportation Planning Agency for Tehama County, directed by a duly comprised board of directors of elected officials responsible for carrying out federal, and state regulations, and statutes for planning and coordination; and

WHEREAS, TCTC has received FHWA Congestion Mitigation Air Quality (CMAQ) funding for the purpose of supporting transportation projects that improve air quality and mobility.

WHEREAS, TCTC desires to allocate $200,000 in CMAQ funds for the first year and $100,000 annually thereafter to assist RABA in expanding intercity transit connectivity that benefits Tehama County residents, including access to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other statewide transit systems.

WHEREAS, RABA has an existing memorandum of understanding with the San Joaquin Joint Powers Authority and an agreement with Amtrak to operate bus service between Redding, Red Bluff and Chico and intends to expand that service along I-5 to Sacramento, enhancing connectivity to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and California's intercity network, as funding becomes available; and

WHEREAS, WHEREAS, TCTC's transfer of CMAQ funds is intended to support eligible costs of RABA expanding its existing intercity operations in a manner that directly benefits Tehama County riders and the parties agree that the funding will be administered consistent with federal requirements as described in Exhibit A (Scope of Work) and Exhibits B, C, and D, which include applicable FTA references:

1. FTA Master Agreement, as amended (Exhibit B)
2. FTA Certifications and Assurances, as amended (Exhibit C); and
3. FTA Circular 9040.1H (Formula Grants for Rural Areas) Circular, as amended (Exhibit D); and

WHEREAS, the Parties recognize the mutual benefit of coordinating to expand intercity transit connectivity serving Tehama County residents, Shasta County residents, and travelers along I-5, including improved transfer opportunities to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other regional and statewide transit carriers; and

WHEREAS, the parties recognize the mutual benefit of RABA utilizing regional funding to provide the specified services that will result in improved quality of life opportunities to Tehama and Shasta Counties.

NOW, THEREFORE, IT IS HEREBY AGREED by and between the parties hereto as follows:

1. **AGREEMENT PURPOSE AND INTENT:** The purpose and intent of this Fund Transfer Agreement is to:
   A. Set forth the basic structure for the Parties to cooperate in the administration of funds supporting expanded intercity transit connectivity, as described in Exhibit A (Scope of Work), which is attached hereto and incorporated herein;
   B. Establish a cooperative and mutually beneficial funding relationship through which TCTC will transfer CMAQ funds to RABA to support the expansion of RABA's intercity bus service along I-5 between Redding, Red Bluff, and Sacramento, improving access for Tehama County riders to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other statewide transit systems;
   C. Identify the roles and responsibilities of TCTC and RABA in the administration, reporting, and eligible use of transferred funds;
   D. Ensure that FHWA funds flexed to FTA funds are managed in compliance with federal requirements; and
   E. Ensure that state funds are managed in compliance with all applicable state and federal requirements.

2. **TERM OF AGREEMENT:** The term of this Fund Transfer Agreement shall begin upon the signature of RABA and shall continue on an annual funding cycle basis unless terminated by either Party with a thirty (30) calendar days' written notice.
3. **RESPONSIBILTIIES OF RABA:**
   A. Prior to TCTC submitting the CMAQ funding application or amendment, TCTC and RABA shall coordinate to prepare the required project scope, budget, and supporting documentation to ensure all eligible activities and costs are captured.
   B. RABA will provide TCTC with access to information, data, reports, records, maps and other such information which are in possession of or readily available to RABA, as necessary to document use of funds and performance of activities described in Exhibit A (Scope of Work).
   C. RABA will provide TCTC with all necessary data, reports, invoices, maps, or other information necessary to support grant administration, reporting, invoicing, and/or other activities required for TCTC to administer the CMAQ funding transfer and ensure compliance with applicable federal and state requirements.

   D. RABA shall remain the sole operator and project lead for its intercity public transit service between Redding, Red Bluff, and Sacramento along I-5.
   E. RABA shall utilize the funding provided under this Agreement shall be used solely to support eligible

operational and administrative costs associated with expanding service that benefits Tehama County riders, including improved connectivity to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and related intercity transit systems.

RABA shall provide to TCTC reasonable access to all records, documents, and/or equipment necessary to verify the proper use of funds and compliance with this Agreement. Notwithstanding the foregoing or any other provision in this Agreement, RABA's proprietary information or otherwise confidential or privileged materials shall not be provided to TCTC unless authorized by RABA's General Counsel in accordance with California state law.

4. **RESPONSIBILITIES OF TCTC:**
   A. Prior to TCTC submitting the CMAQ funding application or amendment, TCTC and RABA shall coordinate to prepare the required project scope, budget, and supporting documentation to ensure all eligible activities and costs are captured.
   B. TCTC shall provide RABA with access to information, data, reports, records, maps and other such information that are in its possession or readily available to TCTC as necessary to support administration of the CMAQ funding transfer and completion of the Scope of Work described in Exhibit A.
   C. TCTC will oversee the administration and reporting of all federal, state, or local funds transferred under this Agreement, including CMAQ or other eligible sources, to ensure compliance with applicable federal and state requirements. TCTC's oversight shall be limited to verifying that funds are used for eligible purposes that enhance mobility for Tehama County residents through RABA's intercity transit services along I-5 and connections to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains.
   D. TCTC will provide RABA with any data, reports, or documentation necessary to support RABA's grant reporting, invoicing, or audit compliance obligations under this Funding Transfer Agreement.

   TCTC further agrees to provide to RABA access to all records, documents, and/or equipment reasonably necessary to verify compliance with this Agreement and facilitate the efficient transfer and tracking of funds.
5. **OBLIGATIONS OF THE PARTIES; SCOPE OF SERVICES:** The Parties shall carry out the activities described in Exhibit A (Scope of Work), which define the eligible uses of TCTC's CMAQ funding and the associated reporting and compliance responsibilities. The Parties agree during the term of this Fund Transfer Agreement to cooperate in good faith to ensure that transferred funds are administered and expended solely for eligible purposes that expand intercity transit connectivity benefiting Tehama County riders, including improved transfer opportunities to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other regional and statewide carriers. RABA shall perform the transit service activities described in Exhibit A, and TCTC shall perform funding administration and oversight consistent with applicable federal and state requirements.

6. **COMPENSATION:** TCTC shall transfer up to $200,000 in CMAQ funding to RABA during the first year of this Agreement to support eligible operational and administrative expenses incurred by RABA related to the expansion of RABA's intercity bus service that benefits Tehama County residents, including improved connections to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other statewide transit providers. RABA may charge allowable operating and administrative costs to this grant in accordance with federal cost principles based on RABA Board of Directors adopted fully allocated rate for transit services.

   For each subsequent federal fiscal year following the initial year, TCTC shall transfer up to $100,000 in CMAQ funding to RABA on a reimbursable basis as defined in Section 7, subject to continued eligibility and funding availability. RABA shall charge eligible expenses related to the approved scope of work, including operating costs and allowable indirect costs, consistent with applicable FTA and FHWA requirements. TCTC and RABA shall coordinate annually to update scopes and budgets for inclusion in future CMAQ applications.

If a local or state match is required for federal participation, RABA shall identify and document the match source through a letter to TCTC's designated contract. TCTC's total financial obligation under this Funding Transfer Agreement shall not exceed the amounts specified above unless expressly authorized by the TCTC Board.

The detailed Project Budget attached as Exhibit E shall be incorporated into future CMAQ grant applications administered by TCTC.

7. **REQUEST FOR REIMBURSEMENT:** RABA may request reimbursement for eligible costs incurred in carrying out the activities identified in Exhibit A (Scope of Work) on a reimbursement basis, in arrears, and only for actual eligible costs, as follows:
   A. Invoices shall meet all the requirements of this Fund Transfer Agreement and be itemized using RABA's fully allocated hourly rate based on the number of service hours off the schedule shown in Exhibit A.
   B. Appropriate documentation must accompany each invoice to substantiate all costs claimed for reimbursement. Documentation may include, but is not limited to, employee classifications and hourly rates, contractor invoices, proof of payment, and a description of the work or service performed during the billing period.
   Incomplete or disputed invoices may be returned to RABA unpaid for correction. TCTC shall provide RABA with a detailed explanation of the corrections needed and if a dispute continues, the Executive Director of TCTC and Executive Officer of RABA shall meet and confer to resolve the dispute. Corrected invoices must be resubmitted to TCTC prior to the payment of the invoice.
   C. Upon TCTC's review and acceptance of an undisputed invoice, TCTC shall reimburse RABA for eligible costs, within thirty (30) calendar days. Reimbursement is contingent on the continued availability of CMAQ or other applicable funds and on compliance with all federal and state funding requirements.

8. **ADMINISTRATION OF AGREEMENT:** The Executive Director of TCTC (or designee), and the Executive Officer (or designee) of RABA are the primary individuals responsible for ensuring compliance with the provisions specified in this Fund Transfer Agreement and are authorized to act on behalf of their respective agencies to implement, administer, and amend this Agreement consistent with its terms.

9. **PROJECT MANAGEMENT FOR THIS FUND TRANSFER AGREEMENT:** For RABA, the Project Manager shall be the Transit Manager or designee. For TCTC, the Project Manager shall be the Deputy Director of Public Works – Transportation or designee.

   Each Party shall promptly notify the other in writing of any change in its designated Project Manager or designee as soon as reasonably practicable. The Project Managers shall serve as the primary day-to-day contacts for all matters relating to this Funding Transfer Agreement, including coordination of reimbursement requests, reporting, and documentation of regional benefits to Tehama County riders and connections to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains.

10. **CONFIDENTIALITY:** In connection with the Parties' activities under this Fund Transfer Agreement, each Party may be given access to certain proprietary or confidential information. Each Party agrees to the confidentiality of all such information and shall not disclose it to any third party except as authorized in writing by the originating Party, , or as otherwise required by law. Nothing in this section shall restrict either Party from disclosing records that are subject to the California Public Records Act or other applicable disclosure laws. Each party shall notify the other of such disclosure requests and requirements

at least five (5) business days before disclosure to allow a reasonable opportunity to object to production. If no action is taken to legally withhold the requested information within said period, the records may be released in accordance with the law.

11. **<u>INDEMNIFICATION AND LIMITED LIABILITY:</u>** Each Party shall indemnify, defend, and hold harmless the other Party, its officers, officials, employees, and agents from and against any and all claims, demands, liabilities, damages, losses, costs, or expenses (including reasonable attorneys' fees) arising out of or resulting from the negligent acts, errors, or omissions of the indemnifying Party or its officers, employees, or agents in connection with this Funding Transfer Agreement.

    Nothing in this section shall be construed to create liability for either Party for the acts or omissions of the other Party, nor to waive any immunities or defenses available under the California Government Code or other applicable law. This provision shall survive the termination or expiration of this Funding Transfer Agreement.

12. **<u>TERMINATION OF AGREEMENT:</u>** This Fund Transfer Agreement shall terminate upon any of the following events:
    A. Termination due to Loss of Funding – This Funding Transfer Agreement may be terminated immediately upon written notice should CMAQ or other applicable funding cease, be withdrawn, or be materially reduced, during the term of this Fund Transfer Agreement.
    B. Termination for Default - Should either Party default in the performance of its duties and/or obligations under this Fund Transfer Agreement or materially breach any of its provisions, the non-defaulting Party may, in its option, terminate this Fund Transfer Agreement by giving the defaulting party at least fourteen (14) calendar days prior written notification.
    C. Termination for Convenience: Either Party may terminate this Funding Transfer Agreement without cause by providing thirty (30) calendar days' written notice to the other Party.
    D. Wind Down and Closeout - Upon termination, the Parties shall cooperate to close out all financial and reporting obligations associated with this Funding Transfer Agreement, including the orderly transfer or reassignment of any active grants, documentation, or related materials held by either Party to an entity designated by TCTC for continued administration. RABA may retain CMAQ funds already reimbursed under this Agreement to complete eligible activities through the end of the federal fiscal year in which notice of termination was provided.
    E. Effect of Termination **–** Termination shall not relieve either Party of its obligation to comply with audit, record-retention, or indemnification provisions that by their nature extend beyond the termination date.

13. **<u>AGREEMENT AMENDMENTS:</u>**

    This Funding Transfer Agreement may be amended only by written consent of both Parties. All amendments that affect the total funding amount, scope of work, or term shall require approval by the governing Boards of TCTC and RABA, unless each Board has formally delegated such authority in writing to its Executive Director or Executive Officer. Administrative or technical amendments that do not alter the total funding commitment may be executed by the Executive Director of TCTC (or designee) and the Executive Officer of RABA (or designee).

14. **<u>HEADINGS NOT DETERMINATIVE:</u>**
    A. Section and paragraph headings in this Funding Transfer Agreement are for reference only and shall not affect interpretation or construction of its provisions.

15. **<u>NOTICE:</u>** Any formal notice with regard to this Fund Transfer Agreement shall be in writing and either

personally delivered, either in person or by email, or sent by First Class U.S. Mail, postage prepaid, addressed or emails follows:

TCTC:
Deputy Director of Public Works – Transportation
Tehama County Transportation Commission
Tehama County Transit Agency Board
1509 Schwab Street
Red Bluff, CA 96080
Email: jriskegomez@tehamartpa.org

RABA:
Transit Manager
Redding Area Bus Authority
3333 South Market Street
Redding, CA 96001
Email: RABA@RABAride.com

16. **RECORDS:** Each Party shall maintain complete and accurate financial and programmatic records relating to its performance under this Funding Transfer Agreement, including ledgers, books of account, invoices, vouchers, cancelled checks, and other documents evidencing expenditures or disbursements of funds.

    A. RABA shall maintain all documents and records, which demonstrate performance under this Agreement. Any records or documents required to be maintained pursuant to this Agreement shall be made available for inspection or audit by the TCTC Counsel, TCTC Executive Director, or a designated representative of either of these officers.

    B. TCTC shall maintain all documents and records, which demonstrate performance under this Agreement. Any records or documents required to be maintained pursuant to this Agreement shall be made available for inspection or audit by the RABA General Counsel, RABA Executive Officer, or a designated representative of either of these officers.

    C. The Parties, the Comptroller General of the United States, the State of California, and their duly authorized representatives shall have the right, for purposes of audit and examination, to inspect and copy any books, records, accounts, or other data pertaining to activities funded under this Agreement. Retention Period - All records required to be maintained under this Funding Transfer Agreement shall be retained for not less than three (3) years after final payment or longer if required by federal or state law. Each Party's designated representative may inspect or copy such records during normal business hours upon reasonable advance notice.

Signatures on the next page

Agreement Authorization:

By our signature below, we certify that the respective Board of Directors have authorized entering into this Agreement on behalf of each agency, effective the last date of signature to this document.

TCTC:

Date Executed: ______________________________

Tehama County Transportation Commission (TCTC)

By: ____

____

____

Attest:

____

Approved as to Form: Attached

RABA:

Date Executed: ______________________________

Redding Area Bus Authority (RABA)

By ____

____

____

Attest:

____

SHARLENE TIPTON, RABA Clerk

Approved as to Form:
CHRISTIAN M. CURTIS
GENERAL COUNSEL

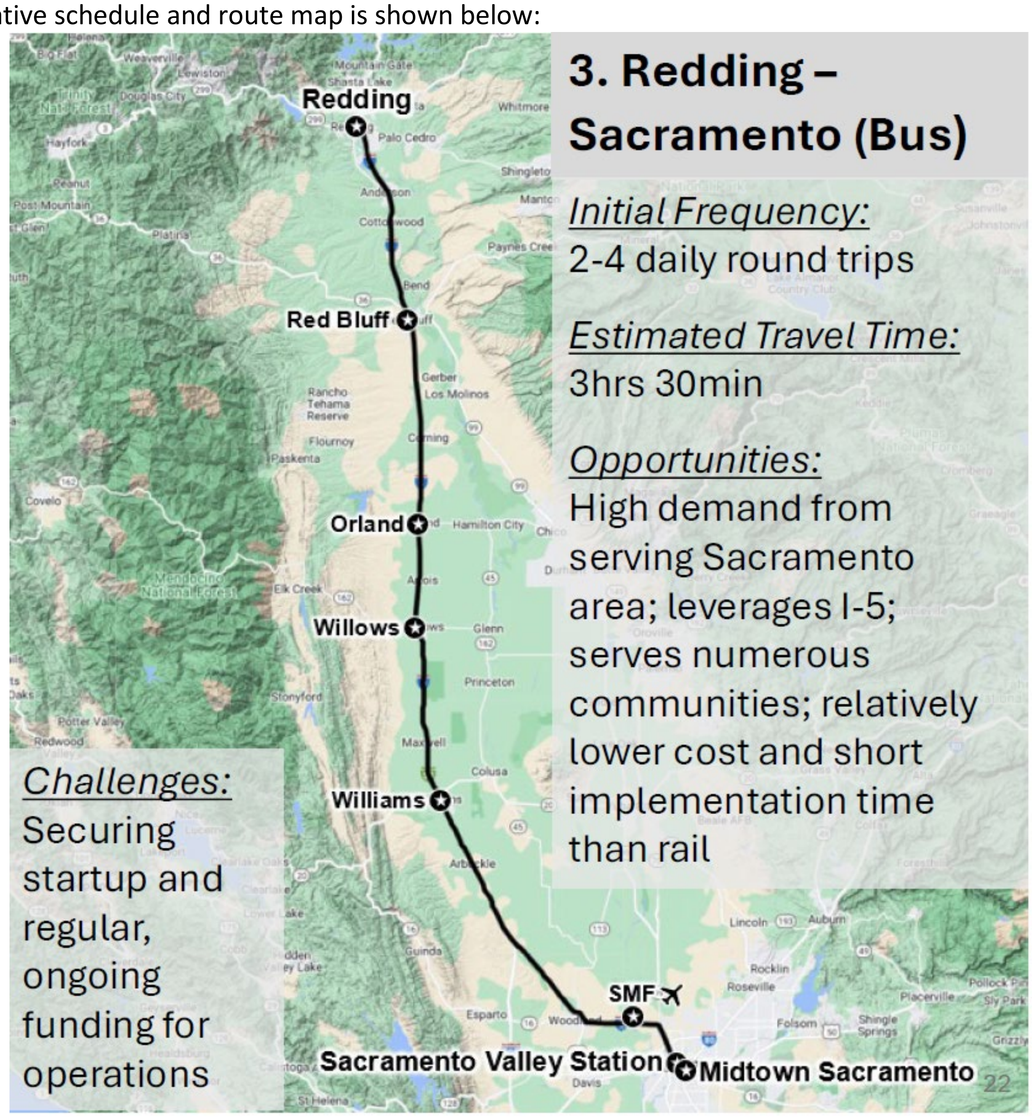
____

Exhibit A – Scope of Work

RABA will operate and manage the operation of two (2) to four (4) round trips of an intercity bus service traveling between Redding and Sacramento with stops in Red Bluff at the Red Bluff Bus & Ride, seven (7) days a week, 365 days a year. This intercity public transit service operates solely under the direction of RABA in partnership with the San Joaquin Joint Powers Authority (SJJPA), National Railroad Passenger Corporation (Amtrak) and TCTC and is designed to enhance mobility for Shasta and Tehama County residents by improving connectivity along the Interstate 5 corridor and providing direct transfer opportunities to Amtrak's Coast Starlight, Gold Runner and Capitol Corridor trains and other statewide intercity transit systems. RABA maintains existing coordination with the Amtrak and SJJPA for route integration and ticketing. RABA may subcontract with a qualified third-party provider for operations and maintenance of the intercity bus service, provided that all such activities remain compliant with applicable federal and state requirements and are consistent with the approved scope of work.

RABA shall provide all necessary supplies, equipment, vehicles, fuel, tools and other resources as required to operate and maintain an intercity bus service along I-5 through Tehama County in support of the regional mobility and air quality goals identified by TCTC.

While the schedule and route map may vary based upon a variety of factors and at RABA's sole discretion, a representative schedule and route map is shown below:



I-5 Backbone Timetable

Southbound

		Trip 2	Trip 3	
Redding	Downtown Transit Center	9:20 AM	**1:20 PM**	Transfer to 299W, RABA, Sage Stage, Trinity Transit, FlixBus, Greyhound
Redding	Redding Regional Airport	9:40 AM	**1:40 PM**	Transfer to RABA
Red Bluff	Red Bluff Bus & Ride	10:15 AM	**2:15 PM**	Transfer to TRAX
Orland	9th Street / SR 32 39.748750, -122.202419	11:00 AM	**3:00 PM**	Transfer to Glenn Ride, TRAX
		11:43 AM	***3:43 PM***	***To Chico***
		12:43 PM	***4:43 PM***	***To Chico (Sat)***
		9:06 AM	***1:36 PM***	***From Chico***
		10:36 AM	***2:36 PM***	***From Chico (Sat)***
Sacramento	Sacramento International Airport Terminals A (38.692583, -121.588691) and B (38.691222, -121.590620)	**12:35 PM**	**4:35 PM**	Transfer to SacRT, Yolobus
Sacramento	Sacramento Valley Station 38.584614, -121.501287	**12:55 PM**	**4:55 PM**	Transfer to SacRT, Yolobus, Roseville Transit, Yuba-Sutter Transit, SCT/LINK, Amtrak San Joaquins, Capitol Corridor
		Bus 2	Bus 1	
		3.58	3.58	

Northbound

		Trip 2	Trip 3	
Sacramento	Sacramento Valley Station	**2:45 PM**	**5:45 PM**	Transfer to SacRT, Yolobus, Roseville Transit, Yuba-Sutter Transit, SCT/LINK, Amtrak San Joaquins, Capitol Corridor
Sacramento	Sacramento International Airport	**3:00 PM**	**6:00 PM**	Transfer to SacRT, Yolobus
Orland	9th Street / Walker	**4:20 PM**	**7:20 PM**	Transfer to Glenn Ride, TRAX
		5:38 PM		***To Chico***
		5:36 PM		***From Chico***
		4:43 PM		***To Chico (Sat)***
		6:36 PM		***From Chico (Sat)***
Red Bluff	Red Bluff Bus & Ride	**5:50 PM**	**8:50 PM**	Transfer to TRAX
Redding	Redding Regional Airport	**6:15 PM**	**9:15 PM**	Transfer to RABA
Redding	Downtown Transit Center (arrives)	**6:30 PM**	**9:30 PM**	Transfer to 299W, RABA, Sage Stage, Trinity Transit, FlixBus, Greyhound
PM Times in BOLD.		Bus 2	Bus 1	

Exhibit B – FTA Master Agreement

The FTA Master Agreement, as amended can be accessed here:

https://www.transit.dot.gov/funding/grantee-resources/sample-fta-agreements/fta-grant-agreements

Exhibit C – FTA Certifications and Assurances

[To be attached]

Exhibit D – FTA Circular 9040 1.H

The FTA Circular 9040 1.H. as amended can be accessed here:
https://www.transit.dot.gov/regulations-and-programs/fta-circulars/formula-grants-rural-areas-program-guidance

Exhibit E – Project Budget

	Base Year 1	Base Year 2	Base Year 3	Base Year 4	Base Year 5	Base Year 6	Base Year 7	Option Year 1	Option Year 2	Option Year 3
	6/1/2025-6/30/2026	7/1/2026-6/30/2027	7/1/2027-6/30/2028	7/1/2028-6/30/2029	7/1/2029-6/30/2030	7/1/2030-6/30/2031	7/1/2031-6/30/2032	7/1/2032-6/30/2033	7/1/2033-6/30/2034	7/1/2034-6/30/2035
2 Trips Expense	*$ 750,863*	*$ 788,407*	*$ 827,827*	*$ 869,218*	*$ 912,679*	*$ 958,313*	*$ 1,006,229*	*$ 1,056,540*	*$ 1,109,367*	*$ 1,164,836*
Amtrak Fares - 10% Y1 to Y4, 25% Y5 to Y10 recovery	$ (75,086)	$ (78,841)	$ (82,783)	$ (86,922)	$ (228,170)	$ (239,578)	$ (251,557)	$ (264,135)	$ (277,342)	$ (291,209)
Bus Only Fares - 2% Y1 to Y4, 5% Y5 to Y7, 10% Y8 to Y10 recovery	$ (15,017)	$ (15,768)	$ (16,557)	$ (17,384)	$ (45,634)	$ (47,916)	$ (50,311)	$ (105,654)	$ (110,937)	$ (116,484)
SJJPA	$ (304,096)	$ (358,798)	$ (321,664)	$ (400,000)	$ (238,875)	$ (270,819)	$ (304,360)	$ (286,751)	$ (321,089)	$ (357,143)
TCTC	$ (200,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)	$ (100,000)
5311 (f)	$ -	$ -	$ (228,488)	$ (264,912)	$ (300,000)	$ (300,000)	$ (300,000)	$ (300,000)	$ (300,000)	$ (300,000)
Caltrans Division of Rail	$ (156,664)	$ (235,000)	$ (78,336)	$ -	$ -	$ -	$ -	$ -	$ -	$ -
(Surplus) or Deficit	*$ (0)*	*$ 0*	*$ 0*	*$ 0*	*$ 0*	*$ 0*	*$ 0*	*$ 0*	*$ (0)*	*$ 0*

2.05 Minimum Revenue Guarantee

If fare revenues from ticket sales for RABA's service between Redding and Chico do not cover the operating costs for the service, SJJPA will authorize Amtrak to reimburse RABA for any difference in revenue minus costs, up to $392,145 for year 1 and adjusted annually thereafter based on realized fare revenue collection and the rate paid to RABA's transit operations contractor. Amtrak will then invoice SJJPA quarterly to cover any deficit as the revenue guarantee for RABA. This guarantee would also apply to RABA extending service between Redding and Sacramento via the I-5 corridor, up to $400,000 annually. This minimum revenue guarantee is subject to the annual approval of the SJJPA Business Plan. The overall goal for this service is that over time, ridership would grow so that passenger revenue, inclusive of all markets (bus and rail destinations), will exceed the cost of this thruway bus service. Under no circumstance shall RABA subsidize this route. Should the subsidy and fare amount not cover the cost of the service, RABA reserves the right to reduce the service to match the available subsidy or provide notice to terminate the MOU due to lack of funding.

Assumptions made:

1. Amtrak fares start at 10% recovery in years 1 to 4, increases to 25% recovery in years 5 to 10
2. Bus only fares start at 2% recovery in years 1 to 4, increases to 5% in years 5 to 7 and 10% in years 8 to 10
3. Assumes TCTC funds first three years. Years 4 to 10 is conditional upon Caltrans acceptance of TCTC response regarding CMAQ eligbility for new
4. Assumes Caltrans will award 5311 (f) starting in Year 3 to replace State Rail Assistance. While Year 1 application is being reviewed, its questionat could apply again in Year 2.
5. Assumes no expansion beyond two trips.
6. Bus only fares also include RABA selling tickets through Greyhound/Flixbus platform. Flixbus keeps a percent of the sales.
7. RABA's fully allocated cost used with MTM costs, increased by CPI with MTM's costs @ 5%

E-Contract Review
Approval as to Form

Department Name: Tehama County Transportation Commission

Contractor Name: Redding Area Bus Authority

Contract Description: Fund Transfer Agreement to Expand Intercity Transit Connectivity Along Interstate 5

APPROVED AS TO FORM:

Office of the Tehama County Counsel
Brittany T. Ziegler, Deputy County Counsel

Date: 11/17/2025

Tehama County

Agenda Request Form

File #: 26-0061 **Agenda Date:** 1/26/2026 **Agenda #:** 10.

Environmental Systems Research Institute, Inc. (ESRI) Master Agreement - Deputy Director Riske-Gomez

Requested Action(s)

a.) Approve a three-year Master Product and Services (Enterprise) Agreement with Environmental Systems Research Institute, Inc. (ESRI) for geographic information system (GIS) software, licensing, and support services.

b.) Find that ESRI constitutes a sole-source provider and that waiving the formal competitive bidding process is in the best interest of the public, consistent with County and Commission procurement policies.

c.) Authorize the Interim Executive Director to execute all necessary agreements and related documents.

Financial Impact:

The total cost of the three-year Enterprise Agreement is $160,300.00, structured as follows:

- Year 1: $45,000.00
- Year 2: $55,000.00
- Year 3: $60,300.00

The pricing and term structure are documented in ESRI quote, dated September 25, 2025.

An Independent Cost Estimate (ICE) prepared in accordance with federal procurement guidance confirms the total cost as fair and reasonable

Funds have been budgeted through the Overall Work Program (OWP) GIS Element.

Background Information:

Commission staff have solicited a Small Municipal and County Government Enterprise Agreement with Environmental Systems Research Institute, Inc. (ESRI) to support the Tehama County Transportation Commission's core geospatial operations and to align with a coordinated, countywide GIS licensing strategy.

This Enterprise Agreement provides comprehensive access to ESRI software, cloud-based services, user licensing, data hosting, technical support, and system updates for a three-year period. The agreement directly supports the Commission's role as the steward of transportation-related spatial data and public-facing GIS applications that serve residents, partner agencies, emergency responders, and regional stakeholders.
The ESRI Enterprise platform underpins all Commission-managed GIS datasets and applications,

including but not limited to:

- Road closures and incident locations
- Collision and transportation safety analysis data
- Road classifications and asset management dashboards
- Drought-impacted wells
- Sandbag distribution locations
- Districts, boundaries, and jurisdictional layers
- Emergency, warming, and cooling center locators

Examples of Commission-developed GIS content, including interactive web maps, dashboards, and publicly available data downloads, are maintained on the Tehama County Transportation Commission website within the GIS section and the Interactive Map Viewer pages, and are also published through the Commission's ESRI organizational environment.

These pages provide the Commission, partner agencies, and the public a transparent reference point for the operational tools supported by this Enterprise Agreement and demonstrate the breadth of GIS applications currently deployed for transportation planning, emergency information, and public service delivery.

<https://tehamartpa.org/gis/>

These tools are actively deployed through Commission-maintained GIS platforms and application galleries. The Enterprise Agreement ensures continuity of service, system security, interoperability with existing datasets, and the ability to scale mapping and data services in response to emergency events, transportation planning needs, and public information requests.

The ESRI platform is deeply integrated into existing Commission workflows, historical datasets, web services, and interagency data-sharing arrangements. Migration to an alternative GIS platform would require substantial system re-engineering, data conversion, staff retraining, and redevelopment of applications, while also resulting in loss of compatibility with regional, state, and federal partner systems. Such a transition would introduce significant cost, operational risk, and service disruption without a corresponding public benefit.

Sole Source Justification

Approval of this agreement is requested as a sole-source procurement based on the following findings:

- **Proprietary Platform:** ESRI is the sole developer, licensor, and authorized distributor of ArcGIS Enterprise, ArcGIS Online, and related ESRI products. No other vendor can legally provide the same software, licensing structure, updates, or technical support.
- **Compatibility and Integration:** The Commission's GIS infrastructure, historical datasets, published applications, and automated workflows are built entirely on ESRI technology. Procurement of an alternative system would require full replacement of existing infrastructure and applications.
- **Operational Continuity:** Continued use of ESRI ensures uninterrupted access to mission-critical mapping, emergency response tools, and public-facing GIS applications relied upon by

residents, partner agencies, and regional stakeholders.

- **Cost Reasonableness:** An Independent Cost Estimate and price analysis confirm that the proposed pricing is fair and reasonable, based on historical pricing, published rates, and direct vendor quotation, as documented in the Independent Cost Estimate and Price Analysis Summary.
- **Public Interest:** Waiving the formal bid process avoids unnecessary delay, duplicative costs, and service disruption, and is consistent with County Code provisions that allow sole-source procurement where competition is not feasible.

These findings are formally documented in the Independent Cost Estimate and Price Analysis Summary and the Waiver of Formal Bids - Findings Form, which conclude that ESRI is the sole-source provider and that continuation of ESRI licensing is in the best interest of the County and the Commission.

Approval of the ESRI Master Product and Services (Enterprise) Agreement will ensure the continued operation, security, and expansion of the Commission's GIS program, which is foundational to transportation planning, emergency response coordination, public information, and interagency collaboration. The agreement represents a prudent and cost-effective investment in existing infrastructure and aligns with established procurement policies governing proprietary technology systems.

esri | THE SCIENCE OF WHERE

Environmental Systems Research Institute, Inc.
380 New York St
Redlands, CA 92373-8100
Phone: (909) 793-2853
DUNS Number: 06-313-4175   CAGE Code: 0AMS3

To expedite your order, please attach a copy of this quotation to your purchase order.
Quote is valid from: 8/1/2025 To: 10/30/2025

Quotation # Q-554397

Date: September 25, 2025

Customer # 150688   Contract #

Tehama County Transportation Commission
1509 Schwab St
Red Bluff, CA 96080-4577

ATTENTION: Jessica Riske-Gomez
PHONE: 530-385-1462 x3028
EMAIL: jriskegomez@tehamartpa.org

Material	Qty	Term	Unit Price	Total
193206	1	Year 1	$45,000.00	$45,000.00
Populations of 50,001 to 100,000 Small Government Enterprise Agreement Annual Subscription				
193206	1	Year 2	$55,000.00	$55,000.00
Populations of 50,001 to 100,000 Small Government Enterprise Agreement Annual Subscription				
193206	1	Year 3	$60,300.00	$60,300.00
Populations of 50,001 to 100,000 Small Government Enterprise Agreement Annual Subscription				

Subtotal:	$160,300.00
Sales Tax:	$0.00
Estimated Shipping and Handling (2 Day Delivery):	$0.00
Contract Price Adjust:	$0.00
Total:	$160,300.00

Esri may charge a fee to cover expenses related to any customer requirement to use a proprietary vendor management, procurement, or invoice program.

For questions contact:	Email:	Phone:
Michael Arias	marias@esri.com	(909) 793-2853

The items on this quotation are subject to and governed by the terms of this quotation, the most current product specific scope of use document found at https://assets.esri.com/content/dam/esrisites/media/legal/product-specific-terms-of-use/e300.pdf, and your applicable signed agreement with Esri. If no such agreement covers any item quoted, then Esri's standard terms and conditions found at https://go.esri.com/MAPS apply to your purchase of that item. If any item is quoted with a multi-year payment schedule, Esri may invoice at least 30 days in advance of each anniversary date without the issuance or a Purchase Order, and Customer is required to make all payments without right of cancellation. Third-party data sets included in a quotation as separately licensed items will only be provided and invoiced if Esri is able to provide such data and will be subject to the applicable third-party's terms and conditions. If Esri is unable to provide any such data set, Customer will not be responsible for any further payments for the data set. US Federal government entities and US government prime contractors authorized under FAR 51.1 may purchase under the terms of Esri's GSA Federal Supply Schedule. Supplemental terms and conditions found at https://www.esri.com/en-us/legal/terms/state-supplemental apply to some US state and local government purchases. All terms of this quotation will be incorporated into and become part of any additional agreement regarding Esri's offerings. Acceptance of this quotation is limited to the terms of this quotation. Esri objects to and expressly rejects any different or additional terms contained in any purchase order, offer, or confirmation sent to or to be sent by buyer. Unless prohibited by law, the quotation information is confidential and may not be copied or released other than for the express purpose of system selection and purchase/license. The information may not be given to outside parties or used for any other purpose without consent from Esri. Delivery is FOB Origin for customers located in the USA.

Quotation # Q-554397

Date: September 25, 2025

Customer # 150688   Contract #

Environmental Systems Research Institute, Inc.
380 New York St
Redlands, CA 92373-8100
Phone: (909) 793-2853
DUNS Number: 06-313-4175   CAGE Code: 0AMS3

Tehama County Transportation Commission
1509 Schwab St
Red Bluff, CA 96080-4577

ATTENTION: Jessica Riske-Gomez
PHONE: 530-385-1462 x3028
EMAIL: jriskegomez@tehamartpa.org

To expedite your order, please attach a copy of this quotation to your purchase order.
Quote is valid from: 8/1/2025 To: 10/30/2025

If you have made ANY alterations to the line items included in this quote and have chosen to sign the quote to indicate your acceptance, you must fax Esri the signed quote in its entirety in order for the quote to be accepted. You will be contacted by your Customer Service Representative if additional information is required to complete your request.

If your organization is a US Federal, state, or local government agency; an educational facility; or a company that will not pay an invoice without having issued a formal purchase order, a signed quotation will not be accepted unless it is accompanied by your purchase order.

In order to expedite processing, please reference the quotation number and any/all applicable Esri contract number(s) (e.g. MPA, ELA, SmartBuy, GSA, BPA) on your ordering document.

BY SIGNING BELOW, YOU CONFIRM THAT YOU ARE AUTHORIZED TO OBLIGATE FUNDS FOR YOUR ORGANIZATION, AND YOU ARE AUTHORIZING ESRI TO ISSUE AN INVOICE FOR THE ITEMS INCLUDED IN THE ABOVE QUOTE IN THE AMOUNT OF $__________, PLUS SALES TAXES IF APPLICABLE. DO NOT USE THIS FORM IF YOUR ORGANIZATION WILL NOT HONOR AND PAY ESRI'S INVOICE WITHOUT ADDITIONAL AUTHORIZING PAPERWORK.

Please check one of the following:

___ I agree to pay any applicable sales tax.

___ I am tax exempt, please contact me if exempt information is not currently on file with Esri.

[signature] 9/30/2025
Signature of Authorized Representative   **Date**

Jessica Riske-Gomez
Name (Please Print)

Deputy Director
Title

The quotation information is proprietary and may not be copied or released other than for the express purpose of system selection and purchase/license. This information may not be given to outside parties or used for any other purpose without consent from Environmental Systems Research Institute, Inc. (Esri).

Any estimated sales and/or use tax reflected on this quote has been calculated as of the date of this quotation and is merely provided as a convenience for your organization's budgetary purposes. Esri reserves the right to adjust and collect sales and/or use tax at the actual date of invoicing. If your organization is tax exempt or pays state tax directly, then prior to invoicing, your organization must provide Esri with a copy of a current tax exemption certificate issued by your state's taxing authority for the given jurisdiction.

Esri may charge a fee to cover expenses related to any customer requirement to use a proprietary vendor management, procurement, or invoice program.

For questions contact:	**Email:**	**Phone:**
Michael Arias	marias@esri.com	(909) 793-2853

The items on this quotation are subject to and governed by the terms of this quotation, the most current product specific scope of use document found at https://assets.esri.com/content/dam/esrisites/media/legal/product-specific-terms-of-use/e300.pdf, and your applicable signed agreement with Esri. If no such agreement covers any item quoted, then Esri's standard terms and conditions found at https://go.esri.com/MAPS apply to your purchase of that item. If any item is quoted with a multi-year payment schedule, Esri may invoice at least 30 days in advance of each anniversary date without the issuance or a Purchase Order, and Customer is required to make all payments without right of cancellation. Third-party data sets included in a quotation as separately licensed items will only be provided and invoiced if Esri is able to provide such data and will be subject to the applicable third-party's terms and conditions. If Esri is unable to provide any such data set, Customer will not be responsible for any further payments for the data set. US Federal government entities and US government prime contractors authorized under FAR 51.1 may purchase under the terms of Esri's GSA Federal Supply Schedule. Supplemental terms and conditions found at https://www.esri.com/en-us/legal/terms/state-supplemental apply to some US state and local government purchases. All terms of this quotation will be incorporated into and become part of any additional agreement regarding Esri's offerings. Acceptance of this quotation is limited to the terms of this quotation. Esri objects to and expressly rejects any different or additional terms contained in any purchase order, offer, or confirmation sent to or to be sent by buyer. Unless prohibited by law, the quotation information is confidential and may not be copied or released other than for the express purpose of system selection and purchase/license. The information may not be given to outside parties or used for any other purpose without consent from Esri. Delivery is FOB Origin for customers located in the USA.

Esri Use Only:
Cust. Name ____________
Cust. # ____________
PO # ____________
Esri Agreement # ____________

SMALL ENTERPRISE AGREEMENT
COUNTY AND MUNICIPALITY GOVERNMENT
(E214-3)

This Agreement is by and between the organization identified in the Quotation (**"Customer"**) and **Environmental Systems Research Institute, Inc.** (**"Esri"**).

This Agreement sets forth the terms for Customer's use of Products and incorporates by reference (i) the Quotation and (ii) the Master Agreement. Should there be any conflict between the terms and conditions of the documents that comprise this Agreement, the order of precedence for the documents shall be as follows: (i) the Quotation, (ii) this Agreement, and (iii) the Master Agreement. This Agreement shall be governed by and construed in accordance with the laws of the state in which Customer is located without reference to conflict of laws principles, and the United States of America federal law shall govern in matters of intellectual property. The modifications and additional rights granted in this Agreement apply only to the Products listed in Table A.

Table A
List of Products

Uncapped Quantities (annual subscription)

ArcGIS Enterprise Software and Extensions ArcGIS Enterprise (Advanced and Standard) ArcGIS Monitor ArcGIS Enterprise Extensions: ArcGIS 3D Analyst, ArcGIS Spatial Analyst, ArcGIS Geostatistical Analyst, ArcGIS Network Analyst, ArcGIS Data Reviewer	**ArcGIS Enterprise Additional Capability Servers** ArcGIS Image Server **ArcGIS Online User Types** ArcGIS Online Viewer User Type **ArcGIS Enterprise User Types** ArcGIS Enterprise Viewer User Type

Capped Quantities (annual subscription)

ArcGIS Online User Types		**ArcGIS Enterprise User Types**	
ArcGIS Online Contributor User Type	30	ArcGIS Enterprise Contributor User Type	30
ArcGIS Online Mobile Worker User Type	150	ArcGIS Enterprise Mobile Worker User Type	150
ArcGIS Online Creator User Type	150	ArcGIS Enterprise Creator User Type	150
ArcGIS Online Professional User Type	40	ArcGIS Enterprise Professional User Type	40
ArcGIS Online Professional Plus User Type	40	ArcGIS Enterprise Professional Plus User Type	40
ArcGIS Pro (Add-on Apps) for ArcGIS Online Creator or Professional User Type		**ArcGIS Pro (Add-on Apps) for ArcGIS Enterprise Creator or Professional User Type**	
ArcGIS 3D Analyst, ArcGIS Data Reviewer, ArcGIS Geostatistical Analyst, ArcGIS Network Analyst, ArcGIS Publisher, ArcGIS Spatial Analyst, ArcGIS Workflow Manager, ArcGIS Image Analyst	40 each	ArcGIS 3D Analyst, ArcGIS Data Reviewer, ArcGIS Geostatistical Analyst, ArcGIS Network Analyst, ArcGIS Publisher, ArcGIS Spatial Analyst, ArcGIS Workflow Manager, ArcGIS Image Analyst	40 each
ArcGIS Online Apps and Other		**ArcGIS Enterprise Apps and Other**	
ArcGIS Location Sharing for ArcGIS Online	40	ArcGIS Location Sharing for ArcGIS Enterprise	40
ArcGIS Online Service Credits	100,000	ArcGIS Advanced Editing User Type Extension for ArcGIS Enterprise	30

Other Benefits

Number of Esri User Conference registrations provided annually	4
Number of Tier 1 Help Desk individuals authorized to call Esri	4
Five percent (5%) discount on all individual commercially available instructor-led training classes at Esri facilities purchased outside this Agreement	

Customer may accept this Agreement by signing and returning the whole Agreement with (i) the Quotation attached, (ii) a purchase order, or (iii) another document that matches the Quotation and references this Agreement ("**Ordering Document**"). **ADDITIONAL OR CONFLICTING TERMS IN CUSTOMER'S PURCHASE ORDER OR OTHER DOCUMENT WILL NOT APPLY, AND THE TERMS OF THIS AGREEMENT WILL GOVERN.** This Agreement is effective as of the date of Esri's receipt of an Ordering Document, unless otherwise agreed to by the parties ("**Effective Date**").

Term of Agreement: Three (3) years

This Agreement supersedes any previous agreements, proposals, presentations, understandings, and arrangements between the parties relating to the licensing of the Products. Except as provided in Article 4—Product Updates, no modifications can be made to this Agreement.

Accepted and Agreed:

____
(Customer)

By: ________________________________
Authorized Signature

Printed Name: Jessica Riske-Gomez

Title: Deputy Director

Date: 9.30.25

CUSTOMER CONTACT INFORMATION

Contact: ____________________

Telephone: ____________________

Address: ____________________

Fax: ____________________

City, State, Postal Code: ____________________

E-mail: ____________________

Country: ____________________

Quotation Number (if applicable): ____________________

1.0—Additional Definitions

In addition to the definitions provided in the Master Agreement, the following definitions apply to this Agreement:

"Case" means a failure of the Software or Online Services to operate according to the Documentation where such failure substantially impacts operational or functional performance.

"Deploy", "Deployed" and "Deployment" mean to redistribute and install the Products and related Authorization Codes within Customer's organization(s).

"Fee" means the fee set forth in the Quotation.

"Maintenance" means Tier 2 Support, Product updates, and Product patches provided to Customer during the Term of Agreement.

"Master Agreement" means the applicable master agreement for Esri Products incorporated by this reference that is (i) found at https://www.esri.com/en-us/legal/terms/full-master-agreement and available in the installation process requiring acceptance by electronic acknowledgment or (ii) a signed Esri master agreement or license agreement that supersedes such electronically acknowledged master agreement.

"Product(s)" means the products identified in Table A—List of Products and any updates to the list Esri provides in writing.

"Quotation" means the offer letter and quotation provided separately to Customer.

"Technical Support" means the technical assistance for attempting resolution of a reported Case through error correction, patches, hot fixes, workarounds, replacement deliveries, or any other type of Product corrections or modifications.

"Tier 1 Help Desk" means Customer's point of contact(s) to provide all Tier 1 Support within Customer's organization(s).

"Tier 1 Support" means the Technical Support provided by the Tier 1 Help Desk.

"Tier 2 Support" means the Esri Technical Support provided to the Tier 1 Help Desk when a Case cannot be resolved through Tier 1 Support.

2.0—Additional Grant of License

2.1 **Grant of License.** Subject to the terms and conditions of this Agreement, Esri grants to Customer a personal, nonexclusive, nontransferable license solely to use, copy, and Deploy quantities of the Products listed in Table A—List of Products for the Term of Agreement (i) for the applicable Fee and (ii) in accordance with the Master Agreement.

2.2 **Consultant Access.** Esri grants Customer the right to permit Customer's consultants or contractors to use the Products exclusively for Customer's benefit. Customer will be solely responsible for compliance by consultants and contractors with this Agreement and will ensure that the consultant or contractor discontinues use of Products upon completion of work for Customer. Access to or use of Products by consultants or contractors not exclusively for Customer's benefit is prohibited. Customer may not permit its consultants or contractors to install Software or Data on consultant, contractor, or third-party computers or remove Software or Data from Customer locations, except for the purpose of hosting the Software or Data on Contractor servers for the benefit of Customer.

3.0—Term, Termination, and Expiration

3.1 **Term.** This Agreement and all licenses hereunder will commence on the Effective Date and continue for the duration identified in the Term of Agreement, unless this Agreement is terminated earlier as provided herein. Customer is only authorized to use Products during the Term of Agreement. For an Agreement with a limited term, Esri does not grant Customer an indefinite or a perpetual license to Products.

3.2 **No Use upon Agreement Expiration or Termination.** All Product licenses, all Maintenance, and Esri User Conference registrations terminate upon expiration or termination of this Agreement.

3.3 **Termination for a Material Breach.** Either party may terminate this Agreement for a material breach by the other party. The breaching party will have thirty (30) days from the date of written notice to cure any material breach.

3.4 **Termination for Lack of Funds.** For an Agreement with government or governmentowned entities, either party may terminate this Agreement before any subsequent year if Customer is unable to secure funding through the legislative or governing body's approval process.

3.5 **Follow-on Term.** If the parties enter into another agreement substantially similar to this Agreement for an additional term, the effective date of the follow-on agreement will be the day after the expiration date of this Agreement.

4.0—Product Updates

4.1 **Future Updates.** Esri reserves the right to update the list of Products in Table A—List of Products by providing written notice to Customer. Customer may continue to use all Products that have been Deployed, but support and upgrades for deleted items may not be available. As new Products are incorporated into the standard program, they will be offered to Customer via written notice for incorporation into the Products schedule at no additional charge. Customer's use of new or updated Products requires Customer to adhere to applicable additional or revised terms and conditions in the Master Agreement.

4.2 **Product Life Cycle.** During the Term of Agreement, some Products may be retired or may no longer be available to Deploy in the identified quantities. Maintenance will be subject to the individual Product Life Cycle Support Status and Product Life Cycle Support Policy, which can be found at https://support.esri.com/en/other-resources/product-life-cycle. Updates for Products in the mature and retired phases may not be available. Customer may continue to use Products already Deployed, but Customer will not be able to Deploy retired Products.

5.0—Maintenance

The Fee includes standard maintenance benefits during the Term of Agreement as specified in the most current applicable Esri Maintenance and Support Program document (found at https://www.esri.com/en-us/legal/terms/maintenance). At Esri's sole discretion, Esri may make patches, hot fixes, or updates available for download. No Software other than the defined Products will receive Maintenance. Customer may acquire maintenance for other Software outside this Agreement.

a. Tier 1 Support

1. Customer will provide Tier 1 Support through the Tier 1 Help Desk to all Customer's authorized users.
2. The Tier 1 Help Desk will be fully trained in the Products.
3. At a minimum, Tier 1 Support will include those activities that assist the user in resolving how-to and operational questions as well as questions on installation and troubleshooting procedures.
4. The Tier 1 Help Desk will be the initial point of contact for all questions and reporting of a Case. The Tier 1 Help Desk will obtain a full description of each reported Case and the system configuration from the user. This may include obtaining any customizations, code samples, or data involved in the Case.
5. If the Tier 1 Help Desk cannot resolve the Case, an authorized Tier 1 Help Desk individual may contact Tier 2 Support. The Tier 1 Help Desk will provide support in such a way as to minimize repeat calls and make solutions to problems available to Customer's organization.
6. Tier 1 Help Desk individuals are the only individuals authorized to contact Tier 2 Support. Customer may change the Tier 1 Help Desk individuals by written notice to Esri.

b. Tier 2 Support

1. Tier 2 Support will log the calls received from Tier 1 Help Desk.
2. Tier 2 Support will review all information collected by and received from the Tier 1 Help Desk including preliminary documented troubleshooting provided by the Tier 1 Help Desk when Tier 2 Support is required.
3. Tier 2 Support may request that Tier 1 Help Desk individuals provide verification of information, additional information, or answers to additional questions to

supplement any preliminary information gathering or troubleshooting performed by Tier 1 Help Desk.

4. Tier 2 Support will attempt to resolve the Case submitted by Tier 1 Help Desk.

5. When the Case is resolved, Tier 2 Support will communicate the information to Tier 1 Help Desk, and Tier 1 Help Desk will disseminate the resolution to the user(s).

6.0—Endorsement and Publicity

This Agreement will not be construed or interpreted as an exclusive dealings agreement or Customer's endorsement of Products. Either party may publicize the existence of this Agreement.

7.0—Administrative Requirements

7.1 **OEM Licenses.** Under Esri's OEM or Solution OEM programs, OEM partners are authorized to embed or bundle portions of Esri products and services with their application or service. OEM partners' business model, licensing terms and conditions, and pricing are independent of this Agreement. Customer will not seek any discount from the OEM partner or Esri based on the availability of Products under this Agreement. Customer will not decouple Esri products or services from the OEM partners' application or service.

7.2 **Annual Report of Deployments.** At each anniversary date and ninety (90) calendar days prior to the expiration of this Agreement, Customer will provide Esri with a written report detailing all Deployments. Upon request, Customer will provide records sufficient to verify the accuracy of the annual report.

8.0—Ordering, Administrative Procedures, Delivery, and Deployment

8.1 **Orders, Delivery, and Deployment**

a. Upon the Effective Date, Esri will invoice Customer and provide Authorization Codes to activate the nondestructive copy protection program that enables Customer to download, operate, or allow access to the Products. If this is a multi-year Agreement, Esri may invoice the Fee up to thirty (30) calendar days before the annual anniversary date for each year.

b. Undisputed invoices will be due and payable within thirty (30) calendar days from the date of invoice. Esri reserves the right to suspend Customer's access to and use of Products if Customer fails to pay any undisputed amount owed on or before its due date. Esri may charge Customer interest at a monthly rate equal to the lesser of one percent (1.0%) per month or the maximum rate permitted by applicable law on any overdue fees plus all expenses of collection for any overdue balance that remains unpaid ten (10) days after Esri has notified Customer of the past-due balance.

c. Esri's federal ID number is 95-2775-732.

d. If requested, Esri will ship backup media to the ship-to address identified on the Ordering Document, FOB Destination, with shipping charges prepaid. Customer acknowledges that should sales or use taxes become due as a result of any shipments of tangible media, Esri has a right to invoice and Customer will pay any such sales or use tax associated with the receipt of tangible media.

8.2 **Order Requirements.** Esri does not require Customer to issue a purchase order. Customer may submit a purchase order in accordance with its own process requirements, provided that if Customer issues a purchase order, Customer will submit its initial purchase order on the Effective Date. If this is a multi-year Agreement, Customer will submit subsequent purchase orders to Esri at least thirty (30) calendar days before the annual anniversary date for each year.

a. All orders pertaining to this Agreement will be processed through Customer's centralized point of contact.

b. The following information will be included in each Ordering Document:

(1) Customer name; Esri customer number, if known; and bill-to and ship-to addresses
(2) Order number
(3) Applicable annual payment due

9.0—MERGERS, ACQUISITIONS, OR DIVESTITURES

If Customer is a commercial entity, Customer will notify Esri in writing in the event of (i) a consolidation, merger, or reorganization of Customer with or into another corporation or entity; (ii) Customer's acquisition of another entity; or (iii) a transfer or sale of all or part of Customer's organization (subsections i, ii, and iii, collectively referred to as "**Ownership Change**"). There will be no decrease in Fee as a result of any Ownership Change.

9.1 If an Ownership Change increases the cumulative program count beyond the maximum level for this Agreement, Esri reserves the right to increase the Fee or terminate this Agreement and the parties will negotiate a new agreement.

9.2 If an Ownership Change results in transfer or sale of a portion of Customer's organization, that portion of Customer's organization will transfer the Products to Customer or uninstall, remove, and destroy all copies of the Products.

9.3 This Agreement may not be assigned to a successor entity as a result of an Ownership Change unless approved by Esri in writing in advance. If the assignment to the new entity is not approved, Customer will require any successor entity to uninstall, remove, and destroy the Products. This Agreement will terminate upon such Ownership Change.

SOLE SOURCE LETTER

Environmental Systems Research Institute, Inc. (Esri)
380 New York Street
Redlands, CA 92373

DATE: January 2, 2026

TO: Whom It May Concern

FROM: Jackie Ricks, Contracts Specialist I, Contracts and Legal Services Dept.

RE: **Esri Sole Source Justification for Small Municipal and County Government Enterprise Agreement**

This letter confirms Esri, as owner and manufacturer, is the sole source provider of all U.S. domestic Small Municipal and County Government Enterprise Agreements (EA). The Small Municipal and County Government EA is a bundled package of term limited software licenses and maintenance that includes the right to copy.

Subject to the disclosures set forth below, Esri is the only source that can grant a right to copy and deploy Enterprise Software within your organization (Enterprise). Also, domestically Esri is the only source of maintenance (updates and technical support) for all Esri® software.

Esri has authorized certain resellers to resell Small Local Government Cloud-Based Enterprise Agreements for populations of less than 15,000.

If you have further questions, please feel free to call our Contracts and Legal Services Department at 909-793-2853, extension 1990.

J. Ricks
Jackie Ricks

COUNTY OF TEHAMA

WAIVER OF FORMAL BIDS OVER $10,000 - FINDINGS FORM

This form must be attached to an Agenda Request Form

Pursuant to Tehama County Code Sections 4.24.080 and 4.24.110, competitive procurement must be used unless there is substantial justification for waiving the formal bid process

DATE: 1/12/2026 DEPARTMENT: Transportation

REQUESTED BY: Jessica Riske-Gomez TITLE: Deputy Director

PROPOSED ACQUISITION: ESRI Liscencing - 3 year agreement

REQUESTED ACTIONS BY THE BOARD OF SUPERVISORS:

a) Request to adopt the finding(s) as indicated below

b) Request to find it in the best interest of the County to waive the formal bid process for the acquisition based on the finding(s)

When requesting waiver of the bidding process, the written request shall include finding(s) which indicate that bidding procedures would not be in the best interest of the people -- Tehama County Code Section 4.24.080

Check applicable finding(s):

[ ] **Sole Source Acquisition:** Based on a finding declaring the vendor as the sole supplier who could feasibly supply the equipment or products needed by the Department.

[ ] **Participation In Existing Bid**: ______

Based on the finding that the existing bid meets all Tehama County Bidding Criteria and allows the County to take advantage of special low pricing without the time and expense involved with conducting a formal bid process.

[X] **Compatibility:** Based on the finding that the acquisition of a specific type or brand of product is required by the County in order to allow for full integration with existing equipment or facilities. **Explain:**

Tehama County currently utilizes a wide range of ESRI products. ESRI is the leader in GIS technology, and it is in the best interest of the county to continue using ESRI products to maintain compatibility with existing map data and deployed software solutions.

[ ] **Other, List Finding(s):**

Additional Justification:

ESRI is the sole-source provider of ESRI products in the U.S. commercial, state, and local government marketplace. This licensing agreement will ensure that all county departments can utilize all ESRI products covered under the Small Enterprise Agreement. Furthermore, Tehama County currently utilizes a wide range of ESRI products. ESRI is the leader in GIS technology, and it is in the best interest of the county to continue using ESRI products to maintain compatibility with existing map data and deployed software solutions.

Recommended: ______ Date: 1/12/2026

****Submittal to Purchasing must occur at least 7 working days prior to agenda deadline****

INDEPENDENT COST ESTIMATE (ICE) AND PRICE REASONABLENESS DETERMINATION

Date of Estimate: January 12, 2026

Description of Goods/Services:
Esri Small Municipal and County Government Enterprise Agreement

Procurement Type

- ☒ New Procurement
- ☐ Contract Modification (Change Order)
- ☐ Exercise of Option

Method of Obtaining Estimate

- ☐ Published Price List
- ☐ Historical Pricing
- ☒ Comparable Purchases by Other Agencies
- ☐ Engineering or Technical Estimate
- ☐ Independent Third-Party Estimate
- ☐ Other (specify): ___________________________
- ☐ Pre-established pricing resulting from competition

Explanation

An Independent Cost Estimate (ICE) was prepared to evaluate the reasonableness of the proposed three-year ESRI Small Municipal and County Government Enterprise Agreement prior to contract approval. Because ESRI software is proprietary and offered through a standardized government enterprise licensing program, pricing is not established through traditional competitive bidding. Accordingly, the ICE relies on benchmarking against publicly available ESRI enterprise agreements approved by comparable California public agencies, in addition to review of historical pricing and the ESRI programmatic pricing structure.

Summary of California Examples for ICE Benchmarking

Agency / Jurisdiction	Term	Total Contract Amount	Notes
City of Sacramento	3 years	$888,000	Enterprise Agreement: Metropolitan
City of Anaheim	3 years	$450,000	Enterprise Agreement: Metropolitan
City of Simi Valley	3 years	$225,300	Enterprise Agreement: Small Municipal
Mendocino County	3 years	$180,900	Enterprise Agreement: Small Municipal
Placer County	3 years	$866,000	Enterprise Agreement: Metropolitan
Tehama County	3 years	$160,300	Enterprise Agreement: Small Municipal

Price Reasonableness Determination

Based on the comparison above, the proposed Tehama County Transportation Commission agreement totaling $160,300 over three years falls at the low end of the range for California public agencies utilizing ESRI Small Municipal and County Government Enterprise Agreements. When adjusted for scale and scope, the proposed pricing is consistent with ESRI's standardized government pricing structure and is determined to be fair and reasonable.

Concurrence and Approval

I have reviewed the Independent Cost Estimate (ICE) and Price Reasonableness Determination for the proposed ESRI Small Municipal and County Government Enterprise Agreement and concur that the pricing has been evaluated in accordance with applicable procurement requirements. Based on the analysis and benchmarking against comparable public agency agreements, I find the proposed cost to be fair and reasonable and support proceeding with the procurement as proposed.

Concurred By:

Tom Provine
Interim Executive Director
Tehama County Transportation Commission
Date: ______________________

Reviewed and Concurred:

Debbie Schmidt
Senior Buyer, Purchasing
County of Tehama
Date: ______________________

E-Contract Review
Approval as to Form

Department Name: Tehama County Transportation Commission

Contractor Name: Environmental Systems Research Institute, Inc.

Contract Description: Three Year Software Licensing Agreement

APPROVED AS TO FORM:

Office of the Tehama County Counsel
Brittany T. Ziegler, Deputy County Counsel

Date: 01/12/2026

Tehama County

Agenda Request Form

File #: 26-0076 **Agenda Date:** 1/26/2026 **Agenda #:** 11.

BUILD Grant Application Support - Deputy Director Riske-Gomez

Requested Action(s)
Informational item regarding the use of the Interim Executive Director's signature authority to retain grant writing services to assist staff with preparation of a FY 2026 USDOT BUILD grant application for the Lake California Drive Reconstruction Project.

Financial Impact:

The agreement is within the Interim Executive Director's authorized signing authority and is funded within existing budget allocations. No additional local funding is required at this time.

Background Information:

The Lake California Drive Reconstruction Project is a priority corridor improvement project that has advanced through prior planning and project development and currently relies on a combination of programmed federal, state, and local transportation funding sources, including Regional Transportation Improvement Program (RTIP) funds and other formula and discretionary programs. These funds support project development and implementation but remain constrained within a competitive and capacity-limited regional funding environment.

The FY 2026 USDOT Better Utilizing Investments to Leverage Development (BUILD) grant program presents an opportunity to supplement the project's existing funding strategy with federal discretionary funding. If awarded, BUILD funds would augment currently programmed resources and could offset a portion of RTIP commitments, allowing those regional funds to be reprogrammed to other eligible transportation priorities.

To support staff capacity, reduce schedule risk, and ensure a complete and competitive application, the Interim Executive Director's delegated signature authority was exercised to retain professional grant writing and application development services. The agreement is a professional services contract with a not-to-exceed amount of $40,000, executed within authorized signing authority and funded through existing budget allocations. No additional local funds are required at this time.

Consultant support includes coordination, preparation of required narratives and forms, development of a BUILD-compliant benefit-cost analysis, project budget documentation, and application submittal support. Grant writing services are an eligible project development expense and are intended to position the project to secure external federal funding that would supplement the project's current funding mix and improve overall program flexibility. All final approvals, certifications, and application submittal remain under the authority of the Tehama County Transportation Commission.

Tehama County

Agenda Request Form

File #: 25-2108 **Agenda Date:** 1/26/2026 **Agenda #:** 12.

Informational Presentation on Self-Help Counties - Deputy Director Riske-Gomez

Requested Action(s)

Informational presentation on the Self-Help Counties Coalition and statewide transportation planning practices and provide direction to staff on any future educational topics the Commission would like brought forward.

Financial Impact:

None. This item is informational only and does not commit the Commission to any program, funding mechanism, or policy action.

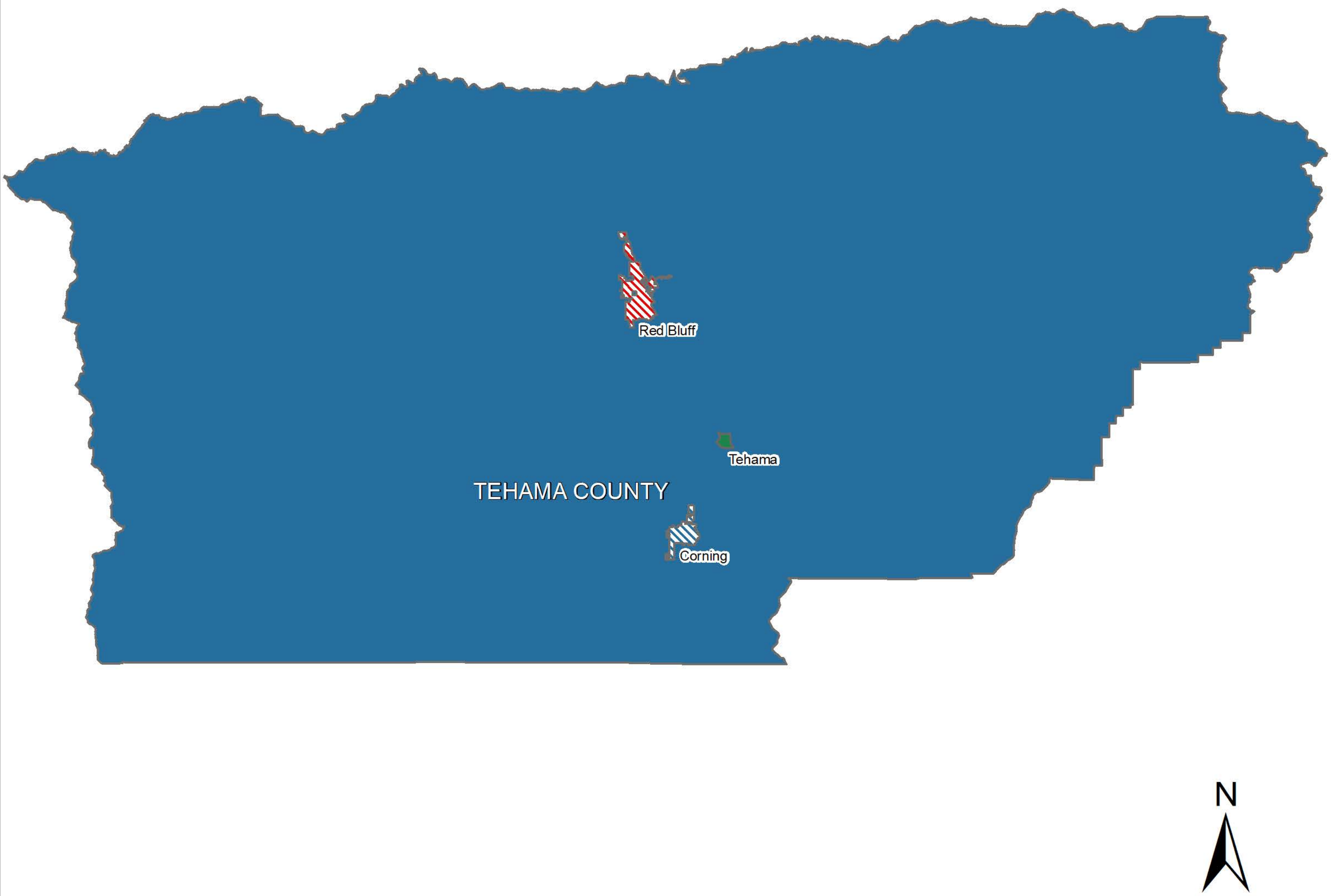
Background Information:

The Self-Help Counties Coalition (SHCC) is a statewide organization that supports counties in planning and delivering long-range transportation improvements. SHCC provides educational resources on transportation program development, project prioritization, and collaborative approaches used across California to maintain and improve roadways, bridges, transit, and related infrastructure.

This presentation is intended to introduce Commissioners to common statewide practices, frameworks, and tools used by peer agencies to manage transportation systems over multiple years. The information will help support future discussions about long-term transportation needs, system preservation strategies, and approaches used by other counties to ensure consistent investment in their transportation networks.

This item is educational only and does not propose or imply any local funding mechanism or policy direction.

Tehama County



Pavement Condition Index

Reported		Estimated	
Good (71-100)		Good (71-100)	
At Lower Risk (61-70)		At Lower Risk (61-70)	
At Higher Risk (50-60)		At Higher Risk (50-60)	
Poor (0-49)		Poor (0-49)	

Red Bluff • Corning • Tehama • Tehama County
1509 Schwab Street, Red Bluff, CA 96080 • (530) 602-8282

SELF-HELP COUNTIES

A Statewide Model for Long-Range Transportation Investment

(Informational Overview for Commissioners & Board Members)

What Are "Self-Help Counties"?

Self-Help Counties are California counties that have established locally directed transportation investment programs to improve roads, bridges, transit, pedestrian/bike safety, and mobility. These counties participate in the Self-Help Counties Coalition (SHCC), a collaborative statewide group that shares best practices, project-delivery strategies, and long-range planning tools.

Becoming a Self-Help County does not happen automatically, it is a structured, voter-controlled process defined in state law.

Why Do Counties Use This Model?

Across California, counties face similar challenges:

- Aging road and bridge infrastructure
- Long-term pavement maintenance needs
- Increasing storm, fire, and flood impacts on transportation systems
- Limited and unpredictable state and federal funding
- Growing demands for mobility, safety, and access improvements

Self-Help Counties develop stable, multi-year transportation programs that help maintain system reliability and deliver local priorities more efficiently.

1509 Schwab Street, Red Bluff, California 96080 • (530) 602-8282
E-mail: jriskegomez@tehamartpa.org • Web Site: https://tehamartpa.org

What Do Self-Help Counties Typically Invest In?

Examples of projects delivered through Self-Help County transportation programs include:

- Roadway rehabilitation and resurfacing
- Bridge repair and replacement
- Safety improvements, guardrails, and intersection upgrades
- Traffic congestion relief projects
- Transit operations, vehicles, and facility improvements
- Sidewalk, bicycle, trail, and ADA accessibility enhancements
- Emergency access, evacuation routes, and resilience investments

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Benefits Observed in Peer Counties

Self-Help Counties often experience:

- More predictable project delivery due to long-term planning
- Greater local control over project priorities
- Improved leverage when competing for state and federal grants
- Transparency and accountability through annual reporting and oversight committees
- Enhanced resiliency to disasters through planned investments in infrastructure

These outcomes vary by county and depend on each county's adopted long-range program.

HOW SELF-HELP COUNTY PROGRAMS ARE CREATED

(Understanding the Legal Process in California)

California requires a clear, transparent, voter-controlled process before any county can become a Self-Help County. Local agencies cannot implement transportation investment programs on their own, they must follow the steps below, established by state law.

---

1. The Program Must Be a Stand-Alone Measure

Under the California Transactions & Use Tax Law (Rev. & Tax. Code §7251 et seq.) and Proposition 218:

- A transportation program must be presented to voters as its own ballot measure
- It must include a detailed expenditure plan
- Voters must understand exactly what the funds would be used for

This ensures complete transparency.

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2. A Detailed Expenditure Plan Is Required

Before anything can appear on a ballot, counties must prepare a plan outlining:

- Categories of projects (roads, bridges, transit, safety, etc.)
- Estimated funding allocations
- Oversight and accountability provisions
- Sunset or renewal timelines
- Relationship to existing transportation plans and state/federal requirements

This plan must be published and publicly reviewed.

---

3. The Governing Board Must Formally Approve the Plan

California requires:

- Approval by the Board of Supervisors or a Transportation Authority,
- Review by County Counsel, and
- Adoption of ballot language prior to submission to the Registrar of Voters.

Local boards cannot bypass these steps.

4. Voters Must Approve the Program

Because transportation programs are considered special taxes, they require:

- Two-thirds (66.67%) voter approval, per Proposition 218.

Only the voters can authorize the creation of a Self-Help County program.

---

5. Accountability Measures Are Mandatory

If voters approve a program, the county must provide:

- Annual independent financial audits
- Public reporting of expenditures
- Oversight committee reviews
- Strict adherence to the adopted expenditure plan

These requirements ensure transparency and long-term trust.

Why This Information Is Being Shared Now

This flyer is intended to educate commissioners and board members on statewide practices used by transportation agencies across California. Understanding how other counties structure long-range transportation investment programs help support informed future planning discussions.

This information:

- Does not propose or endorse any funding mechanism
- Does not initiate a local measure
- Does not commit the County or TCTC to any action
- Is solely provided for education and awareness

Learn More

Self-Help Counties Coalition: **www.selfhelpcounties.org**

Self-Help Counties Coalition

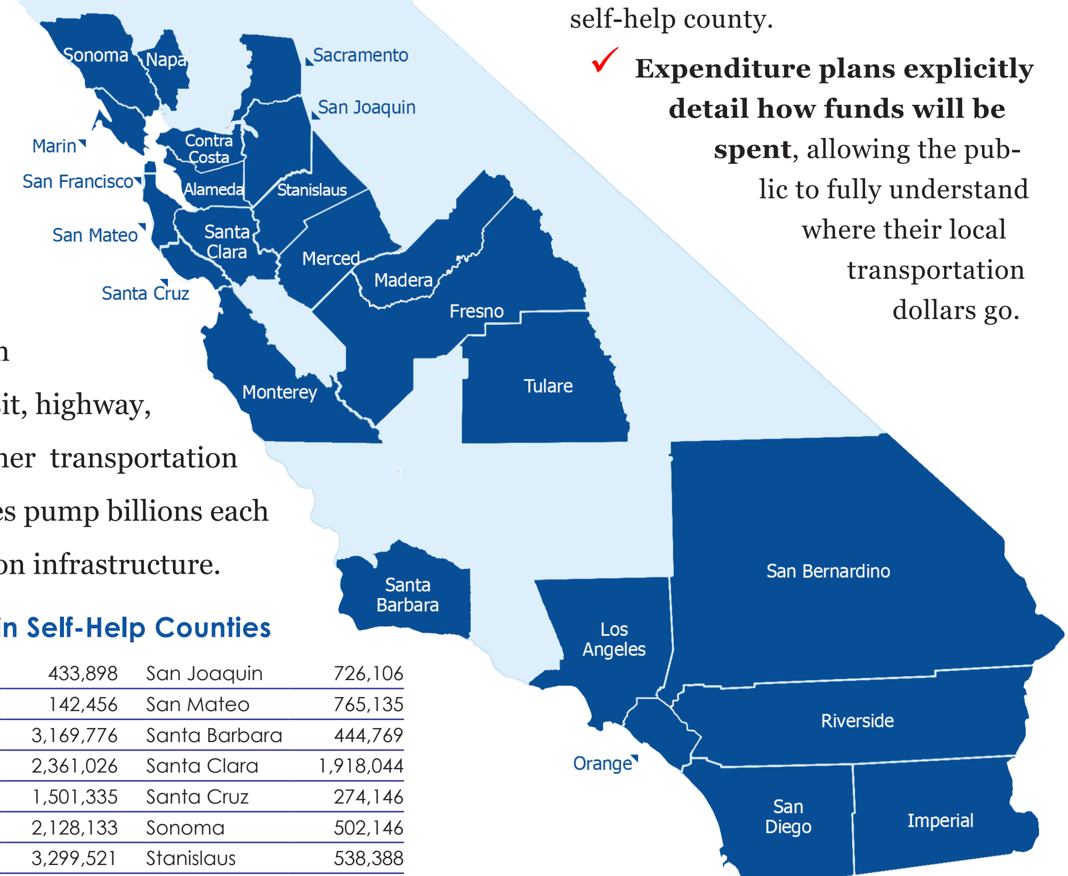
Locally Funded Transportation Investments

California's Economy Fueled by Local Sales Tax Measures

THROUGHOUT California, 24 county transportation agencies have formed the Self-Help Counties Coalition (SHCC). **Self-Help Counties move people, goods and services that are vital to the quality of life and economic strength of California.** Californians depend on these agencies for accessible, safe, innovative and cutting-edge transportation solutions. Each county delivers voter-approved (by super-majority) transportation sales tax measures that fund transit, highway, freight, bicycle, pedestrian and other transportation programs. Together, these counties pump billions each year into California's transportation infrastructure.

In California, 24 Self-Help Counties will fund approximately $194 billion of voter-approved transportation investments by mid-century, injecting billions each year into essential transportation programs and projects.

- ✓ **Self-Help Counties create and maintain jobs** for transportation infrastructure, operations and maintenance.
- ✓ The SHCC provides a **reliable and stable funding stream** that far outstrips state and federal funding on an annual basis.
- ✓ The SHCC has **extensive accountability** measures and six oversight on all taxpayer's dollars.
- ✓ The public has **direct access to local decision-makers**, and public meetings are held each month throughout the state with public opportunities to participate in every self-help county.
- ✓ **Expenditure plans explicitly detail how funds will be spent**, allowing the public to fully understand where their local transportation dollars go.



88% of California's population is in Self-Help Counties

Alameda	1,638,215	Monterey	433,898	San Joaquin	726,106
Contra Costa	1,126,745	Napa	142,456	San Mateo	765,135
Fresno	974,861	Orange	3,169,776	Santa Barbara	444,769
Imperial	180,191	Riverside	2,361,026	Santa Clara	1,918,044
Los Angeles	10,170,292	Sacramento	1,501,335	Santa Cruz	274,146
Madera	154,998	San Bernardino	2,128,133	Sonoma	502,146
Marin	261,221	San Diego	3,299,521	Stanislaus	538,388
Merced	268,455	San Francisco	864,816	Tulare	459,863

Total Population: 34 Million

Local Funding for Major Transportation Initiatives

CALIFORNIA REPRESENTS the largest economy in the U. S., and the sixth largest in the world. Its diverse industries range from agriculture to mining to biotechnology to the Internet, all of which support the state's economic strength.

Each industry relies on a backbone of transportation to move its people, goods and services.

Local sales tax dollars represent a stable fund source to finance critical transportation programs and projects, despite volatile federal and state funding. The Self-Help Counties spend a small portion of the sales tax on administration. The majority of sales tax expenditures result in:

- ✓ **Job creation:** Local sales tax dollars are pumped back into the local economy through contracts with local firms. Transportation system improvements require the services of architects, engineers, construction workers, project managers and other professionals. High-quality, efficient transportation systems attract and retain businesses in California.
- ✓ **Mobility:** The Self-Help Counties invest in multimodal transportation that provides choices for the traveling public — from express bus services, pathways for bicyclists and pedestrians, and public transit for youth, seniors and people with disabilities, to road and highway investments in arterials and the state's goods movement infrastructure.

Local goods movement investments support state and national economic strength.

- ✓ **Technological innovation:** Implementing technologies on heavily traveled roadways such as express lanes, adaptive ramp metering, real-time signage, monitoring and incident management reduces congestion and travel time and improves safety. Throughout California, the SHCC is implementing state-of-the-art transportation solutions.

Technical innovations reduce congestion and travel time and improve air quality.

- ✓ **Community vitality:** Reinvesting local dollars back into communities attracts additional funding resources. Leveraging these local dollars allows counties to complete major capital infrastructure projects, operate public transit and paratransit services and focus on transit oriented development to revitalize communities and meet the needs of people at all income levels.

Local dollars reinvested help meet the transportation needs of the community.

Providing multimodal alternatives to driving reduces greenhouse gas emissions.

- ✓ **Sustainability:** Multimodal investments — bicycle and pedestrian improvements, public transit and paratransit for seniors and people with disabilities — support greenhouse gas reduction mandates in California Assembly Bill 32, the Global Warming Solutions Act, and California Senate Bill 375, the Sustainable Communities and Climate Protection Act of 2008. These investments also support Sustainable Communities Strategies across the state.

Self-Help Transportation Spending in California

Based on the projections from the individual Self-Help Counties' expenditure plans, approximately $194 billion will be infused in California's transportation infrastructure from local transportation sales tax measures over the next 30-40 years.

Multimodal Investments

- ✓Capital Projects
- ✓Local Streets & Roads
- ✓Mass Transit
- ✓Paratransit
- ✓Express Bus
- ✓Bicycle & Pedestrian
- ✓Program Administration
- ✓Transit Oriented Development

Total: $194 Billion

SJSU SAN JOSÉ STATE UNIVERSITY

MTI MINETA TRANSPORTATION INSTITUTE

How Do California's Local Governments Fund Surface Transportation? A Guide to Revenue Sources

California State University Transportation Consortium

MINETA TRANSPORTATION INSTITUTE

Founded in 1991, the Mineta Transportation Institute (MTI), an organized research and training unit in partnership with the Lucas College and Graduate School of Business at San José State University (SJSU), increases mobility for all by improving the safety, efficiency, accessibility, and convenience of our nation's transportation system. Through research, education, workforce development, and technology transfer, we help create a connected world. MTI leads the Mineta Consortium for Transportation Mobility (MCTM) funded by the U.S. Department of Transportation and the California State University Transportation Consortium (CSUTC) funded by the State of California through Senate Bill 1. MTI focuses on three primary responsibilities:

Research

MTI conducts multi-disciplinary research focused on surface transportation that contributes to effective decision making. Research areas include: active transportation; planning and policy; security and counterterrorism; sustainable transportation and land use; transit and passenger rail; transportation engineering; transportation finance; transportation technology; and workforce and labor. MTI research publications undergo expert peer review to ensure the quality of the research.

Education and Workforce Development

To ensure the efficient movement of people and products, we must prepare a new cohort of transportation professionals who are ready to lead a more diverse, inclusive, and equitable transportation industry. To help achieve this, MTI sponsors a suite of workforce development and education opportunities. The Institute supports educational programs offered by the Lucas Graduate School of Business: a Master of Science in Transportation Management, plus graduate certificates that include High-Speed and Intercity Rail Management and Transportation Security Management. These flexible programs offer live online classes so that working transportation professionals can pursue an advanced degree regardless of their location.

Information and Technology Transfer

MTI utilizes a diverse array of dissemination methods and media to ensure research results reach those responsible for managing change. These methods include publication, seminars, workshops, websites, social media, webinars, and other technology transfer mechanisms. Additionally, MTI promotes the availability of completed research to professional organizations and works to integrate the research findings into the graduate education program. MTI's extensive collection of transportation-related publications is integrated into San José State University's world-class Martin Luther King, Jr. Library.

REPORT 21-32

HOW DO CALIFORNIA'S LOCAL GOVERNMENTS FUND SURFACE TRANSPORTATION? A GUIDE TO REVENUE SOURCES

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San José State University
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16. Abstract

California local agencies raise the revenue to support high-quality transportation services and infrastructure from a patchwork of federal, state, and local sources. To assist policymakers and transportation experts as they explore options for creating a more sustainable funding system, this report presents an overview of the taxes and fees that currently generate revenue ultimately dedicated to paying for transportation at the sub-state—or "local"—level. The discussion covers federal and state as well as local sources. The report also traces the evolving contribution from each level of government for expenditures on California's local streets and roads and public transit, looking back two decades. The report concludes with a discussion of options for increasing local transportation revenue.

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1. INTRODUCTION

California's local governments face a perennial challenge in raising the revenue required to support high-quality transportation services and infrastructure. To assist policymakers and transportation experts as they explore options for creating a more sustainable funding system, this report presents an overview of the taxes and fees that currently generate revenue dedicated to paying for transportation at the sub-state—or "local"—level. We use the term local to refer to counties, cities, and special districts, including entities that have regional responsibility, such as the Bay Area Toll Authority.

Even before the COVID-19 pandemic, funding for both streets and roads and public transit was insufficient to keep the systems in good repair and provide high-quality services. For example, a 2021 assessment from the League of California Cities found that expenditures for local streets and roads would need to be increased by $64 billion over the next ten years in order to achieve a state of good repair for all pavement, bridges, and other essential network components (streetlights, storm drains, sidewalks, etc.).[1] Public transit operators face similar revenue struggles. Ridership across the country has been steadily declining over the years, yet many systems need to upgrade antiquated infrastructure and poorly maintained facilities.

The COVID-19 pandemic brought into sharper focus the long-standing issue of how California's local governments pay for transportation. Most critically, ridership—and therefore fare revenue—fell during the pandemic as much as 90% for some transit operators. For the industry overall, the American Public Transit Association estimated that ridership was down 66% for the week of January 3, 2021, as compared to the same week in January 2020.[2] Further, Americans have modestly reduced vehicle travel and more substantially changed their purchasing behaviors in the face of the pandemic. These changes impact revenue from sources that provide critical transportation funding for local entities, most notably fuel and sales taxes. The extent of those reductions remains to be seen, though a January 2021 update to the state's budget estimated a drop of 8.4% in gasoline consumption, an increase of 3.7% in diesel consumption, and a slight increase in sales tax revenue.[3] The impacts have varied widely across local jurisdictions, however, with some jurisdictions seeing much larger declines in driving, taxable retail sales, and other activities that generate transportation revenue.

This research focuses on the transportation revenue available to the state's local entities. Local governments are responsible for virtually all public transit services and 86% of roads in the state,[4] yet their unique challenges are often overlooked in state-wide policy discussions and research into transportation revenue options.

One major barrier to an effective state-wide discussion about how California can generate stable funding for local transportation is the fact that the current system is, to speak bluntly, bewildering. Every year, 482 cities, 58 counties, and numerous special districts piece together the puzzle of their transportation budgets, drawing upon a complex mix of revenue raised at every level of government—federal, state, regional, and local.[5] Indeed, the budget for the transportation program of even a relatively small city, county, or transit operator relies on revenue raised by at least a dozen sources.

The majority of transportation revenue at the local level comes from a combination of local sales taxes imposed in 25 counties,[6] plus a host of different taxes and fees paid by direct users of the transportation system, with the proceeds dedicated for transportation purposes by law. Examples of user fees include motor fuel taxes, truck weight fees, public transit fares, parking fees, and local vehicle registration fee surcharges. In addition, government entities also make annual allocations from their general fund revenue to supplement the revenue raised directly from transportation users.

This report is the first of a two-part series that aims to support meaningful dialog about local transportation funding options among policymakers, stakeholders, transportation professionals, and researchers. This first report provides a snapshot of the different revenue tools currently used in the state, as well as some options used outside California. (The report provides basic information about the revenue options, but deliberately does not attempt to analyze their suitability or recommend which have more or less merit.) The second study will report findings from a set of interviews with transportation experts about the challenges they face in raising adequate revenue, and their ideas for innovations and reforms.

This report focuses on those taxes and fees that raise at least some revenue that is dedicated for transportation purposes at the local level, whether the revenue is spent by cities, counties, or special districts. In some cases, the revenue is restricted by law to transportation purposes only, while in other cases the governing body has passed a resolution documenting an ongoing intent to allocate revenue for transportation purposes.

The remainder of the report is organized as follows:

- Chapter 2 provides an overview of the different local, state, and federal revenue sources from which at least some portion is earmarked for local transportation;
- Chapter 3 describes the primary federal revenue sources;
- Chapter 4 describes the primary state revenue sources;
- Chapter 5 describes the primary local revenue sources; and
- Chapter 6 concludes the report with a discussion of options for increasing local transportation revenue.

2. AN OVERVIEW OF SOURCES OF SURFACE TRANSPORTATION REVENUE IN CALIFORNIA

This chapter provides a high-level survey of the revenue tools used to raise local transportation funding. The initial sections describe the conceptual differences between taxes and fees, the different types of local government entities that impose taxes and fees, and an overview of the types of taxes and fees that generate revenue dedicated for surface transportation. The last sections present data on the relative amount of revenue contributed by local governments, the state, and the federal government.

2.1. TOOLS TO RAISE REVENUE: TAXES VS. FEES

The State of California's legal code carefully restricts the mechanisms that government entities may use to raise revenue. Many of these laws and constitutional amendments govern activity by both the state itself and local entities. In addition, the state places further limits on the revenue tools available to local governments.

Within California law, the terms "tax" and "fee" refer to different types of charges. "Fees," sometimes known as "enterprise revenues," are charged in exchange for a specific service. The rate should be set so that the governing entity recoups only the revenue needed to provide the service, and the revenue collected must not be used for other purposes. Elected officials may impose fees directly, without voter approval. Examples of fees include charges for obtaining licenses and permits, parking, or driving on a tolled highway.

Local government charges that are not "fees" are usually considered "taxes." The revenue raised from taxes, sometimes called "non-enterprise revenue," typically has fewer restrictions than fees on how the money can be spent. Ad valorem property taxes and parcel taxes are examples of non-enterprise revenues.[7] A final important concept related to taxes is the distinction between "general" and "special" taxes. "Special taxes" are similar in concept to a fee, in that the revenue collected through a special tax can only be spent for specific purposes. Two-thirds of voters are required to approve a special tax. By contrast, general tax revenue can be spent on any purpose, and these taxes need approval from the majority of voters.[8]

Although these are less commonly used tools to generate transportation revenue in California, local governments can also raise revenue through mechanisms such as fines and penalties, franchise agreements on solid waste collection and utilities, and payments that a private entity pays to use public property (rents, royalties, and concessions).[9]

2.2. TYPES OF LOCAL GOVERNMENT ENTITIES THAT IMPOSE TAXES AND FEES

The State of California recognizes three types of local government entities: counties, cities, and special districts.

State land is distributed across 58 counties. Counties provide some services and programs to all residents within their boundaries (e.g., managing federally funded public assistance programs and running local elections), as well as providing essential services for residents who do not live within the boundaries of a city or special district that provides such services. Roads are one essential service that counties provide to residents living in unincorporated areas (i.e., areas that are not part of a city).[10]

An “incorporated city” is an area within a county that has been legally designated as the local entity which will provide (and pay for) an array of basic services for its residents. These responsibilities including the provision and management of local streets. Some cities, known as “full service,” have financial responsibility for providing the great majority of essential services. However, many cities transfer financial responsibility for certain services to either the county or special districts.[11]

Special districts are forms of local government that provide specific public services within their jurisdiction such as water, sewage, electricity, and fire protection.[12] The California State Controller reported over 3,000 active special districts in the state for 2018. These vary in size and services, with some exclusively, or in part, providing transportation infrastructure services.[13] “Independent” special districts have their own governing bodies and are not directly accountable to any other local entity. “Dependent” special districts have a close relationship with another local governing entity, typically a county or city, and that entity’s elected leaders control the special district.[14] Table 1 presents the different types of special districts that have transportation responsibilities.

Two types of special districts that are particularly important from a transportation perspective are congestion management agencies (CMAs) and public transit operators. CMAs are special districts representing a single county that distribute state transportation revenue and may serve as the agency that administers a locally approved transportation sales tax. Some of these, such as the Los Angeles County Metropolitan Transportation Authority, are contiguous with a county, and thus the same elected officials govern both the county and special district. As for public transit districts, these entities’ primary mission is operating local or regional public transportation services (e.g., bus or rail). Two examples of independent special districts that operate transit services are the San Francisco Bay Area Rapid Transit (BART) District and the Alameda-Contra Costa Transit Agency (AC Transit). Each entity has its own governing board and legal authority to impose taxes and fees.

Table 1. Types of Special Districts that Provide Transportation Services or Infrastructure

District type	Purpose
Transit districts	Construct and operate rail lines, bus lines, stations, platforms, terminals, and any other facilities necessary or convenient for transit service
Community services districts	Provide up to 32 different services, including the construction, improvement, and maintenance of streets, roads, rights-of-way, bridges, and sidewalks.
Municipal utility districts	Manage and supply light, water, power, heat, transportation, telephone service, or other means of communication, or means for the collection, treatment, or disposition of garbage, sewage or refuse matter
Public utility districts	Maintain the infrastructure to provide electricity, natural gas, water, power, heat, transportation, telephone service, or other means of communication, or the disposition of garbage, sewage, or refuse matter
Harbor districts	Manage any bay, harbor, inlet, river, channel, etc. in which tides are affected by the Pacific Ocean
Airport districts	Assist in the development of airports, spaceports, and air navigation facilities
Port districts	Maintain and secure the ports
Recreation and park districts	Organize and promote programs of community recreation, parks and open space, parking, transportation, and other related services that improve the community's quality of life

Source: California Special Districts Association, "Special District Formation Guide" (2016), https://calafco.org/sites/default/files/documents/2016%20Formation%20Guide%20WEB.PDF.

2.3. TAXES AND FEES THAT GENERATE EARMARKED TRANSPORTATION REVENUE

It is surprisingly difficult to identify the set of revenue tools that fund transportation, let alone document the amount of revenue that each raises statewide. The following are some of the key reasons:

- While some special taxes or fees are clearly and completely designated for transportation purposes (e.g., fuel taxes), many other revenue instruments are used for transportation in some but not all jurisdictions. For example, only a few jurisdictions designate that some portion of their parking fee revenue be spent for transportation purposes.

- Sometimes only a *portion* of the revenue raised from a specific source may be dedicated for transportation (e.g., the state sales tax on diesel fuel).

- Some taxes and fees that one might reasonably assume must be "transportation user fees" with revenue dedicated to the system are actually not sources of transportation funding. Two examples are the state's Vehicle License Fee and parking revenue from most (but not all) local entities.

- Some portion of local, state, and federal "general fund" (unrestricted) revenues also pay for transportation, but the amount is determined each year in the budget allocation process, and there are no centralized, statewide records documenting statewide what portion of local transportation budgets comes from these general fund sources.

- Least visible of all, but critically important, not all expenditures that directly benefit travel infrastructure and services are labeled as "transportation" expenditures in official reporting. As a result, these remain invisible in any "transportation" accounting even at the level of a single entity. For example, storm-water management infrastructure is typically not documented in accountings of "transportation," even though these systems lie directly along roadways and control roadway flooding. Also, in many locations street-lighting and road-side landscaping are managed by a department of public works rather than a department of transportation, so are not recorded as transportation expenditures. And to give a final example, electric vehicle charging infrastructure has not typically been considered a transportation function in budget reports.

Despite these many complications, there are a set of revenue tools commonly used and documented as raising transportation revenue. Table 2 presents the revenue tools that are the focus of this report—those generating funds that are earmarked for local entities to spend on surface transportation. This set includes federal, state, and local charges. In many cases, the taxes and fees discussed are by statute dedicated for transportation purposes. However, we also describe taxes and fees for which local governing body has formally resolved to spend a portion of the revenue on transportation purposes over many years.

Despite these many complications, there are a set of revenue tools commonly used and documented as raising transportation revenue. Table 2 presents the revenue tools that are the focus of this report—those generating funds that are earmarked for local entities to spend on surface transportation. This set includes federal, state, and local charges. In many cases, the taxes and fees discussed are by statute dedicated for transportation purposes. However, we also describe taxes and fees for which local governing body has formally resolved to spend a portion of the revenue on transportation purposes over many years.

This study excludes from consideration the following types of taxes and fees:

- **Taxes and fees that provide "general fund" revenue, without any accompanying legislative resolution to dedicate the money to transportation:** Although some government entities allocate a portion of their unrestricted general fund revenue for transportation, that decision is made annually and there is no guarantee of a continuing revenue stream. Examples of such general-purposes taxes are general property taxes and income taxes.

- **Taxes and fees paid by users of the transportation system for which the revenue is never transferred to cities or counties for transportation purposes:** Examples include the state driver license and vehicle registration fees (these fund the state's Department of Motor Vehicles and Highway Patrol), the state Vehicle License Fee (a property tax on vehicle ownership), and the parking fees collected in most local jurisdictions.

- **Proceeds from bond measures:** Bonds are a financing tool that allows governments to spend money earlier than they collect it, but bonds do not generate "revenue." As any person with a home loan, auto loan, or credit card knows, borrowed money must eventually be repaid.

Table 2. Types of Revenue Instruments that Raise Funds Earmarked for Local Transportation

Type of revenue instrument, by tax base	Federal	State	Special district	County	City
Fuels					
Gasoline fuel excise tax	✓	✓			
Diesel fuel excise tax	✓	✓			
Diesel fuel sales tax		✓			
Vehicles					
Truck and truck-tire sales tax	✓				
Truck weight fee	✓	✓			
Vehicle registration fee				✓	
Transportation system use					
Toll			✓	✓	
Fares + other transit-operator-generated revenue[a]			✓	✓	✓
Parking fees			✓		✓
Ride-hailing tax					✓
Refuse vehicle impact fee			✓	✓	✓
Real property					
Development fee			✓	✓	✓
User-utility tax			✓	✓	✓
Occupancy tax				✓	✓
Parcel tax			✓	✓	✓
Other					
Sales tax		✓	✓	✓	✓
Transient occupancy tax			✓		✓
Business-license tax			✓		✓
Cap-and-trade program		✓			
Franchise agreements (e.g., utilities)					✓

[a] For example, advertising revenue.

2.4. STREETS AND ROADS: LOCAL, STATE, AND FEDERAL CONTRIBUTIONS

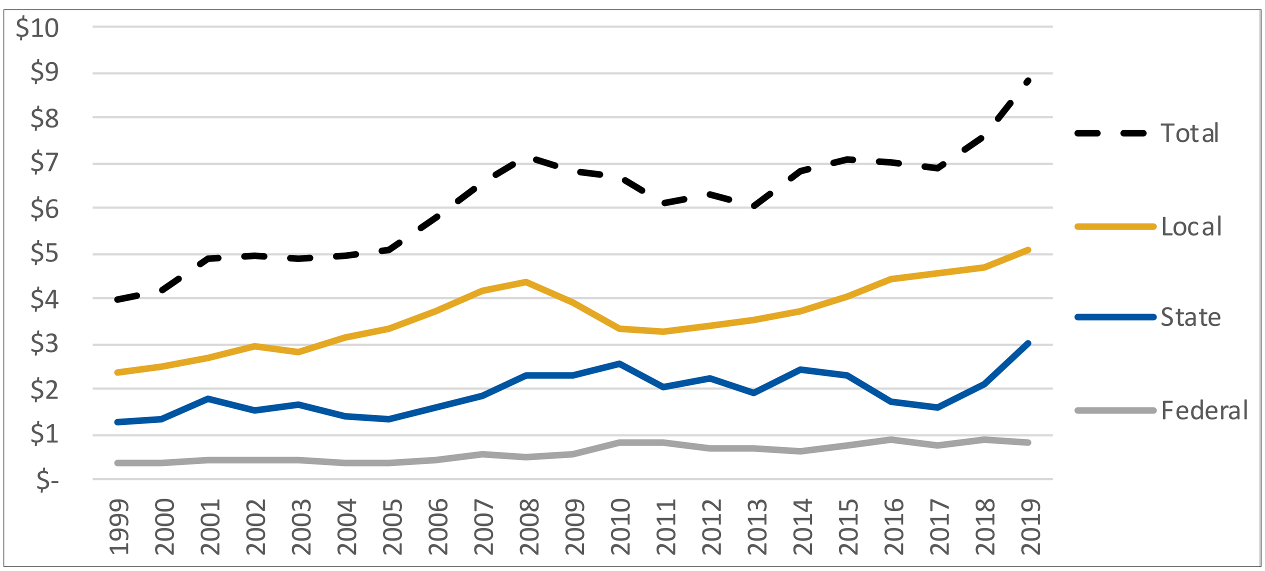
Across all levels of government, the total funding for California's transportation system in fiscal year 2018–2019 has been reported at approximately $35 billion dollars.[15] Local governments contributed just shy of one half of this amount. The state contributed approximately one-third of the total, and the federal government provided the remainder.

Because funding city streets and county roads is at the heart of every city and counties' transportation responsibilities, we looked in detail at how contributions from different levels of government have evolved over the past two decades.

Figure 1 presents the total revenue made available by federal, state, and local governments for streets and roads across a 20-year time period in nominal dollars, Figure 2 shows the same data adjusted to the equivalent of 2020 dollars, and Figure 3 shows the data in terms of the percent contributed annually by each level of government.[16]

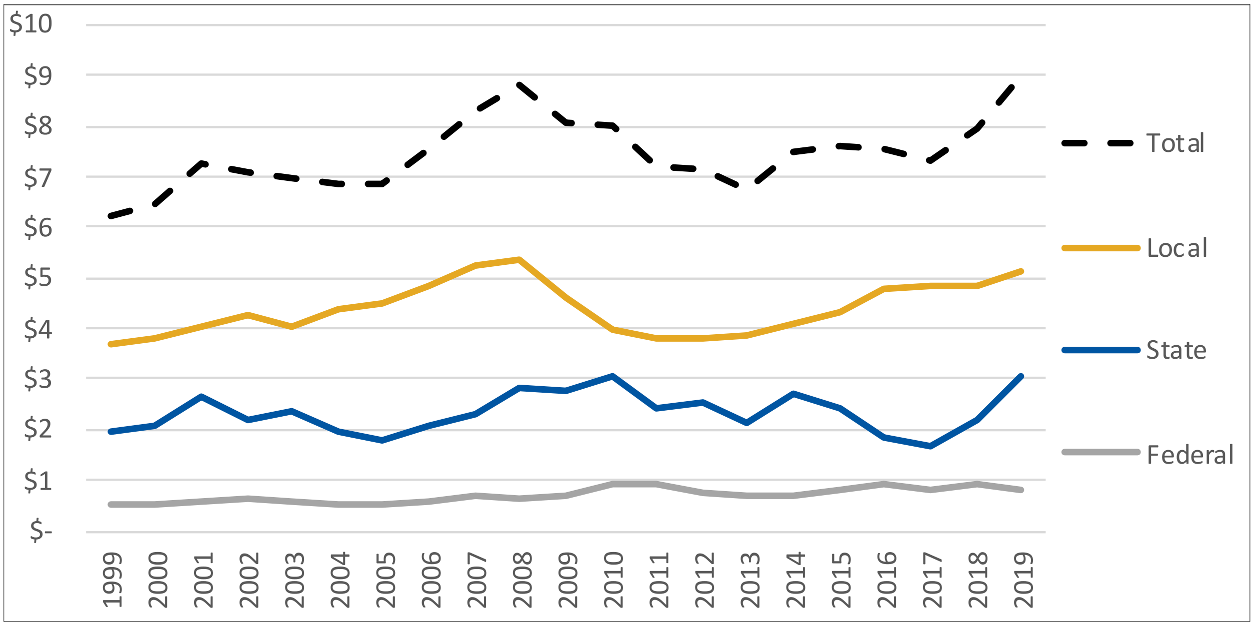
From a first glance at Figure 1, the total amount of revenue available over the two-decade span may look to have been growing at a healthy rate, but that first impression is misleading. In nominal dollars total revenue has roughly doubled, from approximately $4 billion to $9 billion, but once the values are adjusted for inflation, the growth is only about 50%, from roughly $6 billion to $9 billion (Figure 2). During that same period the number of licensed drivers in California grew 28%, roadway miles grew 5%, and the number of bridges grew 9%, expanding the set infrastructure to be maintained.[17] Further, during that period many portions of the state's transportation infrastructure reached the end of its functional lifespan and needed major rehabilitation. As noted earlier, the League of California Cities estimated that expenditures for local streets and roads would need to be increased by $64 billion over the next ten years in order to achieve a state of good repair.[18]

Figure 1. Billions of Nominal Dollars Available for Roads and Streets, by Level of Government, 1999–2019



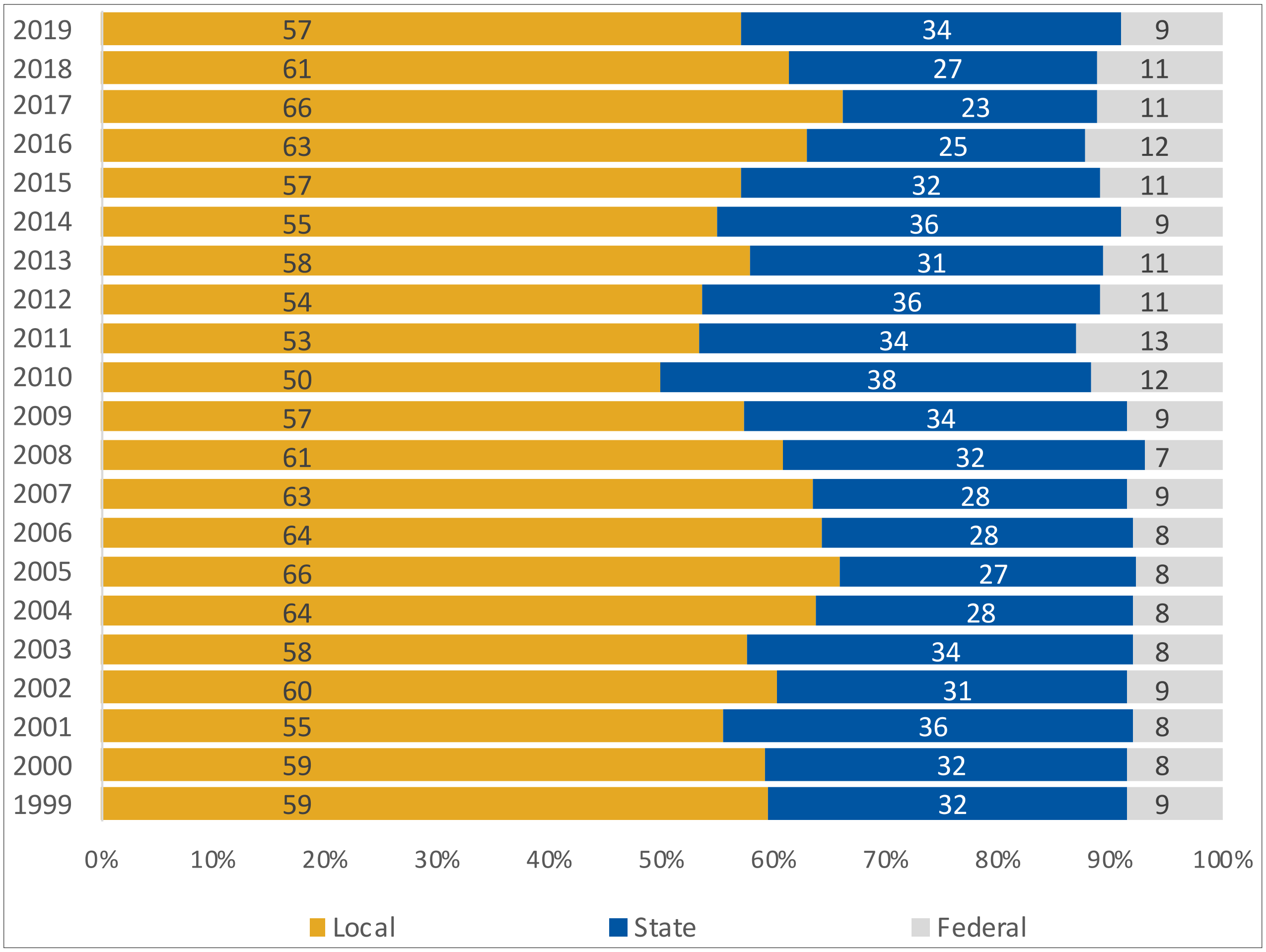
Sources: California State Controller's Office, "California State Controller's Office Local Government Financial Data," accessed May 26, 2020, https://bythenumbers.sco.ca.gov/; California State Controller's Office, "Streets and Roads Annual Report Publications," accessed May 26, 2020, https://sco.ca.gov/ard_locrep_streets.html; *CoinNews Media LLC,* "US Inflation Calculator," accessed May 26, 2020, https://www.usinflationcalculator.com/.

Figure 2. Billions of 2020 Dollars Available for Roads and Streets, by Level of Government, 1999–2019



Sources: "California State Controller's Office Local Government Financial Data," California State Controller's Office, accessed May 26, 2020, https://bythenumbers.sco.ca.gov/; "Streets and Roads Annual Report Publications," California State Controller's Office, https://sco.ca.gov/ard_locrep_streets.html.

Figure 3. Percent of Revenue for Roads and Streets Provided by Each Level of Government, 1999–2019



Sources: California State Controller's Office, "California State Controller's Office Local Government Financial Data," https://bythenumbers.sco.ca.gov/; California State Controller's Office, "Streets and Roads Annual Report Publications," May 26, 2020, https://sco.ca.gov/ard_locrep_streets.html.

Local government revenue sources have consistently provided the majority of funds for streets and roads. Local contributions ranged from one-half to two-thirds of total annual revenue. In nominal dollar terms, the local contribution has, for the most part, steadily increased since 1999. In 1999, locals were generating $2.3 billion annually, but by 2019 they were contributing $5.1 billion. The one exception to this steady increase occurred during the years of the Great Recession, from late 2007 through mid-2009. During this period, local contributions for roads and streets fell sharply, in great part due to reduced sales revenues.

The relative contribution from state sources has fluctuated throughout the twenty years, ranging from 23% to 38% of total revenue. The nominal dollar value over that same period ranged from a low of $1.26 billion in 1999 to a high of $2.99 billion in 2019. Between 2014 and 2017, state transportation revenue fell notably, a slide that was reversed with the passage of Senate Bill 1 (SB1): The Road Repair and Accountability Act. SB1 raised fuel tax rates and imposed new annual vehicle registration fees. Collectively, these taxes and fees are projected to raise $54 billion over a decade, with half going to cities and counties.[19] The impact of SB1 has been immediate, as Figure 1 shows; the state contribution grew from

$1.55 billion in 2017 to $2.09 billion in 2018, a 74% increase. The upward trend continued in 2019, to over $3 billion.

The federal contribution to funding California's streets and roads has been modest throughout the two decades, fluctuating between 7% and 13%. In nominal dollar terms, the federal government contributed $0.34 billion in 1999, with revenues growing more or less steadily to $0.81 billion in 2019. During this period, there was one larger jump in expenditures in 2009 and 2010, when additional federal funds were disbursed to states through the American Recovery and Reinvestment Act.[20]

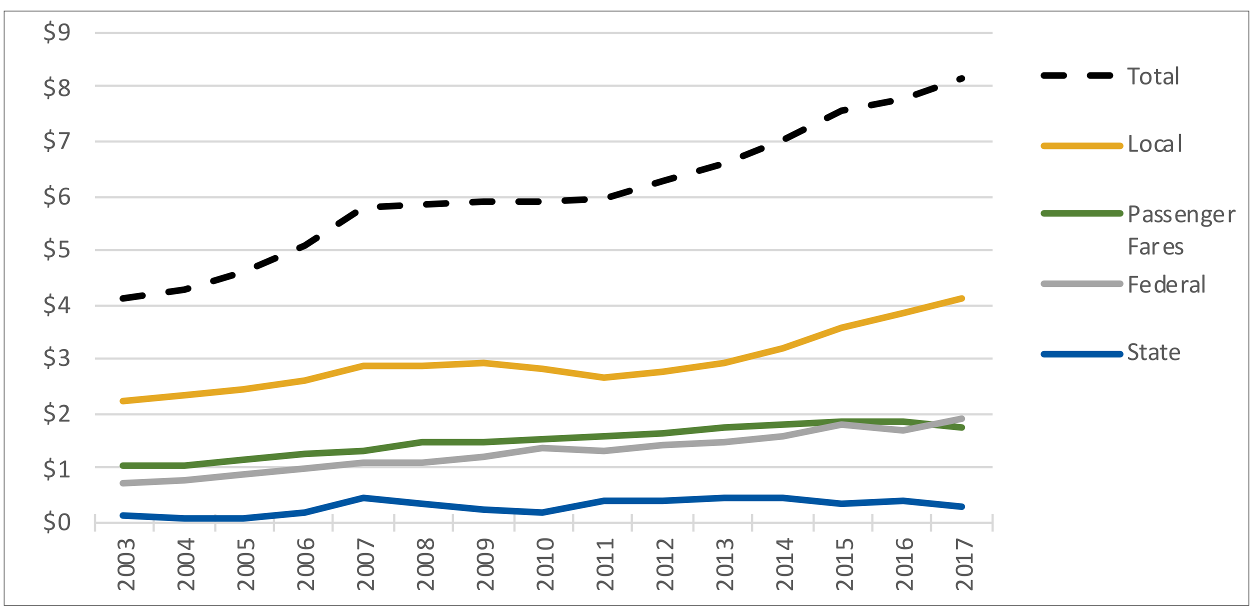
2.5. PUBLIC TRANSIT: LOCAL, STATE, AND FEDERAL CONTRIBUTIONS

Figures 4, 5, and 6 present data on the sources of revenue for California's public transit operators from 2003 to 2017. Figure 4 shows the nominal value of revenue raised by each level of government, as well as from passenger fares, and Figure 5 shows the same data adjusted for inflation. Figure 6 shows the percent of total annual revenue contributed by each source. (Table A2, in Appendix A, presents the data used to construct the figures.)

Total revenue has grown from about $4 billion to $8 billion. Revenue from every level of government has grown slightly throughout the period, with the lowest increase in state funds.

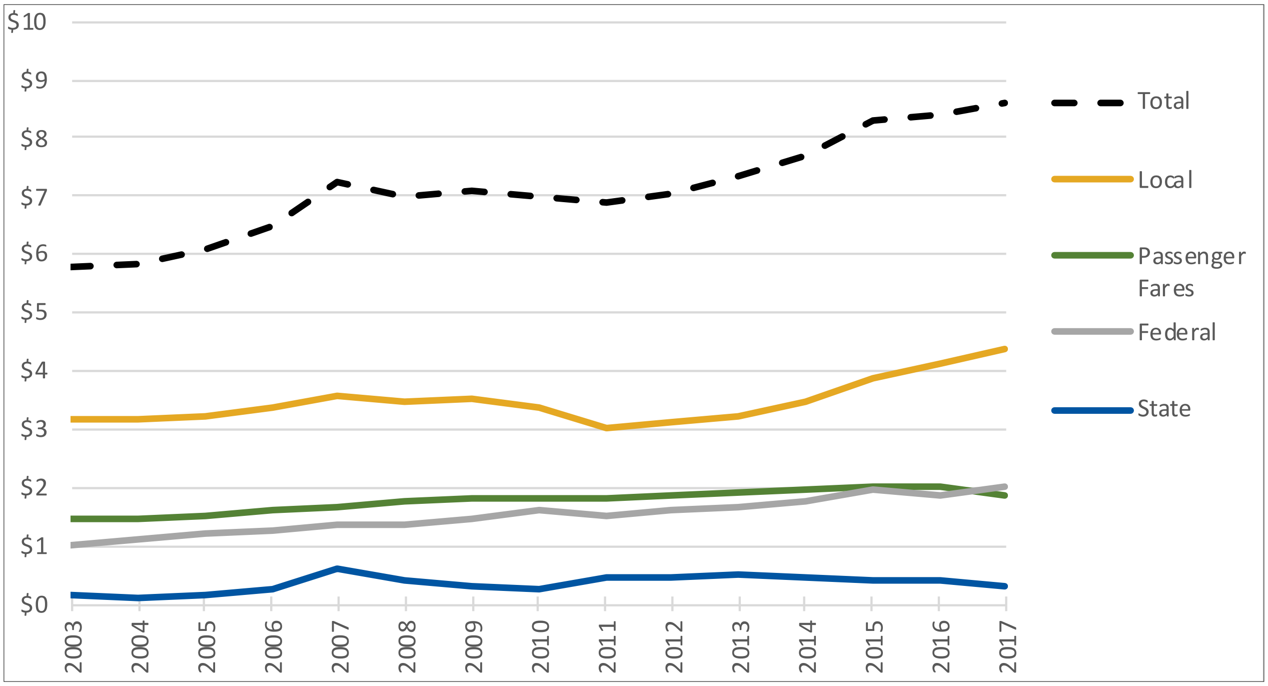
The relative size of the contributions each source makes to the total revenue has changed little over time. The local contribution has been the largest, hovering around 50%. Passenger fares have raised roughly a quarter of revenues, federal revenues have hovered around 20%, and the state's contribution has been the smallest, providing from between just 2% and 8% of annual revenues.

Figure 4. Billions of Nominal Dollars Available for Public Transit, by Level of Government and By Fares, 2003–2017



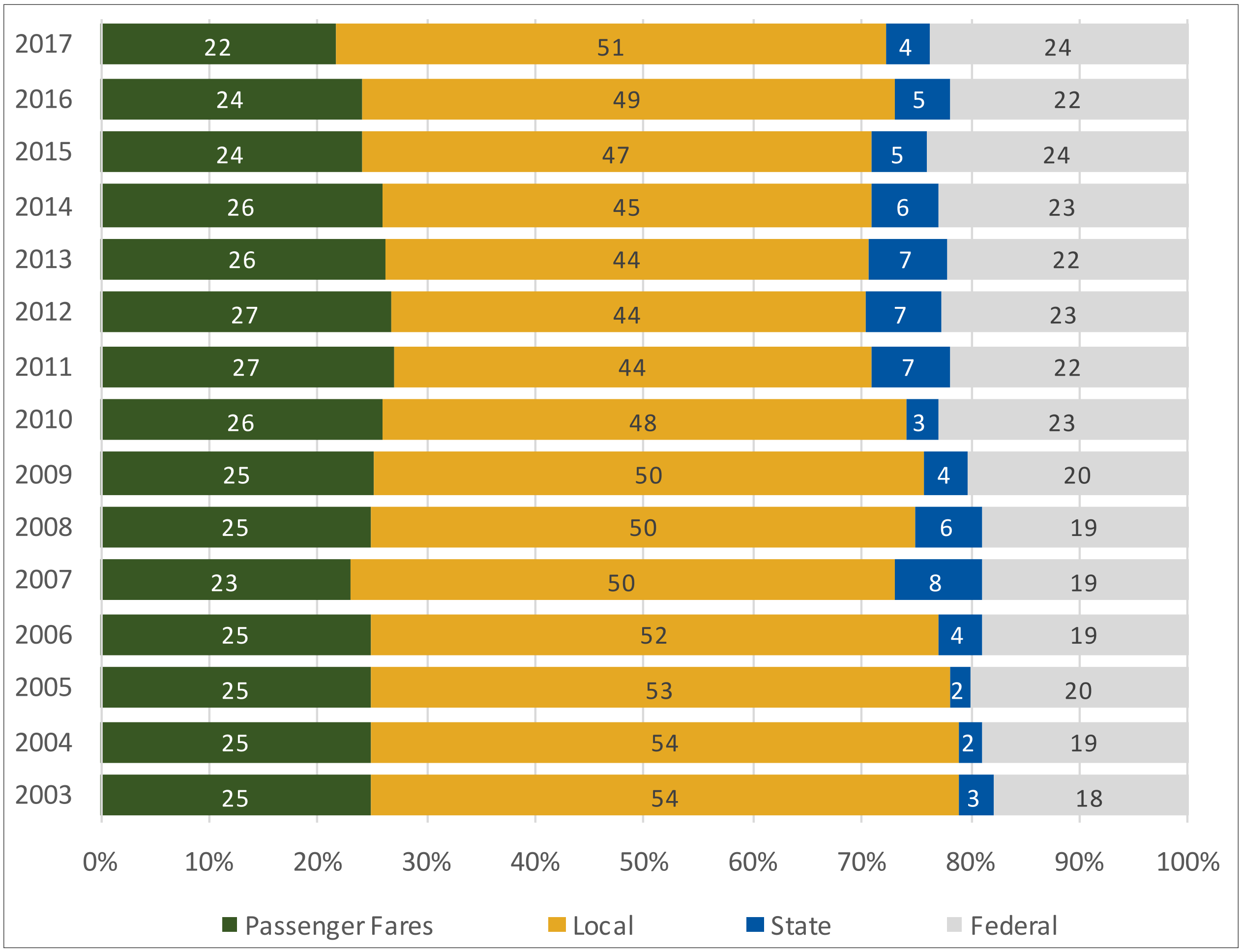
Source: California Transit Association, "Transit Data: An Interactive Repository of Facts and Figures on California Public Transit," 2021, https://caltransit.org/about/transit-data/.

Figure 5. Billions of 2020 Dollars Available for Public Transit, by Level of Government and by Fares, 2003–2017



Source: California Transit Association, “Transit Data: An Interactive Repository of Facts and Figures on California Public Transit,” 2021, https://caltransit.org/about/transit-data/.

Figure 6. Percent of Revenue for Public Transit in Provided by Each Level of Government and By Fares, 2003–2017



Source: California Transit Association, "Transit Data: An Interactive Repository of Facts and Figures on California Public Transit," 2021, https://caltransit.org/about/transit-data/.

3. FEDERAL REVENUE SOURCES

This chapter describes the main federal sources of revenue that fund the Highway Trust Fund (HTF), the principal source of federal transportation revenue.[21] The HTF is composed of two sub-accounts: the Highway Account, which funds highways and bridges, and the Mass Transit Account, which funds capital expenditures for public transit such as bus, rail, and ferry systems. Funds provided by the federal government are distributed to individual states, largely based on allocation formulas established by legislation.

The HTF has traditionally been funded through excise taxes imposed on the sale of gasoline and diesel motor fuels, sales of truck, trailers, and truck tires, and an annual weight fee on heavy vehicles. Taxes on fuels account for more than 80% net total deposits.[22] Since 2008, the federal government has transferred general fund revenue to the HTF to main solvency. These transfers have filled the gap between the amounts allocated and tax revenue collected.[23]

3.1. MOTOR FUEL EXCISE TAX

Tax base:	Gallons of motor fuel
Rate:	18.4 cents per gallon (gasoline); 24.4 cents per gallon (diesel); separate rates for special fuels
Total revenue (national):	$37.7 billion (FY 2019)[24]
Revenue restricted to:	Highway Trust Fund

3.2. HEAVY TRUCK AND TRAILER SALES TAX

Tax base:	Sales of trucks over 33,000 pounds and trailers over 26,000 pounds
Rate:	12%
Total revenue (national):	$5.33 billion (FY 2019)[25]
Revenue restricted to:	Highway Trust Fund

3.3. EXCISE TAX ON HEAVY-DUTY TIRE SALES

Tax base:	Sales of tires for trucks rated with a maximum load capacity of over 3,500 pounds[26]
Rate:	9.45 cents per 10 pounds of tire
Total revenue:	$5.34 million (FY 2019)[27]
Revenue restricted to:	Highway Trust Fund

3.4. HEAVY VEHICLE USE TAX

Tax base:	Trucks with a gross vehicle weight of over 55,000 pounds
Rate:	$100, plus $22 for every 1,000 pounds over the maximum vehicle weight (annual)
Total revenue:	$1.29 billion (FY 2019)[28]
Revenue restricted to:	Highway Trust Fund

4. STATE REVENUE SOURCES

This chapter presents those state taxes and fees for which some portion of the revenue is dedicated for local transportation purposes. Excluded are two major categories of fees paid by transportation system users that are not allocated directly for local transportation purposes: the Vehicle License Fee (VLF) and the state's base vehicle registration fees. Revenue from the VLF is deposited in the state's general fund, and a portion is transferred to local governments as general fund revenue. As for the base vehicle registration fees, revenue from these primarily funds the California Department of Motor Vehicles (DMV) and California Highway Patrol (CHP).[29] Although both the DMV and CHP obviously provide services to transportation system users, neither agency has traditionally been considered part of the state's "transportation" expenditures.

The state relies heavily on user fees to pay for transportation, a trend that has held for over a century. In 1913, California introduced its first such tax, the Motor Vehicle Act of 1913. This act created an annual vehicle registration fee, with the rate varying according to engine horsepower. This new tax was designed to be a "user fee" that drivers paid, and the revenue was dedicated to pay off bonds issued to pay for construction of a planned 3,000-mile state highway system that had been legislatively authorized a decade earlier, in 1901. A weight-based annual registration fee on heavy commercial vehicles was adopted shortly after, in 1915. Less than a decade later, the 1923 California Vehicle Act imposed a two-cent per gallon tax on gasoline fuels.

Since those early days, the state has periodically adjusted the rates of these taxes and added other transportation user fees, including an annual vehicle license fee assessed as a percent of the vehicle's market value (seen as analogous to the property tax on land) and an excise tax on diesel fuel.[30] The most recent major change took place in 2017, when SB1 raised fuel excise tax rates and added two new annual vehicle fees whose proceeds are spent on transportation functions, including at the local level.[31] As discussed in the previous chapter, SB1 proved a watershed moment for local transportation, more than doubling state contributions.

4.1. GASOLINE MOTOR FUEL EXCISE TAX

Tax base:	Gallons of gasoline fuel (excludes gasoline used for off-highway vehicles such as agricultural vehicles and boats)
Rate:	$0.511 (a base excise of 19.2¢ per gallon + an incremental "swap" tax + an SB1 tax (SB1 rates to be adjusted annually, per SB1)[32]
Total revenue:	$6.43 billion (FY 2018–2019)[33]
Revenue restricted to:	State highways, local streets, local roads

4.2. DIESEL MOTOR FUEL EXCISE TAX

Tax base:	Gallons of diesel fuel
Rate:	$0.389 per gallon (as of July 2021)[34]
Total revenue:	$1.16 billion (FY 2018–2019)[35]
Revenue restricted to:	Public transit operations and capital projects, high-speed rail development, road maintenance and rehabilitation, highway construction and improvements, and freight infrastructure improvements via various state funds.[36]

4.3. SALES TAX ON DIESEL FUEL

Tax base:	Sales of diesel fuel
Rate:	5.75%
Total revenue:	$0.90 billion (estimate for 2019)[37]
Revenue restricted to:	Public transit operations

4.4. TRANSPORTATION IMPROVEMENT FEE

Fee base:	Registered light-duty vehicles
Rate:	Currently $27–$188, depending on vehicle value (SB1 directs the state to adjust the fee in accordance with the Consumer Price Index[38]
Total revenue:	$1.67 billion (FY 2018–2019)[39]
Revenue restricted to:	Streets and roads, highways, and public transit

4.5. ROAD IMPROVEMENT FEE

Fee base:	Light-duty, zero-emission vehicles (e.g., electric vehicles) of model years 2020 and later*
Rate:	$100 annually (rate to increase, per SB1)
Total revenue:	$0.02 billion (2020, estimated)[40]
Revenue restricted to:	Road maintenance and rehabilitation

4.6. VEHICLE WEIGHT FEE

Fee base:	Commercial vehicles
Rate:	Ranges from $8–$539 for light-weight trucks, vans, and pickups with unladen weight of 8,000 lbs., charters and carriers with declared gross vehicle weight of <10,000 lbs., and park trailers. Fees are based on unladen weight, number of axles, and electric vehicle designation. Ranges from $332–$2,064 for commercial vehicles that weigh 10,001 lbs. or more and pay the Commercial Vehicle Registration Act of 2001 (CVRA) fees; the rates are based on a weight code and range.[41]
Total revenue:	$1.2 billion (FY 2019–2020, forecasted)[42]
Revenue restricted to:	Debt repayments (through the Transportation Debt Service Fund), mostly for bonds from Proposition 1B (2006) and Proposition 1A (2008)

4.7. BRADLEY-BURNS UNIFORM LOCAL SALES AND USE TAX

Tax base:	Sales of merchandise
Rate:	1.25%[43]
Total revenue:	$9.1 billion in total, with $314 million dedicated to local transportation projects (FY 2018–2019)[44]
Revenue restricted to:	County transportation needs[45]

4.8. CAP AND TRADE PROGRAM

Source of revenue:	Allowances (permits) for metric tons of carbon dioxide equivalent emissions
Price per allowance:	Determined each year by auction
Total revenue:	$0.15 billion for the Low-Carbon Transit Operations program and $0.29 billion for the Transit and Intercity Rail Capital Program (FY 2018–2019)[46]
Revenue restricted to:	Auction proceeds are deposited in the Greenhouse Gas Reduction Fund, which funds a variety of programs, following requirements set out in a series of statutes. Current investment categories that support local transportation are the Transit and Intercity Rail Capital Program and Low Carbon Transit Operations Program. The program also funds other transportation programs, including high-speed rail and clean vehicle technology.[47]

5. LOCAL REVENUES: CITIES, COUNTIES, AND SPECIAL DISTRICTS

This chapter describes the revenue instruments that California's local governments commonly use to raise dedicated transportation revenue. The specific package of measures varies greatly among the state's hundreds of local jurisdictions. There are currently 482 incorporated cities, 58 counties, 68 transit operations, 49 transportation planning districts, and dozens of other special districts in California that are all responsible for some set of transportation infrastructure and services within their jurisdictions.[48]

Although local entities are required to provide most of the transportation services within their jurisdictions—and must balance their budgets annually—the state imposes numerous restrictions on local entities' ability to impose taxes and fees. A 2016 guide to the state's local government finance system summarizes these limitations as follows:

- Property taxes may not be increased except with a two-thirds vote to fund a general obligation bond.
- The allocation of local property tax among a county, and cities, special districts and school districts within each county is controlled by the Legislature.
- Voter approval is required prior to enacting, increasing, or extending any type of local tax.
- Assessments to pay for public facilities that benefit real property require property owner approval.
- Fees for the use of local agency facilities and for services may not exceed the reasonable cost of providing those facilities and services.
- Fees for services such as water, sewer, and trash collection are subject to property owner majority protest.[49]

This chapter describes the different tax and fee options most commonly used to fund surface transportation, including details on key legislative restrictions and one or more examples of California local entities using the tax. For a few tax types we also provide an estimate of annual revenue raised state-wide, but in most cases that information is not available.

5.1. LOCAL-OPTION SALES TAX

Tax base:	Sales of merchandise
Rate:	Maximum 2% rate of combined taxes in any county, or more with state legislative authorization[50]
Total revenue:	County taxes: $8.71 billion (FY 2018–2019)[51]; total state revenue from local option taxes

Transportation-specific local-option sales taxes (LOSTs) serve as a primary revenue source for numerous counties, as well as some special districts operating transit services.[52]

Legislative Authority: The state permits counties and cities to impose local sales taxes, but only under a set of strict condition. To enact a sales and use tax, the proposal must first be approved by a two-thirds majority of the board of supervisors for a county or a two-thirds majority of the governing body of a city. It must then be approved by simple majority (50%) of voters for a general tax measure or by a two-thirds majority for a specific tax, such as a LOST. The law requires that an expenditure plan be created for any tax enacted and that the tax rate be set at a multiple of 0.25%.[53] The statutory maximum of a combined transaction and use tax rate in any California county is limited to two percent.[54]

Permitted Expenditures: Local sales tax revenue can be used for a variety of purposes, but there is a higher legal barrier for special purpose taxes. For sales tax measures that contribute to a local government's general fund, the measure requires a simple majority (50%) to pass. However, a supermajority (two-thirds) is required to approve a sales tax measures where the local government will earmark revenue for specific purposes, such as transportation projects.

Example: In 2016, the Santa Clara Valley Transportation Authority placed Measure B on the ballot, asking voters to approve a 0.5% sales tax to fund transportation-related projects related to bicycle and pedestrian safety, public transit accessibility, and highway congestion. The measure was approved by nearly 72% of the voters, exceeding the supermajority threshold required for transportation-specific sales tax proposals.[55]

5.2. COUNTY TRANSPORTATION PROJECT FEE (VEHICLE REGISTRATION FEE)

Fee base:	Registered vehicles within a participating county
Rate:	$10 per vehicle

Counties may partner with the DMV to collect a $10 County Transportation Project Fee (CTPF) in conjunction with collection of the state's vehicle registration fees. Currently, five counties in the San Francisco Bay Area collect a CTPF.[56] The revenue is spent on local transportation programs.

Table 3. California Counties with a CTPF Registration Charge

County	Legislation	Revenue/year (estimated)	Spending purposes	Eff. date
Alameda	Measure F	$11 million	Local road improvement, traffic congestion relief, local transportation technology, and pedestrian and bike safety	5/2/11
Marin	Measure B	$2.3 million	Local streets and pathways maintenance, senior and disabled persons transit, and congestion and pollution reduction	5/2/11
San Francisco	Proposition AA	$5 million	Street repair and reconstruction, pedestrian safety, transit reliability, and mobility improvements	5/2/11
San Mateo	Measure M	$6.7 million	Local streets and roads and county transportation programs	5/5/11
Santa Clara	Measure B	$14 million	Local transportation improvements, including pothole repair, paving, traffic control signals. Matching state/ federal funds	5/2/11

Sources: "Alameda County Transportation Improvement Measure Expenditure Plan," Alameda County Transportation Commission, published December 2018, https://www.alamedactc.org/wp-content/uploads/2018/12/VRF-Expenditure_Plan-1.pdf; "Measure B – Marin County Vehicle Registration Fee," Transportation Authority of Marin, published August 2017, https://www.tam.ca.gov/wp-content/uploads/2017/08/Measure-B-VehicleRegistrationFee.pdf; "Prop AA Vehicle Registration Fee," San Francisco County Transportation Authority, Accessed March 6, 2020, https://www.sfcta.org/funding/prop-aa-vehicle-registration-fee; "Measure M Implementation Plan," City/County Association of Governments of San Mateo County, Amended May 10, 2012, https://www.ccag.ca.gov/wp-content/uploads/2014/06/Measure-M-Implementation-Plan_May2012Amendment-FINAL.pdf; "2010 $10 Vehicle Registration Fee," Valley Transportation Authority, accessed March 6, 2020, https://www.vta.org/projects/funding/2010-10-vehicle-registration-fee.

Legislative Authority: The authority to impose a CTPF is granted through California Senate Bill 83, which was approved in 2009. County transportation agencies may impose a maximum $10 registration for transportation-related programs, subject to voter approval.[57] Typically special taxes require a supermajority for passage, but CTPFs only require a simple majority due to the provisions in SB83. A county transportation agency may directly coordinate with the Department of Motor Vehicles to set up a contract for the collection of a CTPF and is responsible for any initial program setup costs.

Permitted Expenditures: CTPF revenue must be spent for transportation projects within the taxing jurisdiction and the governing body of the county transportation agency must adopt an expenditure plan detailing how the revenue will be allocated.[58] Permitted transportation-related programs include congestion and pollution mitigation programs, and revenues may also be used to provide matching funds for programs funded by state obligation bonds.[59]

Example: San Mateo County adopted a County Transportation Project Fee in November of 2010 through Measure M, which went into effect in May 2011. In fiscal year 2018–2019, the county reported $7.8 million dollars of revenue collected from Measure M. After deducting administrative and DMV fees, the available revenue for transportation programs totaled $7.4 million dollars.[60]

5.3. PARKING FEES

Fee base:	Vehicle parking
Rate:	Various

A local authority may charge fees to users who park their vehicles on public property. Parking fees are often treated as a user tax, such as when motorists are charged for time spent at a curb space or parked in an off-street garage.

Legislative Authority: Under California Vehicle Code 22508(a), cities have the authority to establish parking meter zones by ordinance, which requires a majority vote by all members of the governing body.

Permitted Expenditures: Revenue is typically deposited in the agency's general fund and may be spent for any purpose.

5.4. TOLLS ON BRIDGES AND ROADS

Fee base:	Vehicle passage
Rate:	Charge per vehicle, with rate based on number of passengers, vehicle axles, and/or congestion patterns

Tolls are user fees charged to drivers for passage on roads, bridges, and highways. Toll facilities are typically operated by regional transportation agencies but must be approved through the California Transportation Commission (CTC) at the state level. Fees are collected via toll facilities or by electronic transponder and can be fixed or varied based on congestion patterns. California contains eight bridges with tolls (all located in Northern California) and several dedicated toll roads and express lanes across the state (see Table 4).

Table 4. Entities Operating Tolled Facilities in California

Governing authority	Facility	Pricing model
Los Angeles County Metropolitan Transportation Authority	10/110 Express Lanes	Variable based on traffic
San Diego Association of Governments	SR-125 South Bay Expressway	Fixed based on distance
San Diego Association of Governments	I-15 Expressway	Variable based on traffic and distance
Orange County Transportation Authority/Riverside County Transportation Commission	91 Express Lanes	Variable based on day, time of day, and direction
Santa Clara Valley Transportation Authority	SR-237 Express Lanes	Variable based on traffic
Alameda County Transportation Commission	I-580 Express Lanes	Variable based on traffic
Sunol Smart Carpool Lane Joint Powers Authority	I-680 Express Lanes	Variable based on traffic
Golden Gate Bridge, Highway and Transportation District	Golden Gate Bridge	Fixed pricing
Bay Area Toll Authority	Antioch, Benicia-Martinez, Carquinez, Dumbarton, San Mateo-Hayward, Richmond- San Rafael, San Francisco-Oakland Bay	Fixed pricing

Legislative Authority: Regional transportation agencies may apply to the California Transportation Commission (CTC) for permission to construct, operate, and maintain toll lanes or other toll facilities. Applications must satisfy several criteria, such as demonstration of improvements and completed funding plans. Agreements must also be made with the California Highway Patrol for law enforcement needs.

Assembly Bill 1467 was signed into law in 2006, allowing regional transportation agencies and Caltrans to apply for the development of high occupancy toll lanes in cooperation with the CTC. Assembly Bill 194, passed in 2015, allows the CTC to set the minimum standards for toll facilities operation and also removed earlier cap of no more than four approved toll facilities. AB194 also allows regional transportation agencies to issue bonds and use toll revenues to pay for the debts accrued from construction.[61]

Permitted Expenditures: Permitted expenditures are outlined in Assembly Bill 193 (Section 149.7, paragraph 4), which state that funds may be used for the operational costs of the toll facility including maintenance, repairs, improvements, and bond repayments. Revenue may also be used for transportation improvements within the corridor, as outlined in an expenditure plan.

***Examples**:* The largest of California's tolling entities, the Bay Area Toll Authority (BATA), collected $724.9 million in fiscal year 2019.[62] To provide additional context for revenues generated by various tolling agencies, toll revenues from LA Metro's ExpressLanes program totaled $62.8 million,[63] while the Golden Gate Bridge, Highway and Transportation District raised $152 million the same fiscal year.[64] At the lower end of the spectrum, the Santa Clara Valley Transportation Authority generated $1.31 million from its toll roads (FY 2019).[65]

5.5. DEVELOPMENT IMPACT MITIGATION FEES

Fee base:	New development
Rate:	Flat fee, determined through a nexus study

Development impact mitigation fees are assessed and charged by local agencies to offset the costs of infrastructure and facilities used for new development. In order to impose a development impact fee, local agencies must provide a nexus study to determine the relationship between the fee amount and the cost incurred through the use of public facilities to support the new development.[66]

Legislative Authority: Legislative authority to create and charge development impact fees is given to local agencies, defined as a county, city, charter city, school district, special district, and municipal public corporation as outlined in California Government Code 66000, also known as the Mitigation Fee Act.[67] Local agencies must satisfy a series of conditions before creating an impact development fee. These conditions include identifying the amount of the fee, identifying which facilities or capital improvements are to receive the revenue, determining the relationship between the fee's use and new development, and determining the relationship between the need for the public facility and the new development.[68]

Permitted Expenditures: The revenue is typically spent on infrastructure improvements to increase service capacity or improve road safety, where such changes are needed to accommodate new development. The specific permitted expenditures of development impact fees are provided in California Government Code 66002, which states that revenue may be used for "[t]ransportation and transit facilities, including but not limited to streets and supporting improvements, roads, overpasses, bridges, harbors, ports, airports, and related facilities."[69] The Mitigation Fee Act does not allow development impact fees to be used for funding existing infrastructure, unless for the purpose of upgrading a public facility to accommodate the additional service needs from new development.[70]

Examples: The City of Irvine, located in Orange County, is home to 280,000 residents. As part of a joint-powers agreement with the county and neighboring cities, Irvine imposes development fees on residential housing to fund transportation facilities within the San Joaquin Hills and Foothill/Eastern transportation corridors.[71] At a regional level, the Western Riverside Council of Governments manages the Transportation Uniform Mitigation Fee (TUMF) Program on behalf of Riverside County and those member cities and special districts that have opted into this regional development impact fee program. Since 2003, the TUMF Program has generated $897 million in revenue to support transportation improvements.[72]

5.6. REFUSE VEHICLE IMPACT FEE

Fee base:	Households receiving refuse services
Rate:	Annual fee charged to refuse collection operator

Refuse collection vehicles, more commonly known as garbage trucks, have significant impacts on local streets and roads due to their size and weight. Because of these impacts, local governments sometimes charge refuse collection companies a fee based on the calculated damage caused by their vehicles.

Legislative Authority: A local government's ability to impose regulatory fees, such as a refuse vehicle impact fee, falls under the police power of a city. According to Article XI, Section 7 of the California Constitution, a city "may enforce local, police, sanitary, and other ordinances and regulations not in conflict with general laws." Cities typically prepare a nexus study in the form of a report to estimate the amount of damage incurred by refuse collection vehicles. A city must hold a public hearing before adopting a new fee per California Government Code Section 66018.

Permitted Expenditures: The revenues generated by refuse vehicle impact fees is intended to pay costs associated with repairing and rehabilitating roadways damaged by heavy refuse vehicles.

Example: The City of San Ramon imposes a Refuse Vehicle Impact Fee through a franchise fee with Waste Management, the city's refuse collection service provider. Analysis by the City of San Ramon to justify its refuse vehicle impact fee concluded that refuse vehicles impose the same impact to pavement as over 9,000 sport utility vehicles.[73] This fee is passed onto residential customers in the form of their service bill. In fiscal year 2018–2019, the Refuse Vehicle Impact Fee generated $484,991.[74]

5.7. TRANSIT FARES

Fee base:	Public transit trips and passes
Rate:	Varies by transit operator

Transit fares are user fees that riders pay when using transportation services. Fares may be charged on a per-ride basis, or for daily, weekly, monthly, or annual passes.

Legislative Authority: Each transit operator sets its own fares, with no limitations imposed by the state.

Permitted Expenditures: Transit fares are used to cover transit agency expenses, without restriction.

5.8. PARCEL TAX

Tax base:	Parcels of real property (land)
Rate:	Either a flat rate per parcel or a variable rate that depends on the size or use of the parcel

Parcel taxes emerged as an alternative for generating revenue from property owners after voters in 1978 approved the constitutional amendment known as Proposition 13. Proposition 13 barred local governments from imposing their own value-based property taxes, with only minor exceptions. While property taxes are assessed against the value of a parcel, parcel taxes set rates that are assessed against some other characteristic of the property. The parcel tax can apply a flat rate to all parcels, or the rate may vary according to property characteristics such as lot size, use type, number of dwelling units, or square foot of development. Although most commonly used to fund school districts, parcel taxes play an important role for fire and police districts and can also be used to fund transportation infrastructure.

Legislative Authority*:* Parcel taxes were originally authorized in California Proposition 13 (1978). Since, a series of other propositions and court cases have further refined how these taxes must be approved and also imposed a requirement for supermajority approval from local voters. [75]

Permitted Expenditures: The revenue is earmarked for a specific purpose.[76]

Example*:* The Gilmore Vista County Service Area is a district located in El Dorado County. In March 2020, county supervisors placed on the ballot Measure J, to establish a parcel tax for that district. The measure passed with 72% approval.[77] Measure J imposes an annual $270 tax on improved parcels and a $120 tax on unimproved parcels within the district. It generates an estimated $11,550 per year for snow removal, road improvements, and maintenance services.[78]

5.9. TRANSIENT OCCUPANCY TAX

Tax base:	Room rentals in hotels, motels, or other related properties
Rate:	2%–15.5% (varies by jurisdiction)

The Transient Occupancy Tax (TOT), also known as the "hotel tax" or "bed tax," is a tax commonly charged as a percentage of rent on a transient user of a hotel, motel, or property shared through a room-sharing service such as Airbnb. A transient is defined as a person with a right to occupancy for a period of 30 calendar days or less.[79] The right to occupancy is established through reason of concession, permit, license, or another form of agreement.

Legislative Authority*:* The authority to impose a TOT comes from Section 7280 of the State of California Revenue and Taxation Code. Counties and cities can both enact a TOT.[80] The process to impose a TOT follows the same procedure as a local sales tax: a governing body must approve the measure and then place it on the ballot for voter approval. General fund TOTs require a simple majority, whereas special-purpose TOTs require a supermajority.

Permitted Expenditures: There are no restrictions on how general-purpose TOT revenue is spent. For special-purpose TOTs, an expenditure plan guides how revenue is spent.

Example: The City of Ojai, located in Ventura County, depends heavily on tourism as its main source of revenue.[81] In 2020, Ojai voters approved Measure C, which raised the TOT by 5%, from 10% to 15%. Measure C is expected to raise an additional $1.3 to $1.7 million dollars in revenue, according to the ballot measure text. Although Measure C revenue is deposited into the city's general fund, the city has declared street maintenance to be a priority project for Measure C funds.[82]

5.10. USER UTILITY TAX

Tax base:	Utility services
Rate:	0%–11%

A user utility tax (UUT) is a tax imposed on utility services such as electricity, gas, water, sewage, and telephone. Local governments determine the rate of taxation which is then collected by utility companies through normal billing procedures.[83]

Legislative Authority*:* User utility taxes can be imposed at either the city or county level.[84] These taxes also follow the legislative requirements outlined in Proposition 13 (1978) and Proposition 218 (1996), which requires that voters approve all taxes and charges to property owners.[85] The vast majority of existing UUTs are general taxes, but they may also be created as a special tax.

Permitted Expenditures: The permitted expenditures of user utility taxes are similar to those of local sales taxes: UUTs may be general fund revenue sources or earmarked for special purposes.

Example: The Isla Vista Community Services District, located in Santa Barbara County, provides and maintains public infrastructure within its boundaries. In 2018, the district proposed an 8% tax on gas, water, electricity, sewage, and garbage disposal utilities in their service district of 23,000 residents. Voters within the district overwhelmingly voted to pass Measure R-2018, with an 83% approval rate.[86] This district-level special tax is estimated to generate approximately $642,000 dollars per year, with a portion of the funds set aside for transportation improvements, including sidewalks and lighting.

5.11. TRANSPORTATION NETWORK COMPANY USER TAX

Tax base:	Ride-hailing trip fares
Rate:	Set by local governments

These taxes are imposed on trips provided by transportation networking companies (TNCs) such as the ride-hailing firms Uber and Lyft. The tax is assessed on the rider (customer), and the rate can be set as a percentage of the trip fee, as a flat fee on all trips, or as a fee whose rate varies with characteristics of the trip.

Legislative Authority*:* Although California state law largely prohibits local governments from imposing taxes directly on the TNCs or drivers, the state does not prohibit municipal governments from impose taxes on customers who take trips that originate or end within the city.[87] The legal basis for these taxes is similar to that permitting local governments to charge TOTs, parking fees, and utility taxes: charter cities may levy taxes so long as these are not preempted by state or federal law.[88] Despite the fact that state law did not preclude local TNC user taxes, in 2018 the State of California adopted A.B. 1184, which granted the City and County of San Francisco the right to tax TNC rides. However, a legal analysis suggests that A.B. 1184 was ultimately not required for San Francisco to adopt a TNC user tax.[89]

Permitted Expenditures: The revenue is either limited to a special purpose or deposited in the city's general fund, depending on the authorizing legislation.

Examples: In 2019, the voters of the city of San Francisco approved the state's first excise tax on trips provided by transportation network companies such as Lyft and Uber. The tax, which went into effect January 1, 2020, set a 1.5% tax on fares for shared rides and rides in zero-emission vehicles, and 3.25% tax on fares for private rides.[90] The tax is estimated raise $30 to $35 million dollars of annual revenue dedicated to public transportation, safety improvements, and traffic congestion reduction efforts.[91] The following year, voters in the City of Berkeley approved Measure GG, which imposed a TNC user tax on rides originating within the city. Measure GG set the rate as $0.50 for solo rides and $0.25 for shared rides.[92]

5.12. BUSINESS LICENSE TAX

Tax base:	Varies: gross receipts, employee headcount, square footage, etc.
Rate:	Set by local governments

Cities and counties may enact business license taxes for which they determine their own rate structure. Rate structures are commonly either a percentage of gross revenue or a flat rate structure, but other options include rates based on the number of employees or square footage.

Permitted Expenditures: Depending on the authorizing legislation, the revenue is either limited to a special purpose or deposited in the city's general fund.

Example*:* In 2019, the City of Mountain View implemented a new form of its "business registration and license tax," which assesses employers a fee based on the number of employees. The rate per employee rises according to company size. As of 2020, the rates ranged from $75 to $150 per person, with the rates to be adjusted annually for inflation.[93] The tax proceeds go to the city's general fund, but the Mountain View City Council passed a resolution pledging to dedicate 80% of the revenue for transportation infrastructure and services.[94]

5.13. ENHANCED INFRASTRUCTURE FINANCE DISTRICTS

Tax base:	Incremental growth in property value within the district
Rate:	N/A
Revenue restricted to:	Community infrastructure; permitted transportation uses include roads, parking facilities, and transit stations

Enhanced Infrastructure Finance Districts (EIFDs) are a tool that allows cities, counties, and special districts to capture incremental growth in property tax revenue within a designated district and dedicate that money for specified infrastructure uses. These districts therefore do not raise new revenue for the taxing jurisdiction, but they capture for a specific purpose revenue that would otherwise have flowed to the general funds of the taxing entity. EIFDs are a variety of Tax Increment Financing (TIF) district. They are governed by a board of local elected officials and community members living in the district.[95]

Legislative Authority: In 2014, California adopted Senate Bill (SB) 628, which established EIFDs as a tool to foster economic development. Subsequent legislation has expanded the purposes for which EIFD revenue may be spent, and to allow EIFDs to issue bonds.

Permitted Expenditures: Revenue must be spent on infrastructure improvements, including roads, public transit stations, and parking facilities.

Examples: In 2017, the City of West Sacramento created the first EIFD in the state. The district is located along the waterfront and covers approximately 25% of the city. Revenue obtained from the EIFD will be spent on a variety of community improvements. Over its lifetime, the district is predicted to generate $535 million (2017 equivalent dollars).[96] The City of La Verne created an EIFD to fund improvements around a planned light rail station. The district will spend the projected $33 million in revenue on a set of designated infrastructure projects that include street improvements, pedestrian connectivity, landscaping, and lighting.[97]

6. MOVING FORWARD: OPTIONS FOR RAISING LOCAL REVENUE

This chapter summarizes the taxes earmarked for transportation at each level of government, describes a number of tax and fee options for raising additional revenue, and concludes with recommendations for additional research.

6.1. A SUMMARY OF REVENUE EARMARKED FOR LOCAL TRANSPORTATION

This report has described the wide range of taxes and fees that raise revenue dedicated for California's local authorities to spend on transportation services and infrastructure. While a certain amount of unrestricted general fund revenue also supports local transportation, the great majority of revenue comes from taxes and fees that are legally or by resolution designated for transportation.

At the state and federal levels, the systems for raising transportation funding are moderately complex. Both entities rely on motor fuel taxes to raise the majority of the revenue they transfer to local entities for transportation expenses. The federal government supplements fuel tax revenue with taxes levied on the sales of heavy-duty vehicles and their tires, plus a weight-based annual fee on heavy-duty vehicles. Neither the specific taxes nor their rates have been adjusted in decades, though in recent years Congress has supplemented these taxes with general fund revenue. As for California, the state supplements motor fuel taxes with annual vehicle registration fees, a vehicle weight fee, a small portion of state sales tax revenue, and revenue raised through the state's cap and trade program. Unlike the federal government, the state has made a number of adjustments to its transportation taxes and fees in recent years. Most notably, the cap and trade program was launched in 2013, and in 2017 the legislature approved SB1, which raised the rates on motor fuel taxes and created two new annual vehicle registration fees.

If the state and federal pictures are moderate complex, the local system is diverse and byzantine. The only constants are that virtually all local entities receive at least a small amount of state and federal earmarked transportation revenue, and the great majority of residents live in communities that have voter-approved local sales taxes earmarked for transportation. (However, even if most residents live in a county with a local transportation sales tax, the same is not true for the majority of *road-miles* in the state, as few of California's rural counties have approved a sales tax.) Finally, virtually all public transit operations generate at least some fare revenue, which is directly used to support transportation.

Most jurisdictions augment federal, state, and local-option sales-tax funding with other taxes and fees. For some jurisdictions, the annual transportation budget may easily incorporate a dozen or more sources, including traffic impact fees on development, community service districts, an employee headcount tax, tolls, and refuse or construction vehicle impact fees.

6.2. LOOKING FORWARD: OPTIONS

As local and state leaders look to the future of local transportation revenue, there are a number of conceptual approaches to consider, as well as specific tax types. This section lays out a variety of options, organizing them by theme. Policymakers may ultimately conclude that many of these taxes and fees are neither desirable nor feasible in California, but considering such a wide variety of options can help policymakers to identify creative new revenue sources that can meet the needs of the state's diverse local jurisdictions.

Raise the rates on existing taxes and fees already earmarked for transportation. This approach will likely be more effective if used for taxes and fees imposed on a broad base, such as motor fuel and sales taxes.

Raise the rates on taxes charged to transportation system users where the revenue is not currently earmarked for transportation and earmark the incremental new revenue for transportation. Parking and traffic citation fees are one such option. Many urban jurisdictions rely on this revenue as a key source of unrestricted general funds, so simply earmarking existing fee proceeds is unlikely to be realistic. However, some urban communities are considering variable parking rates as a congestion management strategy, and part of such a plan could include earmarking a portion of the incremental revenue for improvements to non-driving modes of transportation. Another example would be to add a supplementary sales tax to vehicle purchases and designate the revenue for transportation purposes. For example, in 1989, the State of North Carolina introduced a "Highway Use Tax" of 3% of the purchase price for any vehicle. The money is deposited into the state's Highway Trust Fund and can be used only for transportation purposes. As of 2020, Highway Use Tax revenues make up 54% of the North Carolina Department of Transportation's revenues.[98]

Charge a tax on vehicle-based services that have expanded exponentially in recent years. Two examples of these services are ride-hailing and e-commerce delivery. The private companies running these services rely on public infrastructure to generate their profits, and they also impose costs on the road system, especially in congested areas. Communities may wish to tax some portion of the value that these firms generate, and earmark that revenue for transportation. A few cities have already done this with ride-hailing trips—San Francisco, Berkeley, Chicago, and New York are among them—but most California cities have not.[99]

California local governments do not currently tax e-commerce deliveries, although a few have internally discussed the option. Legislators in both North Carolina and New York State have proposed this type of fee. In December 2020, a New York State Assembly bill was introduced that would have authorized New York City to assess a fee of $3 per box on e-commerce deliveries, with the revenue to be dedicated to the Metropolitan Transportation Authority. The bill would reduce the impact of the fee on low-income residents by waiving the charge on deliveries of food or medical supplies, among other provisions.[100] In 2021, the North Carolina FIRST Commission released a report that proposed a "Road Impact Fee" on e-commerce deliveries. The fee rate would be structured to match existing sales tax rates of 4.75% at the state level and 2.25% at the local level. The Commission's study estimated that this new fee would generate roughly $890 million over ten years.[101]

Adopt a mileage fee to replace or augment motor fuel taxes. Mileage fees, also known as road-user charges or vehicle miles traveled (VMT) fees, are distance-based charges. They are widely considered to be a promising alternative to motor fuel taxes, since the latter will become less effective as a growing share of the fleet becomes highly fuel efficient or uses no motor fuel at all.[102] To date, mileage fees are under study in dozens of states, and small programs have been implemented in Oregon and Utah. The State of California is currently engaged in its second mileage fee pilot program.[103]

While research and pilots to date have primarily examined mileage fees as a state or federal revenue tool, it is theoretically possible to layer local charges on top of those systems. For example, if the State of California were to collect a mileage fee using a technology that records the location of travel, then the state could permit local governments to charge additional fees for travel within their jurisdictions as a whole, on certain facilities, or at certain times of day.

Local motor fuel taxes have set a precedent for the idea of local mileage fees. Currently, over a dozen states permit cities or counties to adopt a local motor fuel tax,[104] and new taxes have been imposed as recently as 2020. For example, in 2020 the voters of Missoula County, Montana, adopted a $0.02-per-gallon local option gasoline tax. Missoula is the first county in Montana to have taken advantage of this option, even though state lawmakers passed authorizing legislation in 1979.[105] Also in 2020, the city council of Fairbanks, Alaska, passed a gas tax in the form of a 5-cent excise tax on wholesale transactions of gasoline.[106] Finally, Virginia's transportation districts benefit from a tax placed on every gallon of gas and diesel fuel sold within a county or city belonging to a transportation district. The rate is 2.1% of the statewide average distributors' price of fuel, and revenues are earmarked for commuter rail services and transit authority capital projects and operations.[107]

Although no California municipality has ever collected a local gasoline tax, voters have approved one such tax. In 1980, just over 50% of voters in the City of San Francisco approved a one-cent-per-gallon local gasoline tax. Ultimately, however, the city never attempted to implement the measure because of legal uncertainty over whether state law would require a simple majority or two-thirds majority to approve such a tax.

Another variation on mileage fees would charge different rates for different types of vehicles, such as a lower rate for less polluting vehicles or a higher rate for heavy vehicles that impose more roadway damage. Precedent for the idea of charging heavy vehicles by the mile comes from other states that impose weight-distance fees on heavy vehicles. Variants on this tax are found in New York, Kentucky, Oregon, and New Mexico. For example, Oregon collects a weight-mile tax on heavy vehicles over 26,000 pounds, in lieu of a motor fuel tax.[108] New Mexico assesses a "trip tax": a fee collected on commercial vehicles not registered in the state that are used for the transportation of persons, property, or merchandise within the state. The trip tax is collected at the various entry ports of the state and revenues are placed into the Road Fund for maintenance and repair costs of the state's public highways.[109]

Tax the electricity used to fuel vehicles. As more and more vehicles rely on electricity, it may become realistic to impose a tax on the electricity they use. Such a tax could be couched as a direct substitute for the fuel taxes paid by internal combustion vehicles.

Although such an e-fuel tax does not exist in the United States, Minnesota legislators have introduced a bill for a so-called “electric fuel tax” that would charge 5.1 cents per kilowatt hour of fuel used to charge an electric vehicle.[110]

Charge property owners monthly “utility” fees for roadway services. Transportation utility fees (TUFs) assess a monthly fee on commercial and residential property occupants, using the proceeds to pay for local streets and roads. A study from 2016 identified 34 cities that impose TUFs. Cities establish the rates in a variety of ways, including a flat rate for all property occupants and rate-scales based on estimated trips generated by the property.[111]

Tax utilities that embed infrastructure in or along roadways. In Virginia, public right-of-way use fees are fees imposed on consumers for cables that provide communication services. For the counties of Arlington and Henrico, which opted to keep jurisdiction over their roads in 1932, 10% of these use fees must be applied to transportation system maintenance and construction.[112] In Florida, HB 7175 was passed by the Florida legislature in 2014 which allows the Department of Transportation to earn revenue from leasing department-owned land for the operation of wireless telecommunication facilities. Proceeds from these lease agreements are placed into the State Transportation Trust Fund.[113]

Given that local entities have such varied infrastructure and services, travel patterns, and tax bases, state policymakers may wish to take the approach of permitting—and encouraging—an expanded range of revenue tools from which local entities pick and choose. For example, a county with a small population but large volumes of heavy-vehicle through traffic might be interested in a tax or fee that raises money from those system users to compensate for wear and tear on pavement. In contrast, a dense urban area might be more interested in a tax on e-commerce deliveries or tolling, and residential suburban communities might gravitate towards some sort of fee or tax assessed on properties.

6.3. STRATEGIES FOR IDENTIFYING THE BEST OPTIONS

Local entities have shown great creativity in raising revenue dedicated for transportation and, as necessity arises, they will continue to do so. However, a well-reasoned and deliberative process conducted state-wide would help elected leaders make wise choices about the most appropriate tax and fee options for their communities.

One value of such a process would be to assemble the data, legal and technical analyses, and stakeholder perspectives needed to assess which options would fare well across a range of criteria, such as:[114]

1. **Revenue generation:** How much revenue will the tax or fee raise, and how stable and predictable will the revenue stream be over time?

2. **Ease of implementation:** What is the cost and complexity of implementing the tax or fee? For example, can the state modify existing tax administration processes, or would it be necessary to create new and complex structures?

3. **Political feasibility:** To what extent will elected officials, stakeholder groups, and

the general public support the tax or fee?

4. **Equity:** Who will directly and indirectly bear the cost of paying the tax or fee, and who will receive the benefits of the expenditures?

5. **Transportation system performance:** Does the tax or fee change the way people use the transportation system in a way that improves or worsens performance?

6. **Impact on larger policy goals:** Will the payment of the tax or fee, as well as expenditure of the revenue, impact public policy goals beyond the transportation system, such as reducing the threat of climate change or improving social equity, public health, or economic strength?

While the implications for each of the six criteria will vary somewhat from place to place, it would be more efficient to have a single entity collect relevant information and develop appropriate analytic tools to assess the taxes and fees. This framework would provide a basis from which both the State of California itself and local entities could develop their own expanded analysis.

As one contribution towards this goal, the authors will publish a companion to this report that draws on the experience and insights from transportation experts across the state to identify promising transportation revenue strategies for California.

APPENDIX A: DETAILS ON REVENUE SOURCE BY LEVEL OF GOVERNMENT

This appendix presents additional detail about the revenue used to create the figures in Chapter 2. Table A1 presents data on local, state, and federal contributions to local streets and roads. Table A2 presents data on the proportion of transit operator revenue contributed by fares, local, state, and federal sources.

Table A1. Revenue Available for Roads and Streets, by Level of Government, 1999–2019 (Billions of Dollars/Percent of Total)

Year	Local	State	Federal
1999	$2.35 (60%)	$1.26 (32%)	$0.34 (8%)
2000	$2.48 (59%)	$1.36 (32%)	$0.36 (9%)
2001	$2.71 (56%)	$1.78 (36%)	$0.40 (8%)
2002	$2.97 (60%)	$1.53 (31%)	$0.42 (9%)
2003	$2.82 (58%)	$1.68 (34%)	$0.39 (8%)
2004	$3.13 (64%)	$1.40 (28%)	$0.39 (8%)
2005	$3.32 (66%)	$1.34 (27%)	$0.39 (7%)
2006	$3.71 (64%)	$1.61 (28%)	$0.45 (8%)
2007	$4.13 (63%)	$1.84 (28%)	$0.56 (9%)
2008	$4.34 (61%)	$2.29 (32%)	$0.49 (7%)
2009	$3.89 (57%)	$2.31 (34%)	$0.58 (9%)
2010	$3.34 (50%)	$2.57 (38%)	$0.79 (12%)
2011	$3.27 (53%)	$2.06 (34%)	$0.80 (13%)
2012	$3.36 (54%)	$2.23 (35%)	$0.68 (11%)
2013	$3.49 (58%)	$1.89 (31%)	$0.65 (11%)
2014	$3.73 (55%)	$2.45 (36%)	$0.62 (9%)
2015	$4.01 (57%)	$2.27 (32%)	$0.77 (11%)
2016	$4.41 (63%)	$1.74 (25%)	$0.85 (12%)
2017	$4.53 (66%)	$1.55 (23%)	$0.77 (11%)
2018	$4.66 (61%)	$2.09 (28%)	$0.86 (11%)
2019	$5.05 (57%)	$2.99 (34%)	$0.81 (9%)

Sources: Data for 1999 through 2017 is compiled from the California State Controller's Office's "Streets and Roads Annual Report Publications" 1999-2017 (https://sco.ca.gov/ard_locrep_streets.html); 2018 and 2019 data is from the "Streets – Revenues" and "Roads – Revenues" sections of the Local Government Financial Data portal (https://bythenumbers.sco.ca.gov/).

Table A2. Revenue Available for Public Transit, by Level of Government, 2003–2017

Year	Local	Passenger Fares	Federal	State	Total
2003	2,245,973,933	1,028,511,040	726,812,986	128,275,864	4,129,573,823
2004	2,326,184,293	1,064,565,725	805,351,703	75,956,864	4,272,058,585
2005	2,443,341,439	1,145,709,621	904,317,016	102,089,173	4,595,457,249
2006	2,630,752,453	1,249,186,718	975,928,594	208,560,833	5,064,428,598
2007	2,869,891,102	1,339,326,234	1,093,744,152	482,735,807	5,785,697,295
2008	2,899,313,757	1,454,894,488	1,124,387,513	354,078,027	5,832,673,785
2009	2,931,526,375	1,496,545,960	1,202,011,012	252,101,849	5,882,185,196
2010	2,841,529,760	1,515,534,684	1,352,635,070	197,054,421	5,906,753,935
2011	2,647,373,459	1,583,703,204	1,328,234,102	413,580,356	5,972,891,121
2012	2,754,473,441	1,658,400,523	1,410,075,649	428,474,717	6,251,424,330
2013	2,915,219,879	1,741,717,286	1,485,232,040	464,735,682	6,606,904,887
2014	3,197,884,039	1,800,219,157	1,606,831,165	433,265,405	7,038,199,766
2015	3,563,904,921	1,856,829,048	1,801,757,139	358,239,734	7,580,730,842
2016	3,834,744,879	1,865,318,560	1,710,446,804	389,132,098	7,799,642,341
2017	4,145,031,295	1,770,430,585	1,917,663,201	311,382,889	8,144,507,970

Source: California Transit Association, "Transit Data: An Interactive Repository of Facts and Figures on California Public Transit" (2021), https://caltransit.org/about/transit-data/.

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Tehama County

Agenda Request Form

File #: 26-0016 **Agenda Date:** 1/26/2026 **Agenda #:** 13.

Public Hearing: Unmet Transit Needs - Deputy Director Riske-Gomez

Requested Action(s)

a) Overview of Annual Unmet Transit Needs process

This step of today's agenda item is to provide a brief overview of the process and invite public comment regarding unmet transit needs. The Unmet Transit Needs process specifically excludes:

- Primary and secondary school transportation.
- Minor operational improvement or changes involving issues such as bus stops, schedules and minor route changes.
- Improvements funded or scheduled for implementation in the following fiscal year.

b) Open Unmet Transit Needs public hearing

This step of today's agenda item is to officially open the public hearing on unmet transit needs, providing an opportunity for stakeholders and community members to voice their concerns and suggestions related to local transit services.

c) Invite public comment on unmet transit needs

This step of today's agenda item invites members of the public to provide input regarding unmet transit needs. Comments should focus on gaps or deficiencies in the current transit system that prevent residents from accessing essential services or activities.

d) Close the public hearing and refer comments to the Social Services Transportation Advisory Council (SSTAC) for review

This step of today's agenda item is to formally close the public hearing on unmet transit needs. All comments received will be forwarded to the SSTAC for thorough review and consideration as part of the decision-making process.

Financial Impact:

None.

Background Information:

The annual unmet needs process and this public hearing are a requirement of the Transportation

Development Act (TDA). This process consists of the following steps:

1. The Transit Agency Board holds a public hearing to receive comments.

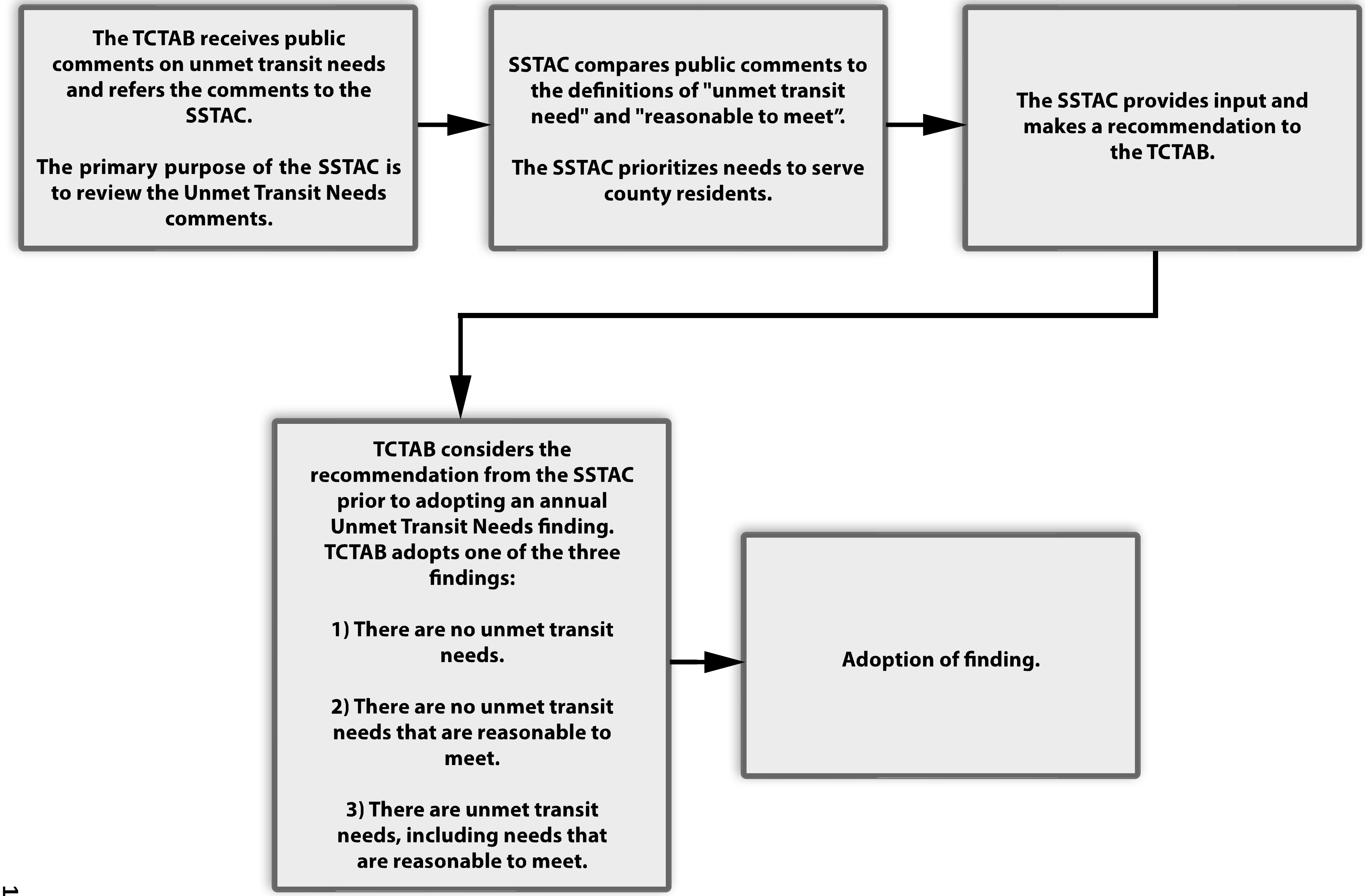
2. The Transit Agency Board of Directors refer public comments to the Social Services Transportation Advisory Council (SSTAC) for review.

3. Identify "unmet transit need" and "reasonable to meet" in order to develop a recommendation for SSTAC who compares the comments to the attached adopted definition for the Board.

4. The Transportation Commission considers the recommendation and then adopts a finding by resolution if transit needs that are 'determined to be reasonable to meet' are funded prior to allocating Local Transportation Funds (LTF) to local streets and roads.

Following today's hearing Senior Transportation Planner Fox will be returning to the February 23, 2026, Tehama County Transportation Commission meeting with a formal presentation of the SSTAC recommended findings and request for adoption.

Unmet Transit Needs Flow Chart



UNMET TRANSIT NEEDS PROCESS

TEHAMA COUNTY TRANSIT AGENCY BOARD

PUBLIC TRANSPORTATION FUNDING

- Fares bring in only 10-20% of operating expenses for public transit
- Money for operations and capital is primarily derived from ¼ of the 1% of fuel sales tax
  - **Local Transportation Funds (LTF) & State Transit Assistance (STA)**
- FTA Grant programs, such as Section **5310** (Enhanced Mobility of Seniors and Individuals with Disabilities) – Paratransit Services, and **5311**- Rural Transit, also provide funding to transit operators
- Coronavirus Aid, Relief, and Economic Security (CARES) Act provides emergency assistance and health care response for individuals, families and businesses affected by the COVID-19 pandemic. Staff will utilize this funding for operations, hazard pay and fare free service.

FUNDING DISTRIBUTION

- As the the advisory board to the Board of Supervisors, TCTAB staff manages transit funding dollars
- Distribution of funds is based on the population of the eligible claimant jurisdiction, i.e., the cities and the unincorporated areas of the county
- Urbanized areas, as defined by the latest Bureau of Census report, are used to determine required farebox recovery ratios
  - TCTAB is within a rural county and has adopted alternative measures, as we are allowed by code. Due to CARES Act funding, effective September 1, 2020, TRAX and ParaTRAX became fare free for the duration of the funding.

- The unmet transit needs process is an **annual review of transit needs of individuals or groups** within the region
- Public hearings are held on an annual basis to determine unmet needs and receive comments from the public
- Unmet transit need comments are also received and analyzed throughout the year
  - We collect surveys, emails, comments and recommendations throughout the year, which we keep on file to include in this process

OVERVIEW

- Requests for transit service must meet the adopted definition of an unmet need
- An unmet need exists if an individual of any age or physical condition is unable to transport himself or herself because of deficiencies in the existing transportation system

DEFINITION

EXCLUSIONS TO THE DEFINITION OF AN UNMET NEED

- Exclusions from the definition of an unmet need:
  - Those requests for *minor* operational improvements such as stops and minor route changes
  - Primary and Secondary educational transportation
  - Those improvements funded and *scheduled* for implementation in the following fiscal year

DETERMINING IF AN UNMET NEED IS REASONABLE TO MEET

- A transit need must pass the "reasonable to meet" definition
- Reasonable to meet is defined as:
  - **Operational Feasibility**:
    - The requested improvement **must be *safe*** *to operate* and there must be *adequate roadways for transit vehicles*
  - **Duplication of Service**:
    - The proposed service **shall not duplicate** other existing transit services
  - **Timing**:
    - The proposed service shall be in response to an **existing need, rather than future needs**

- Service must meet the legally required farebox ratio with fares close to fares of similar service
- A farebox recovery ratio of 10% for social service systems, 10% for rural systems, and 20% for urban systems. However, TCTAB has established alternative measures that better fit Tehama County.
  - Due to CARES Act funding, effective September 1, 2020, TRAX and ParaTRAX are **fare free** for the duration of the funding. The fare box revenue has been replaced with the federal funding.
- A detailed report shall be filed within 90 days after the end of the first fiscal year in which any extension of service is implemented and the associated costs are subject to exclusion from farebox ration recovery requirements.

DETERMINING IF AN UNMET NEED IS REASONABLE TO MEET

CHALLENGES OF FUNDING NEW TRANSIT SERVICE

- ***Safety*** of passengers, drivers, and vehicles is very important
- There is often no transportation sales tax ***money*** for new transit services
- ***Ridership*** on a new service could be insufficient to recover the mandated 10% farebox expense ratio or alternative
  - TCTAB has alternative measures, but they still need to be met

- Each fiscal year TCTAB must adopt one of the following findings:
  - There are no unmet transit needs
  - There are no unmet transit needs that are reasonable to meet
  - There are unmet transit needs, including those that are reasonable to meet

UNMET NEEDS PUBLIC HEARING PROCESS

UNMET NEEDS PUBLIC HEARING PROCESS

- Prior to the annual Unmet Needs hearing, each transit operator/claimant advertises and conducts a **public hearing**.
  - Today is the official public hearing
- The SSTAC submits an annual finding to the governing body after the public hearing and compiling public comment
- Following the hearings and **SSTAC recommendation**, TCTAB **adopts an unmet transit needs finding** by Resolution
- TCTAB staff is then tasked with carrying out findings (if any are identified)

QUESTIONS?

THANK YOU FOR YOUR FEEDBACK!

TEHAMA COUNTY TRANSPORTATION COMMISSION ADOPTED DEFINITIONS OF "UNMET TRANSIT NEEDS" & "REASONABLE TO MEET"
Adopted August 27, 2013

"UNMET TRANSIT NEEDS"

Those public transportation services that have not been funded or implemented but have been identified through public input, including the annual unmet transit needs public hearing, transit needs studies, and other methods approved with the commission.

Unmet transit needs specifically include:

- Public transit services not currently provided for persons who rely on public transit to reach employment or medical assistance, shop for food or clothing, or obtain social services such as health care, county welfare programs and educational programs.

- Trips requested by the transit dependent or transit disadvantaged persons, for which there is no other available means of transportation. Transit dependent or transit disadvantaged shall include, but not be limited to, the elderly, the disabled, and persons of limited means.

Unmet transit needs specifically excludes:

- Primary and secondary school transportation.
- Minor operational improvements or changes, involving issues such as bus stops, schedules and minor route changes.
- Improvements funded or scheduled for implementation in the following fiscal year.

"REASONABLE TO MEET"

The definition of Reasonable to Meet is based on the requirements of the Transportation Development Act (TDA). More specifically, those public transportation services that are Reasonable to Meet are those which meet the following criteria:

(1) Pursuant to the requirements of PUC Section 99401.5(c), a determination of needs that are reasonable to meet shall not be made by comparing unmet transit needs with the needs for streets and roads. The fact that an identified need cannot fully be met based on available resources shall not be the sole reason for finding that a transit need is not reasonable to meet.

(2) If projected cost per passenger by route and/or passenger per hour of the requested service are within 50% of current fiscal year averages. For example 2013 average cost per passenger by route is $12.00 and within 50% would be a cost per passenger by route of $18.00. Thus a new service that meets a cost per passenger by route of $18 is reasonable to meet. Also, in 2013 the average number of passengers per hour was 9 and within 50% would be 4 passengers per hour for a new service. Thus a new service that has 4 passengers per hour is reasonable to meet.

(3) If new service(s) do not meet the above-mentioned performance criteria within six months service may be terminated.

(4 Services which if implemented or funded, would not duplicate or replace existing services. The Commission may use the following as a determinant in the implementation of new services:

a. Forecast of anticipated ridership if service is provided
b. Estimate of capital and operating costs for the provision of such services.

(5) Services, which, if implemented or funded, would not cause the responsible operator to incur expenditures in excess of the maximum amount of:

a. Local Transportation Funds and State Transit Assistance Funds, which may be available for such operator to claim.
b. Federal Transportation Administration (FTA) Funds or other support for public transportation services which are committed by federal and/or state agencies by formula or tentative approval of specific grant requests.

(6) Opportunities for coordination among adjoining public entities or with private transportation providers and/or funding agencies. This should include consideration of other existing resources, as well as the legal or customary responsibilities of other entities (e.g., social services agencies, religious organizations, schools, carpools). Duplication of other services or resources is unnecessary and not a prudent use of public funds

If comment does not meet the definition of unmet transit need, no further review is needed.
If comment is an unmet need, ask if it is a reasonable need to meet.
Or refer comment to staff for cost analysis.

Public Comment for Review	**Does it meet definition of Unmet Transit Need (Yes, No)**	**Is need reasonable to meet? Yes, No, Refer to staff for cost analysis**	**Recommended Action From Executive Director**

LEGAL NOTICE

Notice of Public Hearing

NOTICE IS HEREBY GIVEN: that a Public Hearing for Unmet Transit Needs will be held Monday, January 27, 2025, at 8:45 AM in the Tehama County Board of Supervisors Chambers at 727 Oak Street, Red Bluff, California.

The Tehama County Transit Agency Board is inviting comments on Unmet Transit Needs (a transportation need that is currently not being met) that may exist within Tehama County. An Unmet Transit Needs survey may be found at www.taketrax.com or by calling (530)-602-8282.

If unable to attend the hearing on January 27, 2025, please email written comments to afox@tehamartpa.org or mail to TCTAB Staff at 1509 Schwab Street, Red Bluff CA, 96080.

For free transportation to the public hearing, please call (530) 385-2877.

Current transit information and schedules may be found at www.taketrax.com

By: Ashley Fox, Associate Transportation Planner

Publish:

AVISO LEGAL
Aviso de Audiencia Pública

CON ESTO SE DA NOTIFICACION: de la audiencia pública para las necesidades de tránsito que no se han cumplido tomara lugar el lunes, 27 de enero de 2025 a las 8:45 AM, en el cuarto de reuniones de la mesa de supervisores, 727 Oak Street, Red Bluff, California.

La Comisión de Transportación del Condado de Tehama está solicitando comentarios sobre las necesidades de tránsito sin cumplirse (las necesidades de transportación; que actualmente no han sido cumplidas) que puedan existir dentro del condado de Tehama. Puede encontrar una encuesta sobre Necesidades de Tránsito Sin Cumplirse en el sitio de internet www.taketrax.com o llamando al (530) 602-8282.

Si no puede asistir a la audiencia el 27 de enero de 2025 por favor envié sus comentarios por escrito al correo electrónico a afox@tehamartpa.org o por correo a TCTAB Staff al domicilio 1509 Schwab Street, Red Bluff CA, 96080.

Para un viaje gratuito a la audiencia por favor llame al (530) 385-2877.

La información de tránsito actual y los horarios se pueden encontrar en el sitio de internet www.taketrax.com.

Por: Ashley Fox, Planificador de Transporte Asociado

Publicar:

LEGAL NOTICE

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La informacion de transito actual y los horarios se pueden encontrar en el sitio de internet www.taketrax.com.

Por: Ashley Fox, Planificador de Transporte

Corning Observer
December 18 & 25, 2024 January 1, 8, 15 & 22, 2025
Ad#00304266

Order Receipt

Appeal-Democrat

1530 Ellis Lake Drive
Marysville, CA 95901

Phone: (530) 749-4700
Fax: (530) 749-8393
URL: www.appeal-democrat.com

Legal**
Tehama County Transportation Commission
1515 Schwab Street
Red Bluff, CA 96080

Acct #:	09116094
Phone:	(530) 385-1462
Date:	11/21/2024
Ad #:	00304266
Salesperson:	510
Ad Taker:	510

Class: 3300

Description	Start	Stop	Ins.	Amount
LEGAL NOTICE	12/18/2024	01/22/2025	12	665.50

Ad Text:

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Payment Reference:

Total:	665.50
Tax:	0.00
Net:	665.50
Prepaid:	0.00
Total Due	**665.50**

File #: 25-2115	Agenda Date: 1/26/2026	Agenda #: 14.

Watershed, Flood-Risk, and Infrastructure Assessment Coordination - Deputy Director Riske-Gomez

Requested Action(s)
Informational presentation on TCTC's ongoing coordination with Public Works - Flood Administration, the Resource Conservation District (RCD), and State and federal partners regarding watershed-driven transportation impacts and the development of a countywide infrastructure risk assessment.

Financial Impact:

None.

Background Information:

Over the past several years, Tehama County has experienced increasingly severe transportation impacts tied to storm events, altered watershed behavior, and accelerated geomorphic change. These impacts are no longer isolated maintenance issues; they reflect a systemic shift in how water, sediment, and debris move through our landscapes, influenced by post-fire conditions, invasive vegetation, agricultural grading, and over a century of controlled irrigation and flood manipulation.

Transportation impacts in Tehama County are no longer driven solely by storm intensity. Increasingly, they reflect the interaction between *anthropogenic modification and modern flooding dynamics*, the combined influence of altered floodplains, agricultural grading, regulated river systems, vegetation shifts, and post-fire watershed response. These factors shape how water and sediment move through the county today, producing failures that exceed the design expectations of legacy infrastructure.

The Reeds Creek Road Emergency Repair Project represented a turning point in our understanding of these risks. Repeated channel migration, debris loading, and sediment deposition led to major roadway failures and long-duration access disruptions. Reeds Creek made clear that watershed-scale processes, not local culvert conditions, now dictate the reliability of key transportation corridors.

Since then, multiple storm-driven failures across the county have confirmed that this is a countywide pattern, not a single-corridor anomaly. These events demonstrate how today's hydrology interacts with legacy infrastructure, historic land management, and increasingly volatile weather cycles. Even moderate storms are producing outsized impacts, overwhelming facilities designed for historic conditions and triggering failures in both valley-floor and foothill systems.

Since then, multiple verified storm-driven failures have highlighted the countywide nature of the risk:

Documented Transportation Infrastructure Failures

- **2019 - Squaw Hollow Creek @ Corning Road (Bridge Damage):**

Heavy rainfall on February 27, 2019 caused upstream bank erosion and damage to the wingwall and abutment, washing out the roadway and requiring emergency embankment reconstruction and rock slope protection.

- **January 2023 - Burch Creek (Bridge Collapse):**

Floodwaters caused Abutment 1 to fail, resulting in the collapse of Span 1 into the channel. Caltrans recommended immediate full closure, and the County closed the bridge for safety.

- **February 2025 - Kendrick Creek @ Newville Road (Bridge Closure):**

Following significant storm damage, the County formally closed the bridge due to structural deficiencies aggravated by high-flow events and erosion.

These events confirm that Tehama County is experiencing recurring, watershed-driven structural failures affecting roads, culverts, bridges, and embankments. Beyond the documented failures at Squaw Hollow Creek (2019), Burch Creek (2023), and Kendrick Creek (2025), Tehama County is experiencing broader watershed-driven degradation of transportation assets.

Recurrent storm events have produced bank failures at Woodson Bridge, overtopping at Elder Creek and Dibble Creek, high-velocity erosion along Antelope Creek, river migration impacts near Jelly's Ferry Road, and localized bridge and culvert vulnerabilities on rural facilities such as Cone Grove Road. These conditions illustrate a countywide pattern in which storm hydrology, sediment transport, and post-fire watershed changes are directly affecting roadways, embankments, and bridge structures.

Role of Non-Profits, County Departments and TCTC

While watershed processes fall within the technical expertise of Public Works - Flood Administration, their responsibilities apply specifically to County-owned flood management facilities and public infrastructure, not private lands. Partnering with the Resource Conservation District (RCD) allows the County to better engage private landowners and support collaborative, long-term watershed stewardship solutions that reduce downstream impacts on public roads and critical access corridors.

Because many watershed-driven impacts originate on private or upstream lands but ultimately manifest as failures on the transportation system, TCTC must participate directly. Transportation planning, interagency coordination, and long-range capital programming are core Commission responsibilities, and safe mobility and emergency access depend on understanding how these evolving watershed conditions interact with roads, bridges, culverts, and evacuation routes.

TCTC's role is therefore not to manage watersheds, but to ensure that transportation decision-making is aligned with hydrologic realities and that State, federal, and local partners are coordinated in developing durable, long-term solutions for the region.

State-Led Multi-Agency Technical Assessment

In response to Tehama County's request for assistance, Cal OES has convened a multi-agency team including:

- California Department of Water Resources (DWR)
- California Geological Survey (Department of Conservation)
- Caltrans Emergency Operations
- U.S. Army Corps of Engineers (technical coordination through Readiness Branch)
- Cal OES Inland Region
- Tehama County Public Works - Flood Administration
- Tehama County Resource Conservation District

This team will lead a comprehensive watershed and infrastructure vulnerability assessment, addressing:

- Post-fire hydrology
- Sediment transport and deposition patterns
- Channel migration and erosion risks
- Vulnerabilities in roadways, culverts, bridges, and river-adjacent facilities
- Prioritized mitigation and funding strategies

Tehama County is still awaiting determination regarding inclusion in the State disaster proclamation, which may further strengthen access to State and federal resources.

The first coordination meeting with the team was held the third week of December, with follow-up work commencing in early 2026.

Desired End Project Product Description: Tehama County Resilient Transportation Hazard Screening & Prioritization System

As we continue to face more frequent wildfires, flood events, debris-flow impacts, and drainage failures, it has become increasingly clear that Tehama County needs a consistent, data-driven way to evaluate risk across our entire transportation network. The end product we are working toward is a countywide, GIS-based hazard screening and prioritization system that will allow the Commission to clearly identify where our greatest vulnerabilities are, and which projects should rise to the top for funding, planning, and emergency preparedness.

What the System Will Provide

The ideal completed tool will give the Commission:

> A countywide map of transportation “hot spots,” areas where roads, culverts, or bridges are most at risk from post-fire debris flows, sediment bulking, flooding, riverbank erosion, or repeated storm failures. This information will be made available to first responders, emergency managers, public works crews, planners, and decision-makers so they can anticipate where failures are most likely to occur, stage resources appropriately, plan detours, and prioritize

mitigation actions before and after major events.

A defensible priority ranking of transportation assets, based on hazard, exposure, and consequence, allowing us to clearly identify tiers of project needs.

An interactive ArcGIS On-Line (AGOL) dashboard that Commissioners and partner agencies can view, showing risk levels at each site, the number of residents affected, detour distances, and whether a segment serves as an evacuation route or sole access point.

A repeatable workflow that can be updated after any future wildfire or storm event, ensuring the Commission has the most current information for disaster response, planning, and grant applications.

Why This Matters for the Region

This system will give us, for the first time, a unified, countywide picture of transportation vulnerability, grounded in the same scientific methods used by Cal OES, CGS, DWR, USGS, and Caltrans. It strengthens our ability to:

Prioritize limited transportation dollars
Build competitive, data-supported grant applications
Coordinate across agencies during emergencies
Plan long-range resilient infrastructure improvements beyond fire planning alone
Demonstrate clear need to state and federal partners

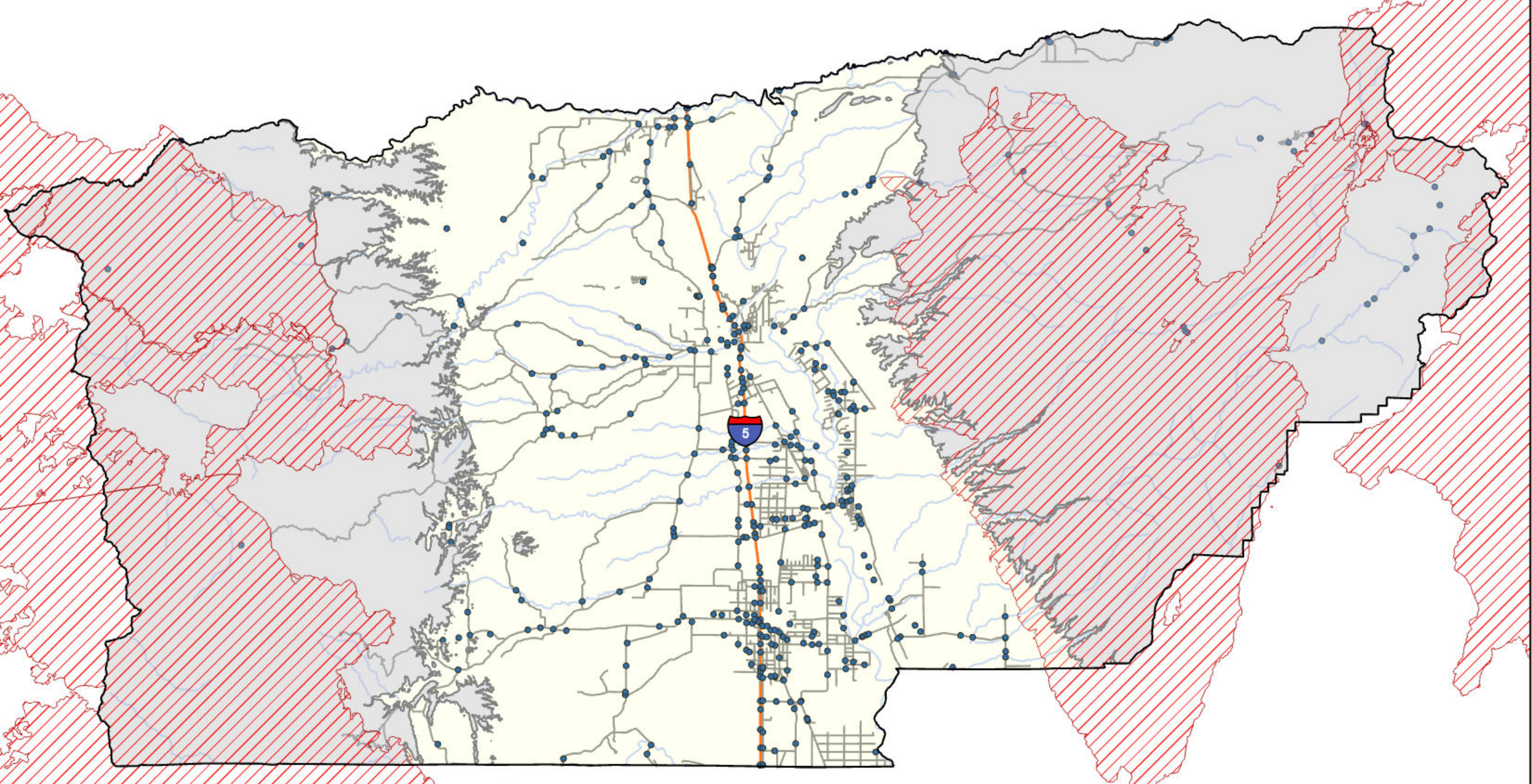
At the end of this effort, the Commission will have

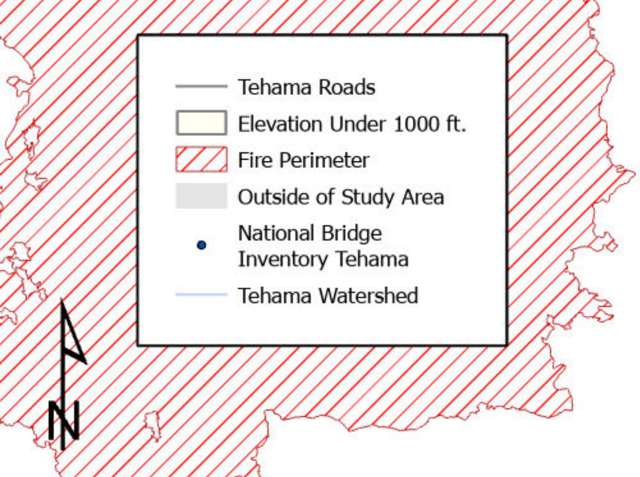
This effort is a natural continuation of the County's Secondary Access Planning work, expanding that same forward-looking approach into a comprehensive, countywide understanding of transportation vulnerability. The goal is to develop a single, authoritative tool that identifies our highest-risk transportation locations, ranks project needs, supports funding decisions, and provides a clear roadmap for improving safety and resilience throughout Tehama County.

The resulting system will not only highlight areas most at risk from post-fire debris flows, sediment bulking, flooding, river erosion, and repeated storm failures, but will also provide actionable information to first responders, emergency managers, public works crews, planners, and decision-makers. By knowing where failures are most likely to occur, agencies can proactively stage resources, plan detours, coordinate emergency response, and prioritize mitigation.

This tool will serve as a foundational component for future planning documents, resilience investments, and interagency coordination. It also positions the Commission to significantly enhance competitiveness for state and federal funding by demonstrating a clear, data-driven understanding of where infrastructure improvements are most urgently needed and how they support community safety, mobility, and emergency preparedness.

CRITICAL INFRASTRUCTURE AND COMMUNITY EXPOSURE BELOW 1,000 FEET – TEHAMA COUNTY





Study Area Description:

This map presents a preliminary study area (central white) focused on flood-prone infrastructure and watersheds in Tehama County below 1,000 feet in elevation. The area includes the low-lying Sacramento Valley floor, where recurring flooding and post-fire watershed impacts have affected key transportation routes and communities.

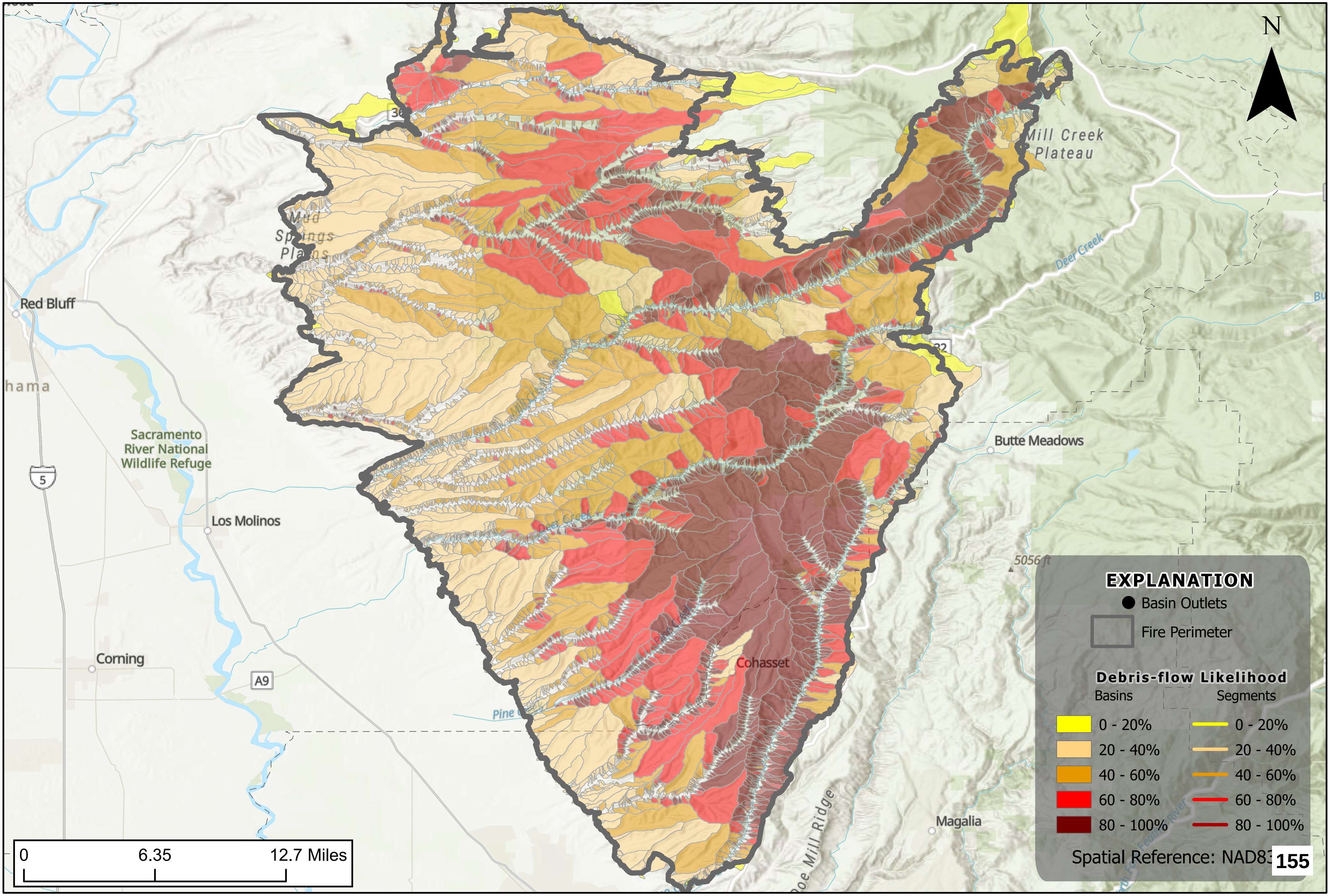
Priority focus is given to Interstate 5, Highways 99W and 99E, which serve as critical corridors for mobility, freight, and emergency response. These routes, along with surrounding rural road networks, face increasing flood risk where they intersect with degraded drainage systems and sediment-loaded waterways.

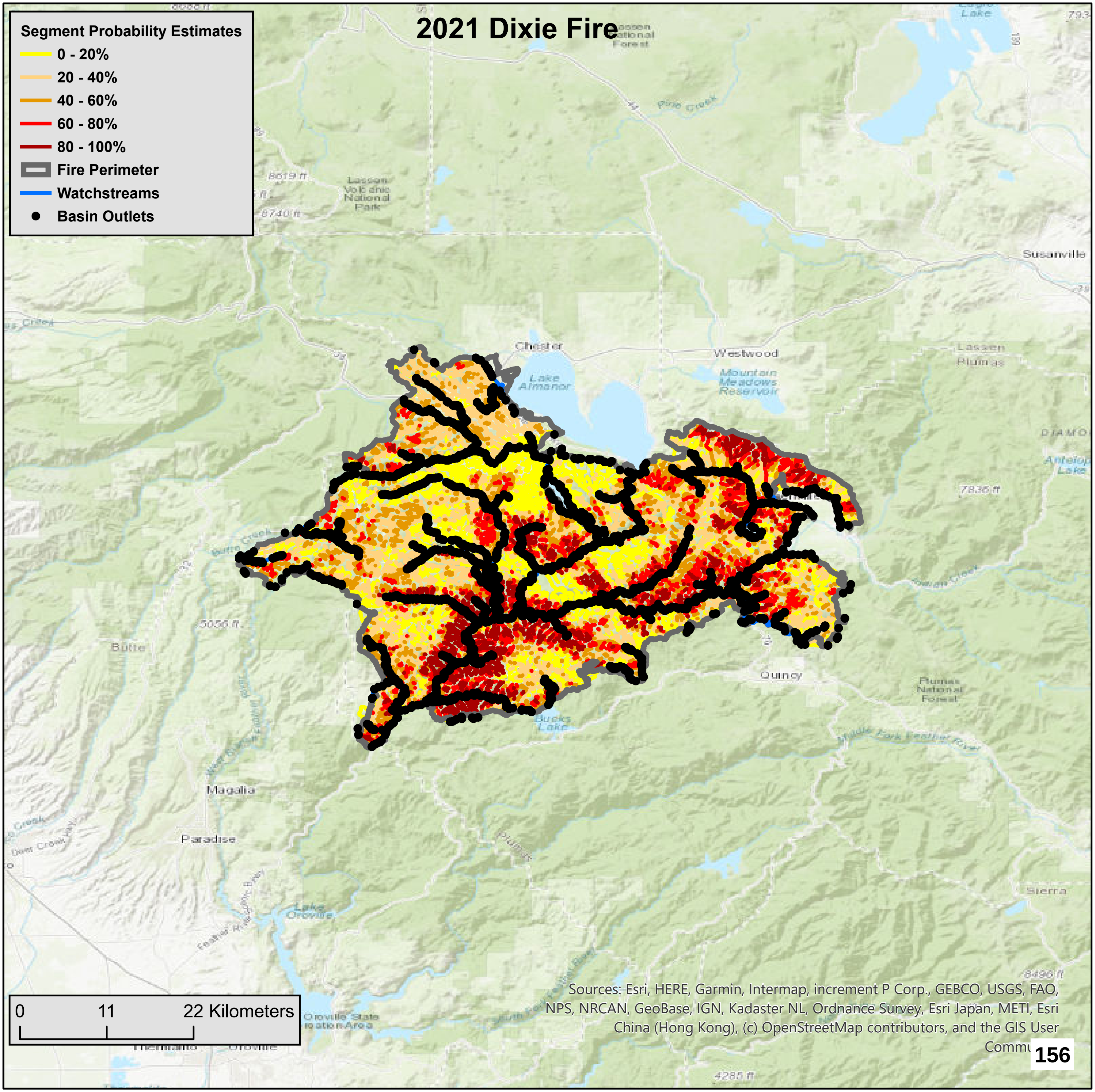
This map is intended as an initial planning tool to support early discussions with USACE. It identifies where infrastructure vulnerability and community access needs converge, and where technical assistance may be needed to support flood preparedness and long-term resilience.

Park Fire, Tehama and Butte Counties, CA, CA

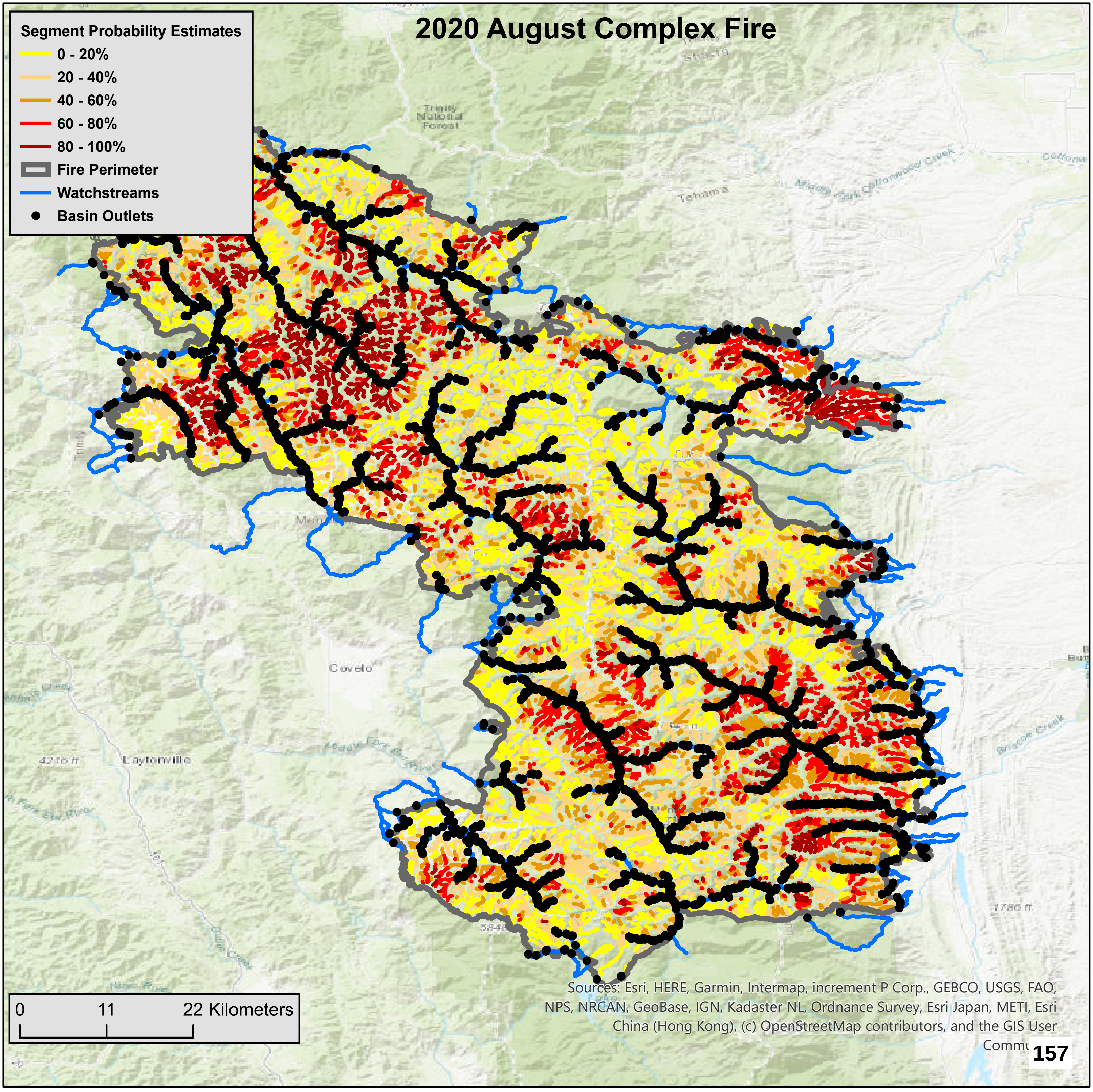
Debris-flow Likelihood

Design storm: Peak 15-minute rainfall intensity at 32mm/hour

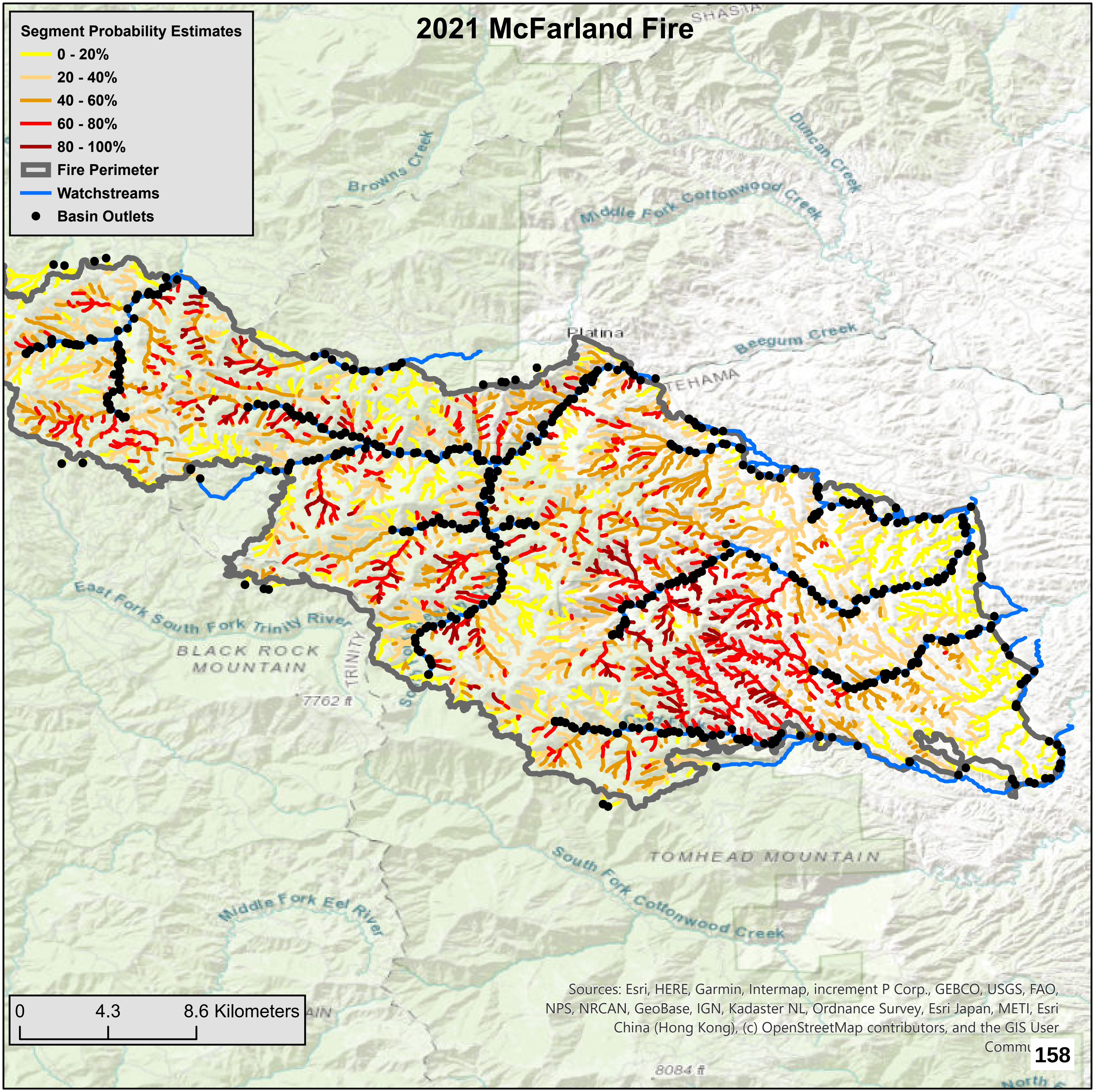




2021 Dixie Fire
Segment Probability Estimates
0 - 20%
20 - 40%
40 - 60%
60 - 80%
80 - 100%
Fire Perimeter
Watchstreams
Basin Outlets
0
11
22 Kilometers
Chester
Westwood
Lake Almanor
Mountain Meadows Reservoir
Susanville
Lassen Volcanic National Park
Quincy
Bucks Lake
Butte
Magalia
Paradise
Lake Oroville
Plumas National Forest
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Commu


2020 August Complex Fire
Segment Probability Estimates
0 - 20%
20 - 40%
40 - 60%
60 - 80%
80 - 100%
Fire Perimeter
Watchstreams
Basin Outlets
Trinity National Forest
Tehama
Middle Fork Cottonwood Creek
Covelo
Laytonville
4216 ft
1786 ft
0
11
22 Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Commu

2021 McFarland Fire



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International Journal of WILDLAND FIRE
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Predicting potential postfire debris-flow hazards across California prior to wildfire

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ABSTRACT

Background. Wildfires and consequent postfire hazards, specifically runoff-generated debris flows, are a major threat to California communities. **Aim.** To help prefire planning efforts across California, we identified areas that are most susceptible to postfire debris flows before fire occurs. **Methods.** We developed a calibration method for an established model that relates existing vegetation type to fire severity, a critical input to the US Geological Survey's postfire debris-flow likelihood model. We calibrated the model for eight regions with data from 81 wildfires that occurred in 2020 and 2021 in California. **Key results.** We predicted debris-flow likelihood, volume, and combined hazard classification, and created statewide maps that use simulated fire frequency and rainfall data to predict the probability that a basin will experience a wildfire and subsequent debris flow. **Conclusions.** We suggest that the model predictions are useful for identifying areas that pose the greatest risk of postfire debris-flow hazard for a simplified wildfire scenario. **Implications.** Although actual patterns of wildfire severity may vary from our simulated products, we show that applying a consistent methodology for all of California is useful for identifying areas that are likely to pose the greatest postfire hazards, which should help focus prefire mitigation efforts.

Keywords: annual probability of postfire debris flow, California wildfires, existing vegetation type, geohazards, postfire debris flows, prefire hazard mitigation, risk assessment, runoff-generated debris flow, simulated burn severity, simulated fire, statewide prefire planning.

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Introduction

Since the 1980s, California wildfires have increased in number, size, and severity, resulting in significant impacts to the environment, economy, and society (Li and Banerjee 2021). This is particularly evident in the past two decades where 18 of the 20 largest wildfires in California history have occurred since 2000, and where 15 of the 20 most costly and destructive fires to property in the state have occurred since 2015 (California Department of Forestry and Fire Protection 2024). Factors influencing the frequency, size, and destructiveness of wildfires include droughts and rising temperatures aggravated by climate change, as well as fire suppression, land management policies, and human encroachment into wildlands (Radeloff *et al.* 2018; Belongia *et al.* 2023).

One of the more impactful postfire hazards in California are runoff-generated debris flows that frequently occur within 3 years following fire and can damage ecosystems, critical infrastructure, and pose a risk to life safety within and downgradient of the burned area (e.g. Kean *et al.* 2019; Thomas *et al.* 2023; Zekkos and Stark 2023; Rundio *et al.* 2024; Swanson *et al.* 2024). Emergency managers, road and critical facility engineers, and flood control district officers are often challenged with little time to design and construct mitigation measures or develop and implement postfire response and evacuation plans

Collection: Establishing Directions in Postfire Debris-Flow Science

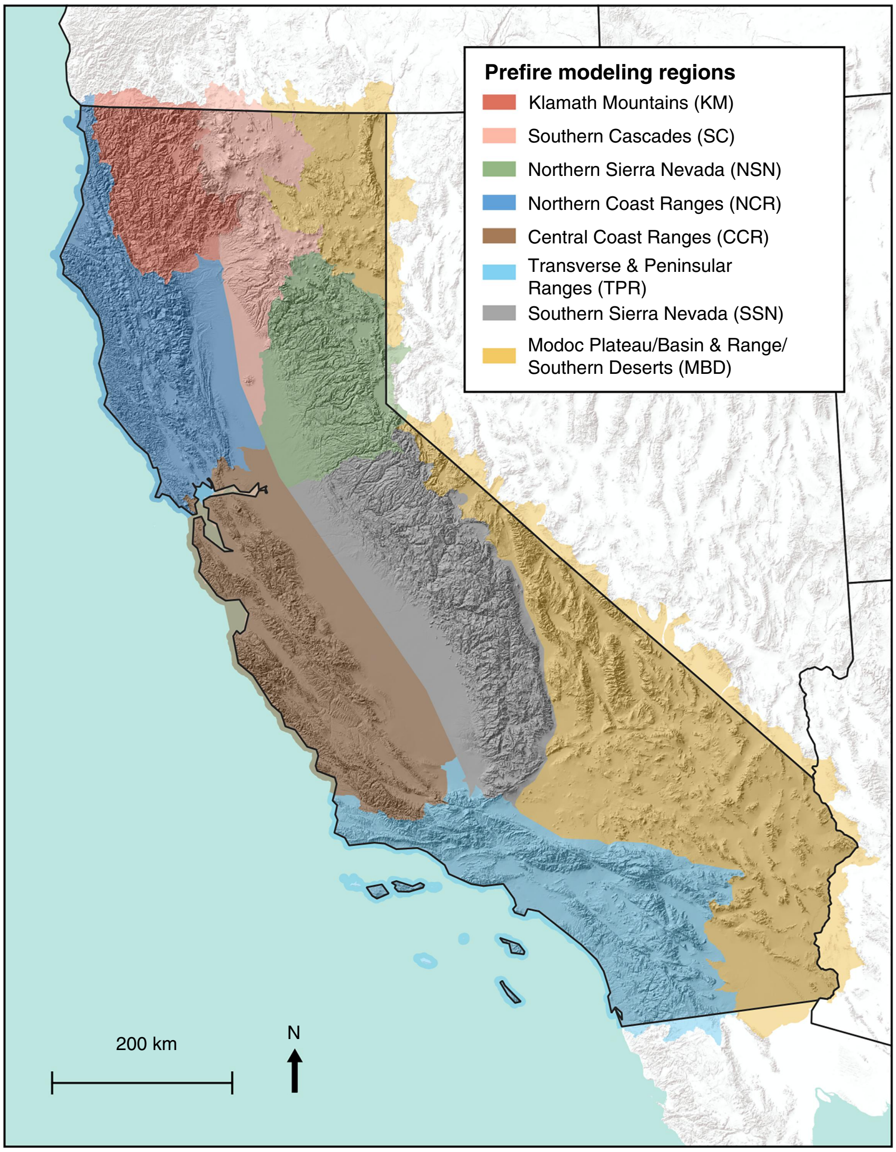

Fig. 1. Prefire modeling regions across California; outer region boundaries were adjusted to match the HU10 watershed boundaries and were split across the centerlines of large valleys.

between the fire and the first triggering rainstorm (Kean *et al.* 2019). Knowing the potential of postfire hazards under hypothetical burn scenarios can provide emergency managers, road and facility engineers, and flood control officers with information to better prepare for inevitable wildfires.

More advanced knowledge of wildfire effects and associated impacts across California is required to make informed decisions prior to fire and build additional resilience against postfire hazards under a changing climate (Kean and Staley 2021). To contribute to this effort, we developed a statewide map that predicts the spatial distribution of fire severity and runoff-generated postfire debris-flow hazards. Benefits of this statewide modeling and mapping effort include (1) an assessment of threats to downstream values at risk (e.g. homes, bridges, and other infrastructure) that can be used to prioritize fuels treatments, (2) readily available data and maps that can immediately inform active suppression operations and emergency response efforts, (3) information that local governments can apply in residential development plans, zoning maps, and local hazard mitigation plans, (4) data to identify additional resource needs and support funding opportunities from federal and state sources (e.g. grant funds), and (5) information to assist in identifying and designing potential mitigation measures to reduce downstream hazards.

Methods

Prefire modeling regions

Because fire behavior and severity vary across California (e.g. Parsons *et al.* 2010; Estes *et al.* 2017), we determined prefire modeling regions based upon patterns in fuels, topography, and climate. To account for differences in fuel type, we referred to the National Vegetation Classification Standard zones (US Forest Service 2009), which group existing vegetation types that co-occur within landscapes with similar climate, substrates, and ecological processes. To account for differences in topography, and other physiographic controls, we referred to a map of geomorphic provinces that are characterized by distinct geology, topography, and plant communities (California Geological Survey 1997). Once the initial regions were identified, their margins were further refined using the watershed hydrologic unit (HU10) boundaries within the Watershed Boundary Dataset (US Geological Survey 2024) and valley centerlines (Fig. 1).

Simulation of regional fire and burn severity for predicting postfire debris-flow hazards across California

As numerous factors affect fire behavior (e.g. van Mantgem *et al.* 2013; Zald and Dunn 2018), many of which cannot be estimated prior to fire, we simulated fire severity across each prefire modeling region using established relationships between observed existing vegetation type and the change in surface and subsurface organic matter composition (i.e. differenced Normalized Burn Ratio: dNBR; Staley *et al.* 2018; Kean and Staley 2021). Staley *et al.* (2018) developed a two-parameter Weibull cumulative distribution function (CDF) for 282 unique LandFire Existing Vegetation Type (EVT) classes present within 3163 historical burn areas across the western US using data available between 2001 and 2014 (LandFire 2022). To incorporate change in landcover across the state associated with disturbances since 2014, including wildfire, we created a map of the most recent EVT classes with established CDF parameters (Staley 2018). Where there were no data values or EVT classes present without corresponding CDF parameters, we back sampled from previous EVT datasets to assign EVT classes that closely matched observed conditions. This enabled us to create a continuous, statewide map of EVT data for which corresponding CDF parameters exist.

To simulate dNBR, we used the CDF parameters for each EVT class and the same parameters for each prefire region. The cumulative probability of the Weibull CDF at which fire severity is being simulated is represented by P_{dsim}. For example, entering the CDF at a P_{dsim} of 0.5 (50th percentile) describes the median fire severity for each EVT class; entering at a P_{dsim} of 0.9 (90th percentile) describes an abnormally high fire severity for that EVT class. We chose to calibrate the P_{dsim} parameter for each prefire region and two calibration approaches are described in the following section. These approaches do not capture variability due to local conditions (e.g. wind direction) but aim to represent potential regional outcomes based on historical burn severity observations. Simulated dNBR for each EVT class was estimated from Eqn 1 in Table 1. Lastly, the simulated dNBR map was classified into Burned Area Reflectance Classification (BARC) categories of unburned/very low, low, moderate, and high burn severity, as described in the next section.

To predict the debris-flow hazard within the first year following fire, the simulated dNBR and BARC maps, along with a fixed 15-min rainfall intensity (I_{15}) of 24 mm h^{-1}, were used as input variables in the US Geological Survey's (USGS) postfire debris-flow hazard assessment model equations for predicting debris-flow likelihood, volumes of sediment deposited by debris flows (herein referred to as 'volume'), and rainfall intensity-duration thresholds (Table 1). We used an I_{15} of 24 mm h^{-1}, as I_{15} is a better predictor of runoff-generated postfire debris-flow occurrence than rainfall intensities measured over longer durations (e.g. Kean *et al.* 2011; Staley *et al.* 2013; Thomas *et al.* 2023) and is also the rainfall intensity metric used in the volume model (Gartner *et al.* 2014). Furthermore, 24 mm h^{-1} is close to the mean and median I_{15} associated with a 1-year recurrence interval within our modeled area. Staley *et al.* (2020) show that postfire debris flows are most commonly triggered by the 1-year recurrence interval I_{15}. For this reason, the 24 mm h^{-1} rainfall intensity is frequently applied in USGS postfire debris-flow hazard assessments (e.g. Staley *et al.* 2017; Barnhart *et al.* 2021). We used a debris-flow likelihood value of 50% to solve for rainfall intensity-duration thresholds (Table 1).

Calibration methods

We considered two calibration methods, one focused on reproducing BARC maps (herein referred to as the 'BARC map calibration') whereas the other focused on reproducing the best match to the debris-flow likelihood results produced by the USGS debris-flow likelihood model using observed dNBR values (herein referred to as the 'DFL calibration'). We refer to the USGS debris-flow likelihood model results as 'observed' because the values are calculated from observed dNBR and observed BARC values from postfire satellite data. Each method used a fire calibration set composed of California wildfires in the Monitoring Trends in Burn Severity (MTBS) database for 2020 and 2021 that contain low-moderate BARC breaks and fire area above 10 km^2 (MTBS 2022; Fig. 2). We focused on low-moderate BARC breaks instead of moderate-high BARC breaks because the USGS debris-flow likelihood and volume models do not distinguish between moderate and high BARC values. We limited our calibration of P_{dsim} to these fires for several reasons, including (1) the distribution of fires included in the calibration set are spatially distributed across a wide range of physiographic regions; (2) the difference in mean MTBS burn severity in the calibration set is not statistically significant ($P = 0.26$) compared to the full set of fires in the MTBS dataset from 1984 to 2021; and (3) the unavailability of post-2021 MTBS data at the time of analysis. We calculated the median of the low-moderate BARC break values for the calibration fires for each prefire modeling region (Fig. 2) to generate regional BARC break values that were used to

Table 1. Summary of prefire simulated dNBR equation and USGS postfire debris-flow hazard models.

Name	Equation	Citation
Simulated differenced Normalized Burn Ratio (dNBR) for each Existing Vegetation Type (EVT) class (SimdNBR)	$\text{SimdNBR} = \lambda\,[-\ln(1-P_{dsim})]^{1/\kappa} \times 2000 - 1000$ (1) λ = best-fit scale parameter for each Weibull cumulative distribution function (CDF) κ = best-fit shape parameter for each Weibull CDF P_{dsim} = percentile of the Weibull CDF at which fire severity is being simulated	Staley *et al.* (2018)
Debris-flow likelihood (DFL)	$\text{DFL} = \exp(X)/(1+\exp(X))$ (2) $X = -3.63 + (0.41 \times X_1 \times R) + (0.67 \times X_2 \times R) + (0.7 \times X_3 \times R)$ X_1 = proportion of upslope basin area burned at high or moderate severity with gradient in excess of 23 degrees X_2 = average dNBR of upslope basin area divided by 1000 X_3 = soil erodibility index of the fine fraction of soils (i.e. Kf factor) R = 15-min rainfall accumulation (mm)	Staley *et al.* (2016)
Debris-flow volume (DFV, m^3)	$\text{DFV} = \exp(4.22 + 0.39 \times \text{sqrt}(I_{15}) + 0.36 \times \ln(\text{Bmh}) + 0.13 \times \text{sqrt}(\text{Relief}))$ (3) I_{15} = 15-min rainfall intensity (mm h^{-1}) Bmh = upslope basin area burned at high or moderate severity (km^2) Relief = upslope basin relief (m)	Gartner *et al.* (2014)
Rainfall intensity-duration threshold (T, mm h^{-1})	$T = (\ln(\text{DFL}/1-\text{DFL}) + 3.63)/((0.41 \times X_1) + (0.67 \times X_2) + (0.7 \times X_3))$ (4) DFL = likelihood value used for debris-flow threshold (i.e. DFL = 0.5) X_1 = proportion of upslope basin area burned at high or moderate severity with gradient in excess of 23 degrees X_2 = average dNBR of upslope area divided by 1000 X_3 = soil erodibility index of the fine fraction of soils (i.e. Kf factor)	Staley *et al.* (2017)

calculate the area burned at moderate and high severity. A calibrated P_{dsim} value was determined for each fire. The regional P_{dsim} value was calculated as the median of the P_{dsim} values for fires in the same region.

For the BARC map calibration, P_{dsim} was chosen to produce a combined moderate and high BARC area, produced from modeled dNBR values and regional BARC breaks, that is equal to or greater than the observed combined moderate and high BARC area. For the DFL calibration, P_{dsim} was calibrated to produce the lowest Root Mean Square Error (RMSE) for the simulated debris-flow likelihood and the observed debris-flow likelihood results. We use the observed MTBS dNBR values, fire-specific MTBS BARC breaks, and 15-min rainfall intensity of 24 mm h^{-1} for basins inside the fire perimeter as input to the USGS debris-flow likelihood model to calculate observed debris-flow likelihood results. These results were generated using the postfire debris-flow ('pfdf') Python library (King 2023). The DFL calibration procedure is summarized in a flowchart in Fig. 3. For the DFL calibration, basins with less than 75% of their area inside the fire perimeter or a median observed dNBR value below the fire-specific MTBS unburned-low BARC break were excluded from the calibration.

Calibration assessment

To assess which calibration approach produced better results, we compared the Nash-Sutcliffe Efficiency (NSE) for the two calibration approaches. NSE was calculated as:

$$1 - \frac{\sum_{i=1}^{n}(\text{DFL}_{obs}^{i} - \text{DFL}_{sim}^{i})^2}{\sum_{i=1}^{n}(\text{DFL}_{obs}^{i} - \overline{DFL_{obs}})^2} \quad (5)$$

where DFL_{obs} is the fire-wide mean observed debris-flow likelihood calculated from the USGS debris-flow likelihood model (Staley *et al.* 2016), DFL_{sim} is the fire-wide mean simulated debris-flow likelihood for the respective calibration approach, i represents each calibration fire, and n is the total number of calibration fires. Regional BARC breaks and regional P_{dsim} values were used for the simulated debris-flow likelihood model runs whereas observed MTBS BARC breaks were used for the observed debris-flow likelihood

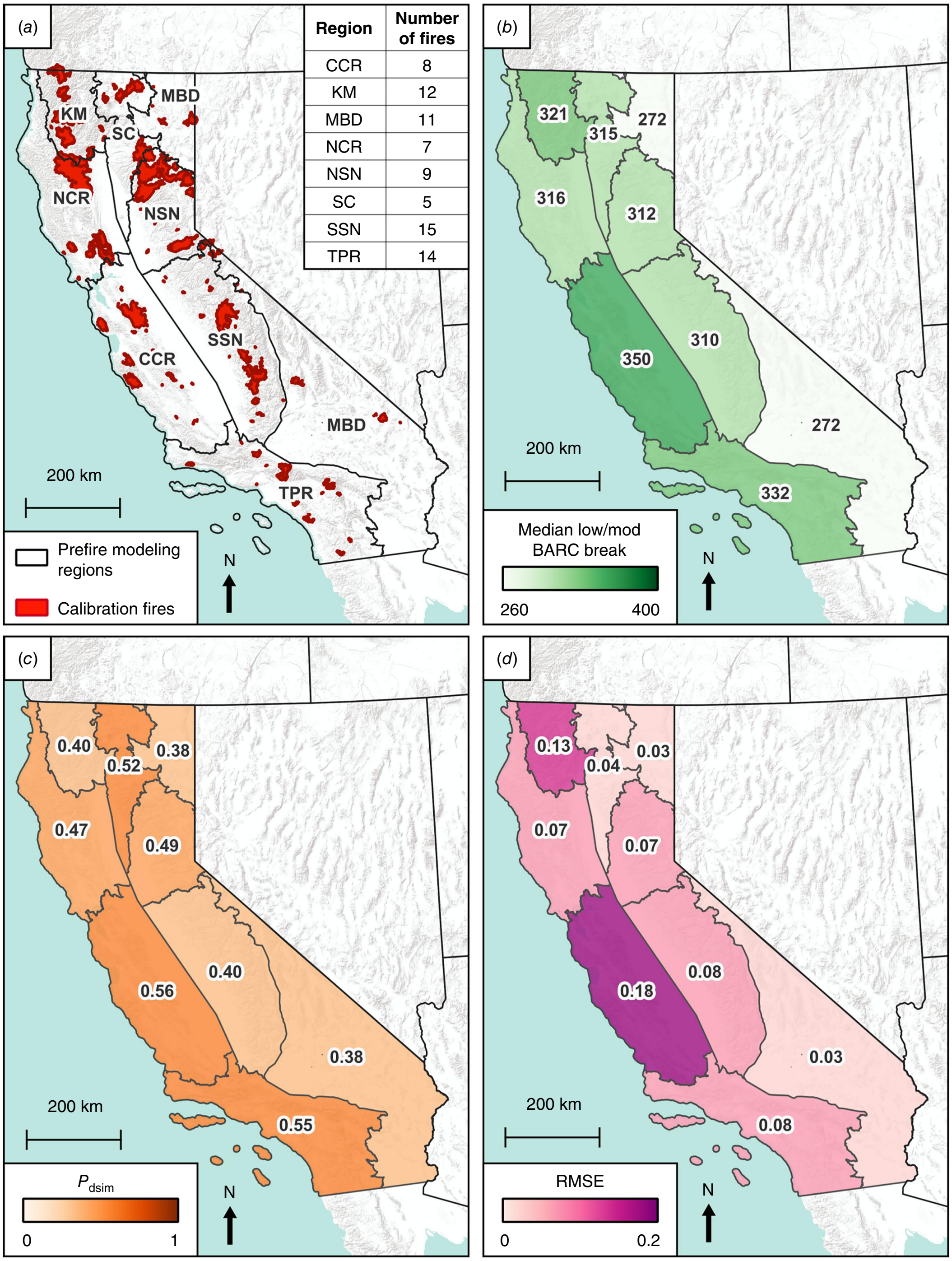

Fig. 2. P_{dsim} calibration methods. Calibration fires (n = 81) from 2020 to 2021, with table showing number of fires by region (*a*); median low-moderate Burned Area Reflectance Classification (BARC) break values (*b*); regional P_{dsim} values (*c*); Root Mean Square Error (RMSE) calculated to compare the simulated and observed debris-flow likelihood for basins inside the fire perimeters (*d*). Abbreviations: CCR, Central Coast Ranges; KM, Klamath Mountains; MBD, Modoc Plateau, Basin and Range, and Southern Deserts; NCR, Northern Coast Ranges; NSN, Northern Sierra Nevada; SC, Southern Cascades; SSN, Southern Sierra Nevada; TPR, Transverse and Peninsular Ranges.

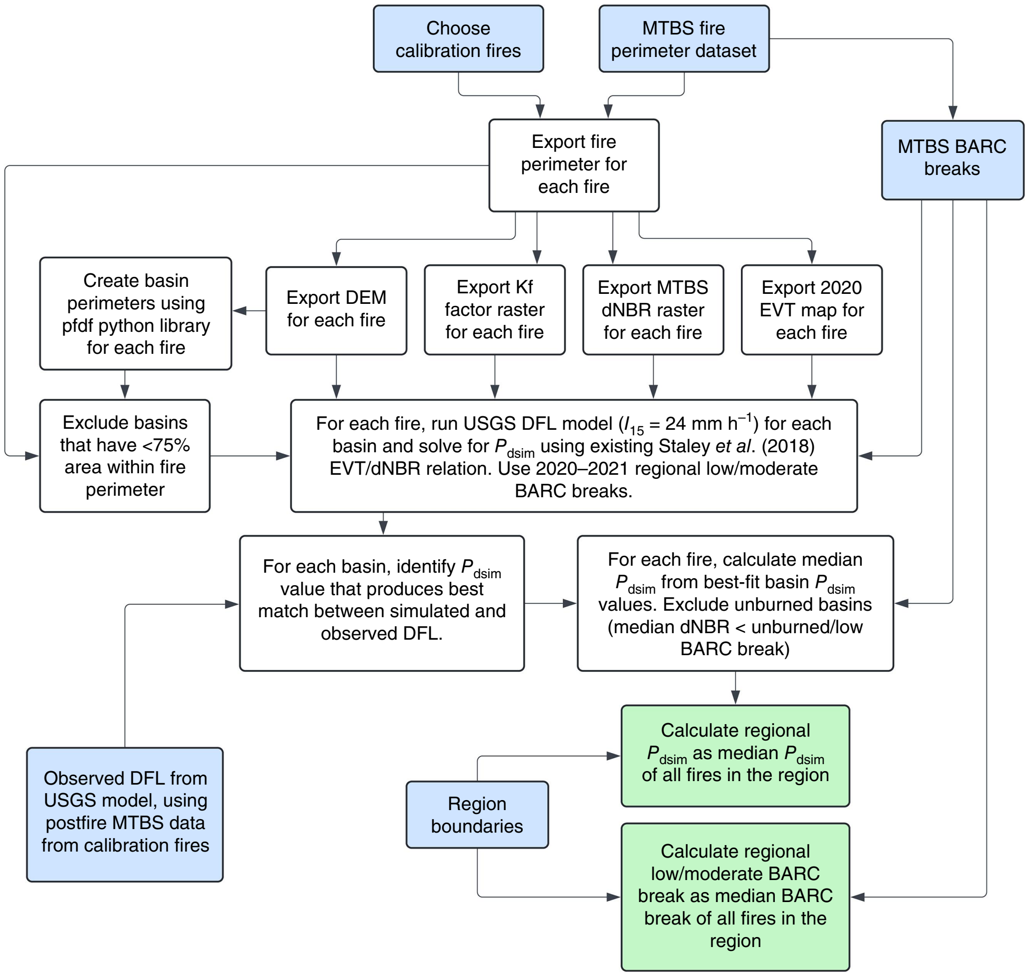

Fig. 3. Flowchart summarizing the regional P_{dsim} calibration and low-moderate Burned Area Reflectance Classification (BARC) break calculation procedure detailed in the Methods section. Inputs, outputs and intermediate steps are shown in blue, green, and white boxes, respectively. Abbreviations: DFL, debris-flow likelihood; dNBR, differenced Normalized Burn Ratio; DEM, Digital Elevation Model; EVT, Existing Vegetation Type; MTBS, Monitoring Trends in Burn Severity.

model runs. We focused our discussion on the calibration approach that produced the highest NSE.

Postfire debris-flow model and prefire inputs

The simulated dNBR map was generated from the EVT map (Table 2) using the established EVT-dNBR relationships (Staley *et al.* 2018) and the regional P_{dsim} values. The simulated dNBR map was then classified into a simulated BARC map using the regional median low-moderate BARC break values.

To only model debris-flow likelihood and volume where runoff-generated postfire debris flows could initiate, we adopted the standard USGS basin area criteria (0.025–8 km^2; Staley *et al.* 2016) and masked the model domain to prevent basin delineation in flat areas (Table 2). Though flat areas could experience inundation from debris flows generated upstream, the USGS models used in this study are only intended to model initiation, not runout. We then ran the debris-flow likelihood and volume models within the pfdf Python library (King 2023) separately for each subbasin hydrologic unit (HU8) boundary in California in the Watershed Boundary Dataset to increase computational efficiency relative to modeling the full state in one iteration. We used subbasins (HU8) for most regions and watersheds (HU10) in the Basin and Range and Southern Deserts region, which we found to minimize basin delineation artifacts.

Annual probability of postfire debris flows across California

The annual probability of occurrence of a particular rainfall intensity varies widely across the diverse climates of California. Therefore, climatological information was required to predict the annual exceedance probability $P(R > T)$ of a rainfall intensity (R) exceeding the modeled rainfall intensity

Table 2. Datasets used in the statewide prefire modeling of postfire debris-flow hazards.

Dataset name	Description	Source
Cumulative distribution function (CDF) parameters	Best-fit Weibull CDF parameters that relate each Existing Vegetation Type (EVT) class to a differenced Normalized Burn Ratio (dNBR) value; used to calculate simulated dNBR.	Staley (2018)
EVT[A,B]	EVT rasters (30-m) used to generate simulated dNBR inputs.	LandFire (2022)
Calibrated P_{dsim} and Burned Area Reflectance Classification (BARC) break values by region	Calibrated P_{dsim} values and the median low-moderate BARC breaks (calibration fire dataset) for each of the eight prefire modeling regions.	MTBS (2022)
Digital Elevation Model (DEM)[A]	Mosaic of 1/3 arc-second digital elevation tiles.	US Geological Survey (2024)
Kf factor[A]	Soil erodibility index of the fine fraction of soils; STATSGO soil polygons assigned with 'KFFACT' attribute; values less than 0 were excluded from the analysis.	Schwartz and Alexander (1995)
Model domains[A]	Subbasin (HU8) and watershed (HU10) boundary polygons from the Watershed Boundary Dataset that were used to define the model domain.	US Geological Survey (2023)
Masks[A]	A set of masks were used to exclude areas of low slope or open water from the model domain where debris flows are unlikely to initiate and to minimize artifacts in basin delineation. Valley mask: A focal statistics algorithm was used to calculate the standard deviation of elevation within a 200 m radius of every cell in the DEM. Clusters of cells with values less than or equal to 5 m were converted to polygons, and all polygons with an area less than 1 km^2 were deleted. Sink mask: To create the sink mask, the portion of the pfdf Python library (King 2023) which generates a flow direction raster was run and DEM conditioning criteria of filled pits, filled depressions, and unresolved flats was selected. The areas marked as null in this output directly correspond to areas mapped erroneously as basins. We converted these clusters of null values to polygons and deleted all polygons with an area less than 1 km^2. To ensure that all polygons of the sink mask were in valley areas, we deleted all polygons that did not intersect the valley mask. Water mask: Two data sources were used to mask out large bodies of water, including water bodies boundaries and the 2022 EVT open water classification.	LandFire (2022), US Geological Survey (2020, 2023)

[A]Projected to California Teale Albers (datum: NAD 1983); 10-m resolution.
[B]We used the LandFire EVT rasters to generate two EVT maps that contain the most recent EVT classes with established CDF parameters to use in the calibration of P_{dsim} (2020 EVT map) and the prefire modeling (2022 EVT map). Pixels that contained a no data value in the EVT maps were assigned an EVT code of 7294 (i.e. barren).

threshold (T). The National Oceanic and Atmospheric Administration (NOAA) Atlas14 product (Perica *et al.* 2014) describes the 15-min rainfall intensity associated with particular recurrence intervals (RI) from 1 to 1000 years. These products are spatially continuous across the state with a cell size of 800 m. The relationship between a particular rainfall intensity and its expected RI is log-linear and can be expressed as Eqn 6 in Table 3. To estimate m and b, the mean values of the 1- and 50-year rainfall intensity (Fig. 4) at each basin were extracted using a zonal statistics algorithm, and m and b were estimated using Eqns 7 and 8 in Table 3. The RI of the modeled rainfall intensity threshold was then computed for each basin. To convert RI to annual exceedance probability P, we used Eqn 9 in Table 3.

With this workflow, we estimated the RI and associated annual exceedance probability of the modeled rainfall intensity threshold at each basin, after it has burned. However, as the aim of this study is to model debris-flow likelihood before a fire occurs, a true prefire estimate of postfire debris-flow likelihood should also take into account the probability that a fire actually occurs (i.e. $P(F)$) in a particular basin (e.g. Kean and Staley 2021). For typical climatic conditions (i.e. neither drought nor extremely wet conditions), we expect a weak relationship between the occurrence of threshold-exceeding rainfall intensity and fire, and we treat their occurrence as independent of one another. For typical conditions, which we aim to model in this study, we estimate the annual probability of a postfire debris flow is thus the product $P(F) \times P(R > T)$.

To estimate $P(F)$ we used the wildfire simulation model (FSim) product developed by Pyrologix in conjunction with the US Forest Service and California Department of Forestry and Fire Protection, which estimates annual fire probability (regardless of severity) in a spatially continuous 30-m grid across the state (Vogler *et al.* 2021; US Forest Service 2023; Fig. 4). The FSim product captures variability in localized

Table 3. Summary of equations used to calculate annual probability.

Name	Equation	Citation
Recurrence interval (RI)	$$\mathrm{RI} = 10^{mI_{15}+b} \quad (6)$$ I_{15} = 15-min rainfall intensity (mm h^{-1}) m = slope of the log-linear relationship between intensity and RI (Eqn 7) b = y-intercept of the log-linear relationship between intensity and RI (Eqn 8)	Perica *et al.* (2014)
m, *b*	$$m = \frac{\log(50) - \log(1)}{50\mathrm{yr}I_{15} - 1\mathrm{yr}I_{15}} \quad (7)$$ $$b = -m \times 1\mathrm{yr}I_{15} \quad (8)$$ $1\mathrm{yr}I_{15}$ = 1-year rainfall intensity (mm h^{-1}) $50\mathrm{yr}I_{15}$ = 50-year rainfall intensity (mm h^{-1})	Perica *et al.* (2014); *m* and *b* calculated using zonal statistics algorithm in QGIS (version 3.34.1)
Annual exceedance probability (*P*)	$$P = 1 - e^{-1/\mathrm{RI}} \quad (9)$$ RI = recurrence interval (Eqn 6)	Feller (1991)

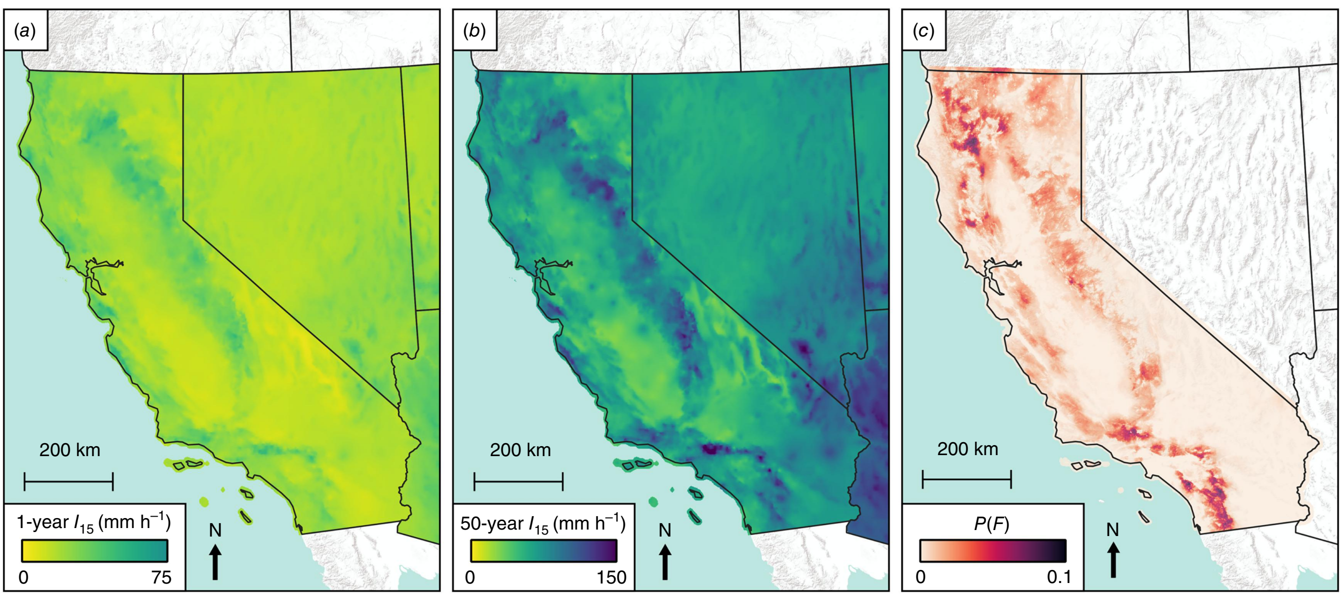

Fig. 4. Maps of inputs to the annual probability analysis: Atlas14 1-year (*a*) and 50-year (*b*) 15-min rainfall intensity (I_{15}), and the FSim annual burn probability product (*P(F)*) (*c*; Vogler *et al.* 2021; US Forest Service 2023).

fire conditions and behavior, including changes in fuel moisture content, combinations of wind speed, wind direction, topography, and historical fire occurrence across the landscape (Vogler *et al.* 2021; U.S. Forest Service 2023). We then computed the mean $P(F)$ value for each basin and multiplied it by the basin's $P(R > T)$ prediction to yield an annual probability of fire followed by above-threshold rainfall in the year following fire. The prefire modeling and annual probability procedure is summarized in Fig. 5.

Results

Existing vegetation type map

The Existing Vegetation Type (EVT) classes that we replaced within the EVT maps varied in total area by region. Approximately 20% of the prefire modeling region domain was mapped with EVT classes drawn from preceding EVT rasters used in both the calibration of P_{dsim} (2020 EVT map) and the simulated differenced Normalized Burn Ratio (dNBR)

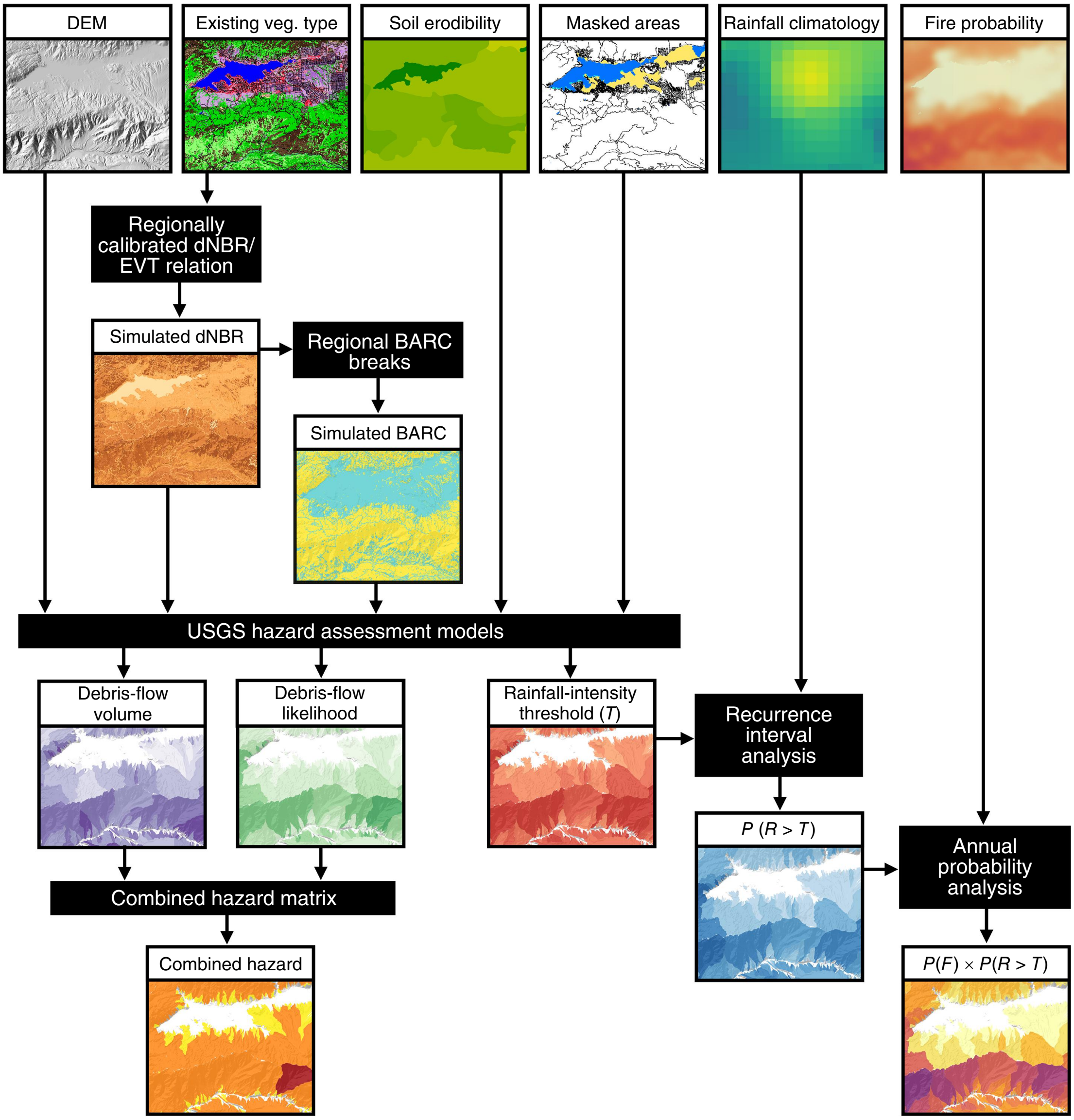

Fig. 5. Flowchart outlining the prefire hazard modeling procedure and associated map products. We used a 15-min rainfall intensity of 24 mm h^{-1} as an input to the debris-flow likelihood and volume models. This procedure is detailed in the Methods section. Abbreviations: BARC, Burned Area Reflectance Classification; dNBR, differenced Normalized Burn Ratio; EVT, Existing Vegetation Type; RMSE, Root Mean Square Error; R, rainfall intensity; T, modeled rainfall intensity threshold; $P(R > T)$, annual probability that the 15-min triggering rainfall intensity is exceeded for a debris-flow likelihood value of 50%; $P(F)$, annual fire probability; $P(F) \times P(R > T)$, annual probability of a fire and subsequent above-threshold rainfall intensity within the year following fire.

maps used in the prefire modeling (2022 EVT map; Fig. 6). The total replaced area of EVT classes ranged from ~5% in the Klamath Mountains to ~35% in the Central Coast Ranges and Southern Sierra Nevada and mostly consisted of low-elevation slopes along the margin of the Sacramento and San Joaquin Valleys.

Comparison of calibration methods

We compared results for two P_{dsim} calibration methods to results for P_{dsim} of 0.50 (Fig. 7) for 81 calibration fires (Table 4). The DFL calibration produced a higher Nash-Sutcliffe Efficiency value (NSE = 0.57) relative to the Burned Area Reflectance Classification (BARC) map calibration (NSE = 0.37) with regionally calibrated P_{dsim} values or using a fixed P_{dsim} of 0.50 (NSE = 0.22; Fig. 7). Because the DFL calibration produced the highest NSE value of the two calibration methods that we considered, we focused our results and discussion on the results from the DFL calibration. We also considered the consequences of predicting debris-flow likelihood using a fire-specific P_{dsim} instead of the regional median P_{dsim}. The fire-specific P_{dsim}

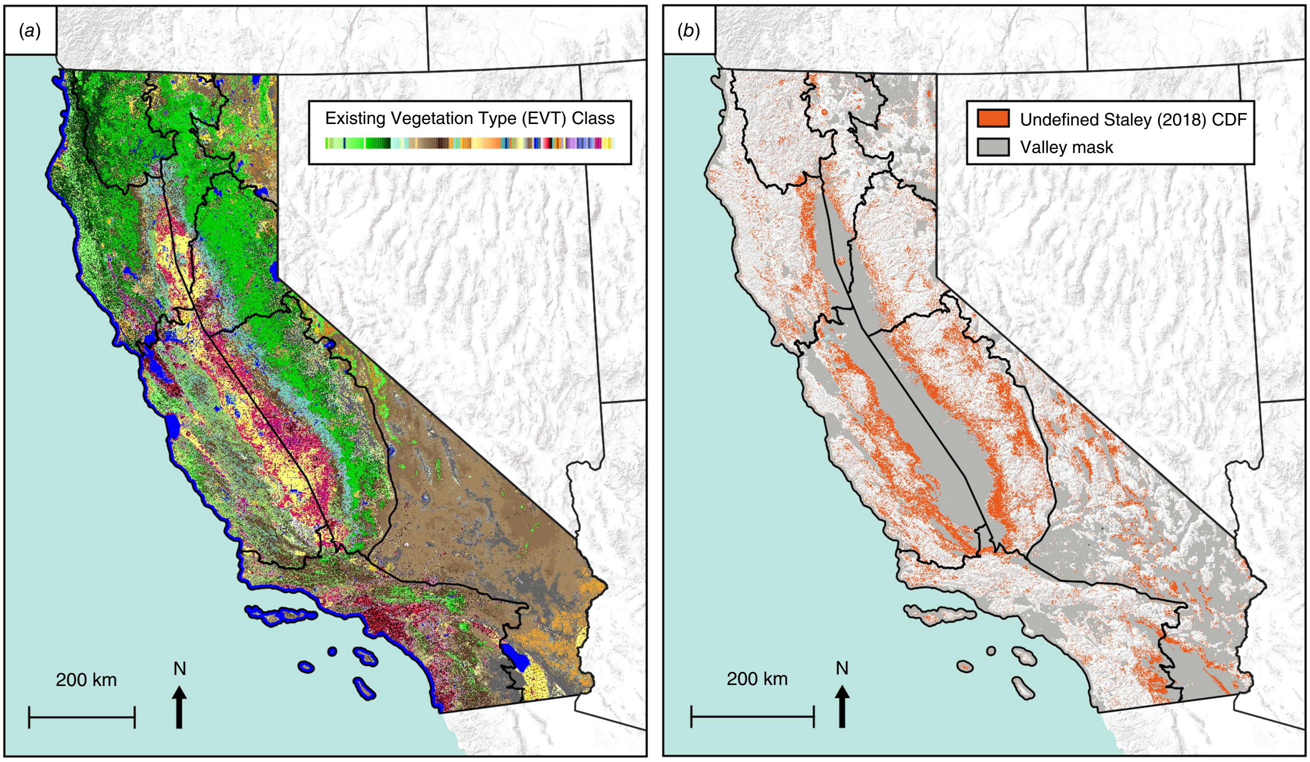

Fig. 6. 2022 EVT map (Table 2) showing the spatial distribution of Landfire EVT classes across the prefire modeling regions, with each Landfire EVT class shown in a different color (*a*) and location of replaced EVT classes across the California prefire modeling region domain, where a Staley (2018) CDF is undefined (*b*).

produced a better relationship between the simulated and observed debris-flow likelihood (NSE = 0.98; Fig. 7).

The Root Mean Square Error (RMSE) values of the calibration were generally low but varied by region (Fig. 7, Table 5). For example, calibration fires for the Central Coast Ranges produced the highest RMSE (0.18) while the region that includes the Modoc Plateau, Basin and Range, and Southern Deserts produced the lowest RMSE (0.03) (Fig. 7, Table 5). Figs 2 and 8 present P_{dsim} results for each region. Basins where the simulated dNBR closely matched the observed dNBR typically produced the closest match between simulated and observed debris-flow likelihood (Fig. 9). Observed basin dNBR exhibits a much wider range in values relative to simulated P_{dsim} values (Fig. 9). The limited range of simulated dNBR values constrained the ability of the model to reproduce observed dNBR distributions. Regions with lower moderate BARC breaks typically produced lower calibrated P_{dsim} values (Fig. 8).

The wide range in calibrated P_{dsim} values (Figs 2, 8) is strong evidence that fire behavior and severity vary widely even for a single region. For some regions, we reproduced the mean debris-flow likelihood using a regional calibration. In particular, the Modoc Plateau, Basin and Range, Southern Deserts and the Southern Cascades produced relatively low RMSE values (0.03 and 0.04, respectively) while the Klamath Mountains (RMSE = 0.13) and Central Coast Ranges (RMSE = 0.18) produced the highest RMSE. The Northern Coast Ranges (RMSE = 0.07), Northern Sierra Nevada (RMSE = 0.07), Southern Sierra Nevada (RMSE = 0.08) and Transverse and Peninsular Ranges (RMSE = 0.08) produced results with intermediate RMSE. In most cases, the ability to predict the mean debris-flow likelihood is much better than the ability to predict the debris-flow likelihood of basins within an individual fire perimeter (Table 5). For example, the RMSE for the fire-wide mean debris-flow likelihood is substantially lower than the RMSE calculated from all calibration basins in the region (RMSE = 0.02 for the fire mean versus RMSE = 0.21 for calibration basins for the fire-specific P_{dsim} and RMSE = 0.09 for the fire mean versus RMSE = 0.22 for calibration basins for the regional P_{dsim}; Table 5).

Statewide prefire map products

Using the methods described above, we generated nine map products relevant to predicting postfire debris-flow hazard prior to fire (Rossi *et al.* 2025). The simulated dNBR and simulated BARC (four classes; Fig. 10) maps were generated prior to running the USGS models and resulted from the simulated burning of existing vegetation according to the regional

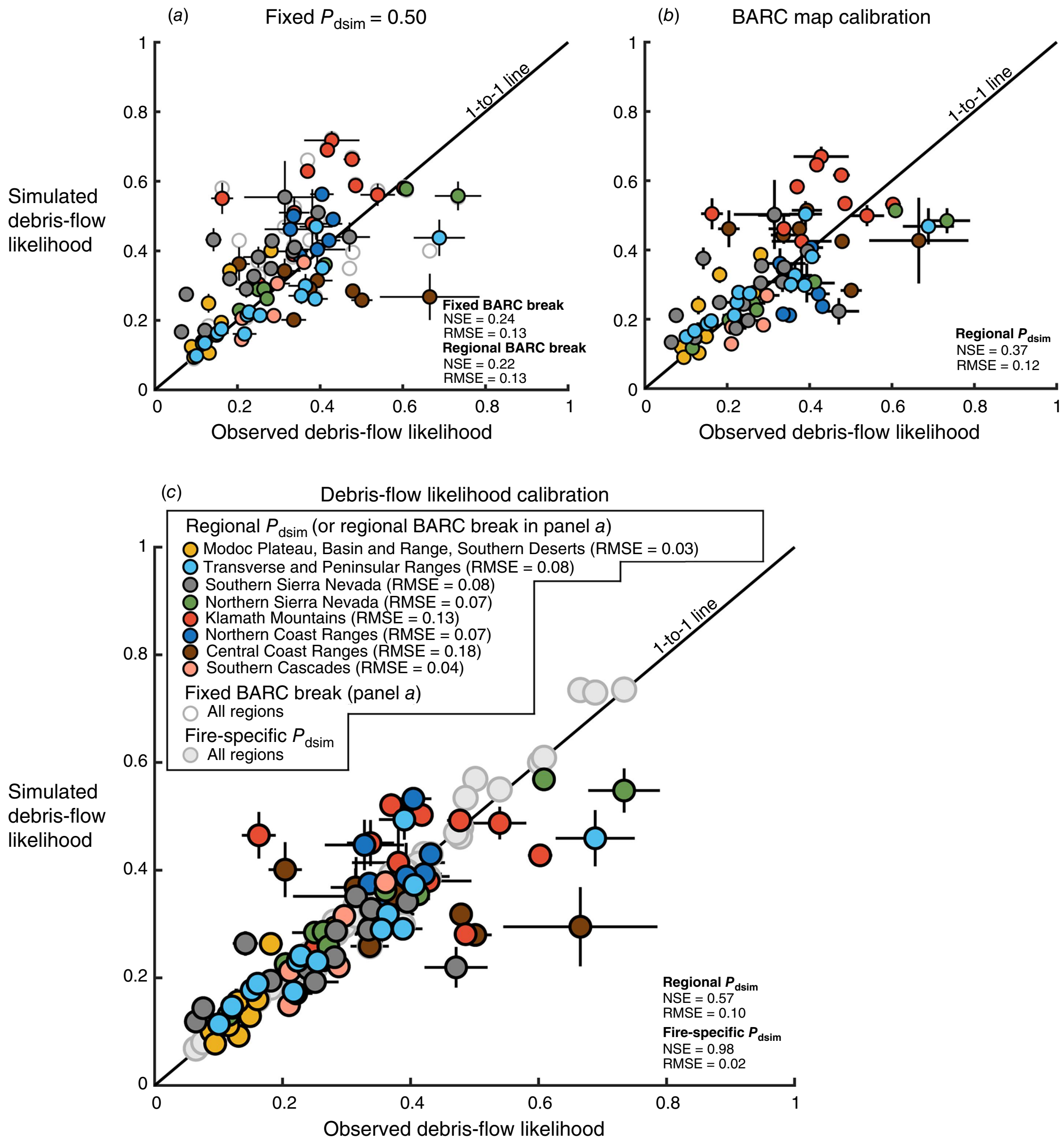

Fig. 7. Comparison of fire-wide mean debris-flow likelihood for fixed P_{dsim} = 0.50 (*a*) and calibration to best match to percent moderate-high burn severity (i.e. Burned Area Reflectance Classification (BARC) map calibration) (*b*), and lowest Root Mean Square Error (RMSE) for observed and simulated debris-flow likelihood (i.e. DFL calibration) (*c*). Uncertainty bars show two standard errors of the mean for the basins inside the respective fire perimeter. The uncertainty bars indicate the relative width of the distributions for the simulated and observed debris-flow likelihood for a single fire (since the sample size for simulated and observed debris-flow likelihood match for the same fire). Results and statistics are for simulated and observed debris-flow likelihood for basin $dNBR_{obs}$ > unburned-low BARC break (T_{low}). Abbreviations: dNBR, differenced Normalized Burn Ratio; NSE, Nash-Sutcliffe Efficiency.

P_{dsim} and regional BARC breaks that provided the best match of simulated to observed debris-flow likelihood results. The spatial data generated by the USGS models include debris-flow likelihood (calculated using I_{15} = 24 mm h^{-1}), rainfall intensity threshold (calculated using debris-flow likelihood = 50%), volume, and combined hazard classification (Fig. 10). Combined hazard classification was determined by combining the USGS modeled debris-flow likelihood and volume and assigning a combined hazard class as low, moderate, or high (Cannon *et al.* 2010). The products associated with the annual probability methods include annual probability of exceedance of the predicted rainfall intensity threshold, annual fire probability, and annual probability of fire and subsequent above-threshold rainfall in the year following fire (Fig. 10).

Table 4. List of calibration fires by region.

Region	Calibration fires[A]
Central Coast Ranges	Carmel (30 km^2), Crews (23 km^2), CZU August Lightning (348 km^2), Dolan (503 km^2), Mineral (121 km^2), River (209 km^2), SCU Lightning Complex (1642 km^2), Willow (13 km^2)
Klamath Mountains	Cronan (31 km^2), Devil (37 km^2), Fawn (37 km^2), Haypress (828 km^2), Knob (10 km^2), McCash (388 km^2), **McFarland** (492 km^2), Monument (915 km^2), Red Salmon Complex (597 km^2), Salt (51 km^2), Slater (639 km^2), Zogg (230 km^2)
Modoc Plateau/Basin and Range/Southern Deserts	Baccarat (41 km^2), Coles Flat (167 km^2), **Dexter** (12 km^2), Gold (88 km^2), Junction Ranch (38 km^2), Mountain View (58 km^2), **North** (28 km^2), **Sheep** (118 km^2), **Slink** (107 km^2), **Tamarack** (284 km^2), W-5 Cold Springs (340 km^2)
Northern Coast Ranges	August Complex (4325 km^2), Glass (275 km^2), Hennessey (1272 km^2), **McFarland** (492 km^2), Meyers (10 km^2), Wallbridge (223 km^2), Woodward (20 km^2)
Northern Sierra Nevada	Caldor (917 km^2), **Dixie** (3965 km^2), Hog (39 km^2), Loyalton (184 km^2), **North** (28 km^2), North Complex (1281 km^2), River (11 km^2), **Sheep** (118 km^2), Sugar (439 km^2)
Southern Cascades	Antelope (574 km^2), Caldwell (331 km^2), **Dixie** (3965 km^2), Lava (106 km^2), Tennant (48 km^2)
Southern Sierra Nevada	Bluejay (28 km^2), Castle (706 km^2), Creek (1544 km^2), **Dexter** (12 km^2), French (111 km^2), KNP Complex (364 km^2), Moc (13 km^2), Rattlesnake (37 km^2), River (41 km^2), **Slink** (107 km^2), Stagecoach (31 km^2), **Tamarack** (284 km^2), Tiltill (11 km^2), Walkers (36 km^2), Windy (396 km^2)
Transverse and Peninsular Ranges	Alisal (72 km^2), Apple (131 km^2), Blue Ridge (56 km^2), Bobcat (468 km^2), Bond (27 km^2), Creek 5 (18 km^2), El Dorado (90 km^2), India (98 km^2), Lake (125 km^2), Ranch 2 (18 km^2), Silverado (51 km^2), Snow (26 km^2), Southern (22 km^2), Valley (67 km^2)

[A]Fire area included in parentheses; fires that were used in more than one region are listed in bold text.

Discussion

Limitations of simulating dNBR

One limitation of our approach is that we used relationships between Existing Vegetation Type (EVT) and differenced Normalized Burn Ratio (dNBR) developed by Staley *et al.* (2018) and new EVT classes have been introduced in California since the Staley *et al.* (2018) study. Instead of developing new EVT-dNBR relationships for the new EVT classes, we reclassified the new EVT classes with previous EVT classes. Updated cumulative distribution function (CDF) parameters could be calculated for areas where we applied replacement EVT classes, but it remains unclear how much these new EVT classes might impact simulated fire severity. For example, California Ruderal Grassland, a new grassland EVT class that widely occurs within the Central Coast Ranges and Southern Sierra Nevada, was replaced in our EVT map with a more spatially variable set of preceding EVT classes that included grassland, shrubland, and forest EVT classes. Updated CDF parameters for this new grassland EVT are likely to represent similar fire severity to our replacement grassland EVT class. In this example, our replacement EVT classes of shrubland and forest likely simulate higher fire severity than the new grassland EVT class and thus we provide a more conservative representation of fire severity in these locations.

P_{dsim} calibration

Expanding the calibration dataset to include additional fires may influence the regionally calibrated P_{dsim} values, but our ability to reproduce variance in basin debris-flow likelihood is unlikely to improve by expanding the calibration dataset. This is because our current approach for predicting dNBR produced a relatively limited range in dNBR values relative to real fire behavior (Fig. 9) and because predicting variability in fire behavior is difficult even with more sophisticated approaches that predict burn severity (Wells *et al.* 2023).

The model requires calibration of a single parameter (P_{dsim}), and we calibrated the model to produce a close match between the mean simulated and observed debris-flow likelihood. Increasing P_{dsim} will shift the mean debris-flow likelihood higher while decreasing P_{dsim} will shift the mean debris-flow likelihood lower. Even within a single region, there was a wide range in fire intensity, which required different values of P_{dsim} to match mean fire-wide debris-flow likelihood (Fig. 8). Because fire-specific P_{dsim} values varied for a region (Fig. 8), we used the median P_{dsim} for a region to estimate debris-flow likelihood and produce our debris-flow likelihood maps. The relatively minimal improvement in Root Mean Square Error (RMSE) for basins using a fire-specific P_{dsim} relative to a regional P_{dsim} (RMSE = 0.21 for fire-specific P_{dsim} versus RMSE = 0.22 for regional P_{dsim}) is evidence that there is limited opportunity to better reproduce the variance in debris-flow likelihood inside a fire perimeter because the fire-specific P_{dsim} is already tuned to a value that minimizes basin debris-flow likelihood RMSE. In other words, the fire-specific P_{dsim} calibration already produced the best match between simulated and observed basin debris-flow likelihood.

In regions with lower RMSE, we have higher confidence in our ability to predict mean debris-flow likelihood. In particular, the Modoc Plateau, Basin and Range, and Southern Deserts and the Southern Cascades produced relatively low RMSE values (0.03 and 0.04, respectively) relative to the Klamath Mountains and Central Coast Ranges,

Table 5. Summary of regional values.

Region			Calibration				Basins inside fire perimeter[A,C]						Fire-wide mean[B,C]	
	Fire area (km^2)	Total basins	Total fires	2020/2021 regional median of low-moderate BARC break	Regional P_{dsim}	Slope (°)	Observed dNBR	Simulated dNBR for regional P_{dsim}	Observed DFL	Simulated DFL for regional P_{dsim}	DFL RMSE for fire-specific P_{dsim}	DFL RMSE for regional P_{dsim}	DFL RMSE for fire-specific P_{dsim}	DFL RMSE for regional P_{dsim}
Central Coast Ranges	2888	4445	8	350	0.56	23.9	352	342	0.41	0.33	0.24	0.26	0.05	0.18
Klamath Mountains	4254	7059	12	321	0.40	26.2	391	326	0.44	0.41	0.29	0.33	0.02	0.13
Modoc Plateau/ Basin and Range/ Southern Deserts	1280	1891	11	272	0.38	14.7	229	231	0.19	0.20	0.11	0.11	0.00	0.03
Northern Coast Ranges	6618	9618	7	316	0.47	22.1	375	347	0.41	0.41	0.24	0.24	0.01	0.07
Northern Sierra Nevada	6982	12,782	9	312	0.49	18.5	422	356	0.41	0.39	0.22	0.22	0.00	0.07
Southern Cascades	5025	7802	5	315	0.52	15.0	378	366	0.34	0.35	0.20	0.20	0.00	0.04
Southern Sierra Nevada	3721	6243	15	310	0.40	20.4	315	308	0.27	0.25	0.19	0.20	0.01	0.08
Transverse and Peninsular Ranges	1269	1939	14	332	0.55	24.5	313	335	0.33	0.31	0.19	0.19	0.03	0.08
Regional mean	4005	6472	10	316	0.47	20.7	347	326	0.35	0.33	0.21	0.22	0.02	0.09

Abbreviations: BARC, Burned Area Reflectance Classification; DFL, debris-flow likelihood; dNBR, differenced Normalized Burn Ratio; RMSE, Root Mean Square Error.
[A]For each region, basins inside fire perimeter values were calculated as the mean value for all calibration fire basin values in the region (for example, the mean RMSE of 4445 basins in the Central Coast Ranges).
[B]Fire-wide mean values were calculated from the mean value for each calibration fire in the region (for example, the mean RMSE of 8 fire values for the Central Coast Ranges).
[C]In both cases, basins with observed dNBR less than or equal to the unburned-low BARC break (T_{low}) were excluded from the calculations.

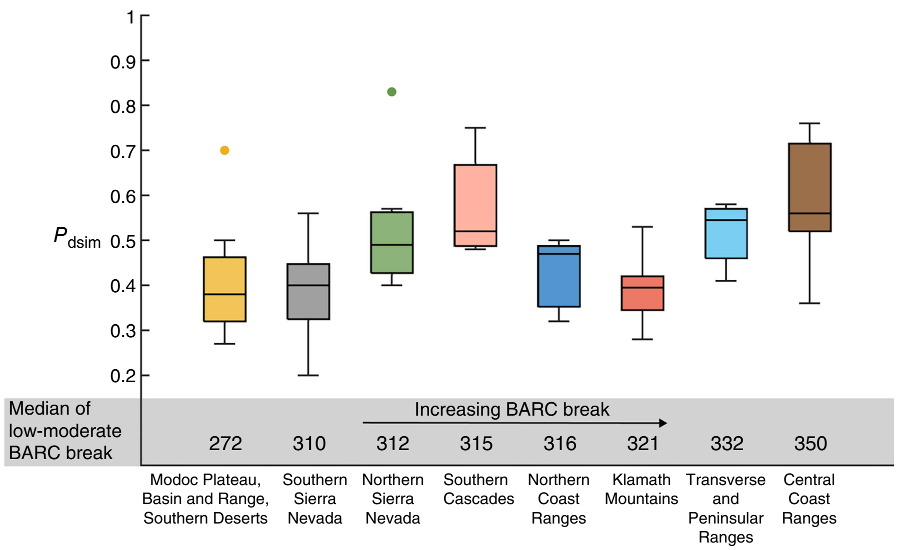

Fig. 8. Box and whisker plots summarizing distributions of fire-wide P_{dsim} values by region with increasing Burned Area Reflectance Classification (BARC) breaks for the lowest Root Mean Square Error (RMSE) method. Outliers shown as circular markers.

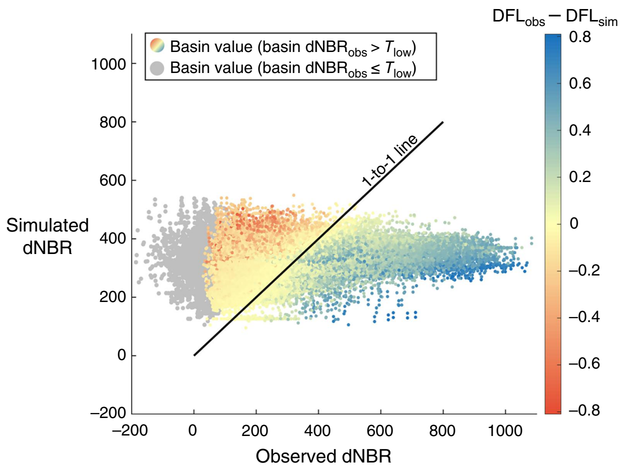

Fig. 9. Comparison of simulated and observed mean differenced Normalized Burn Ratio (dNBR) values for all calibration fire basins. Color shows the difference in the observed and simulated mean basin debris-flow likelihoods (DFL_{obs} and DFL_{sim}, respectively). Basin values with observed dNBR less than the fire-specific unburned-low Burned Area Reflectance Classification (BARC) break (T_{low}) are shown in gray. The difference between DFL_{obs} and DFL_{sim} are typically smallest near the 1-to-1 line. Nash-Sutcliffe Efficiency (NSE, 0.02) calculated for simulated and observed dNBR for basin $dNBR_{obs} > T_{low}$.

which produced relatively high RMSE values (0.13 and 0.18, respectively; Fig. 7).

Recommendations on applying the debris-flow likelihood results

The maps and associated data can be used to identify potential postfire hazards for individual basins as a function of debris-flow likelihood, volume, combined hazard classification, or annual probability of postfire debris flow. These maps can be used to prioritize treatments such as fuel reduction projects to decrease the spatial extent and severity of wildfire; prioritize road maintenance and crossing upgrades to minimize road failures and improve access for public travel, commerce, and emergency services; inform operational plans during active fire suppression activities, especially in basins with a high debris-flow hazard where there are downstream values at risk present. The results can also provide an additional, objective metric to rank basins and watersheds in comprehensive hazard assessments. For example, postfire debris-flow combined hazard classification and annual probability could be applied to identify and rank areas where modeling of debris-flow inundation would support the development of state and local hazard mitigation plans that comply with the Federal Disaster Mitigation Act (2000).

Limitations on applying the debris-flow likelihood results

Fire behavior is highly variable, and we were unable to accurately predict burn severity for individual basins in most cases (Fig. 9). However, we were somewhat successful at predicting the mean debris-flow likelihood even when using a regional P_{dsim} value (Fig. 7). Our results of predicted debris-flow likelihood represent a simplified scenario in which burn severity is controlled by vegetation type only. Using EVT to predict dNBR does help capture some variability observed in fire behavior but is limited by our inability to account for other factors that drive fire behavior. Simulated dNBR and the corresponding Burned Area Reflectance Classification (BARC) maps can be used to identify basins with high debris-flow likelihood under a simplified wildfire scenario that depends solely on EVT. Since fire behavior is difficult to predict, this simplified scenario is best at identifying areas that are naturally more prone to debris flows due to hillslope gradient, soil characteristics (through Kf factor),

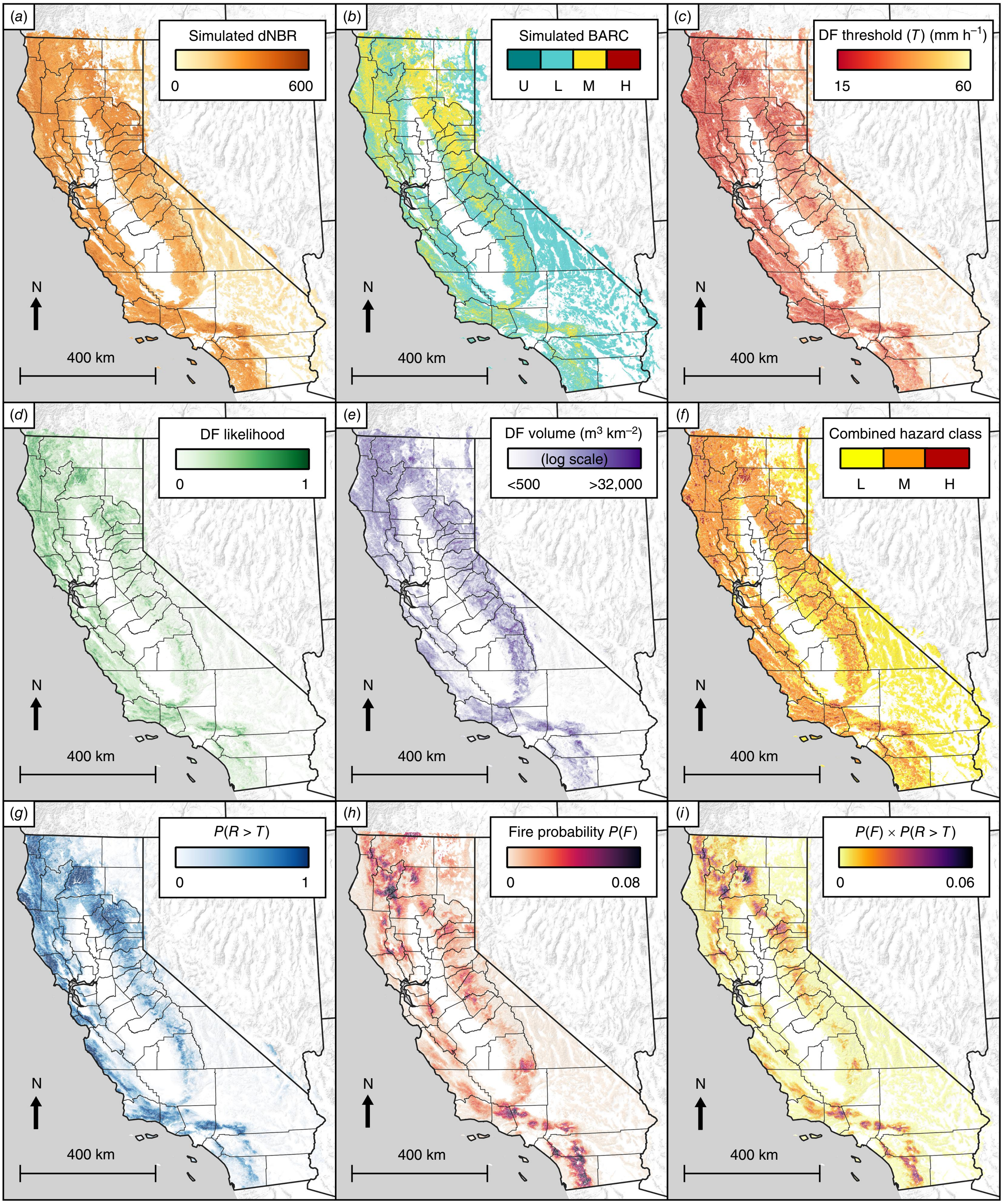

Fig. 10. Statewide prefire modeling results showing simulated differenced Normalized Burn Ratio (dNBR) (*a*), simulated Burned Area Reflectance Classification (BARC); unburned/very low (U), low (L), moderate (M), and high (H) burn severity (*b*), debris-flow (DF) 15-min rainfall intensity threshold (*T*) (*c*), debris-flow likelihood from 24 mm h^{-1} storm (*d*), debris-flow volume (normalized to basin area); (*e*), debris-flow combined hazard class; L: low, M: moderate, and H: high (*f*), annual probability that the 15-min triggering rainfall intensity is exceeded for a debris-flow likelihood value of 50% ($P(R > T)$; *g*), annual fire probability ($P(F)$; *h*), and annual probability of a fire and subsequent above-threshold rainfall intensity within the year following fire ($P(F) \times P(R > T)$; *i*).

and regional fire behavior (via calibrated prediction of dNBR and regional BARC breaks) – all of which are known prior to the fire.

Opportunities for future work

Improving our ability to forecast where landscapes are likely to experience moderate and high burn severity would dramatically improve our ability to accurately predict debris-flow likelihood. Once rainfall intensity is accounted for, moderate and high burn severity in conjunction with slope gradient are the most important factors influencing the occurrence of debris flows (Staley *et al.* 2017). There are likely opportunities to better predict burn severity and debris-flow likelihood using machine learning and other techniques. Although machine learning has been applied to many fire-related investigations, there have been relatively few attempts to use machine learning to predict fire severity (Jain *et al.* 2020; Klimas *et al.* 2025). Fire behavior and effects are fundamentally difficult to predict and the few existing attempts to use machine learning have been limited in their ability to accurately predict burn severity, especially for fires on which the model was not trained (e.g. Birch *et al.* 2015; Kane *et al.* 2015; Wells *et al.* 2023). Conditions immediately prior to the fire such as daily fire weather (air temperature, wind speed and direction, relative humidity, etc.) and fuel moisture are critical drivers of fire behavior (e.g. van Mantgem *et al.* 2013; Zald and Dunn 2018) and cannot be known far in advance; these limitations hamper our ability to incorporate critical factors into a postfire debris-flow likelihood prediction prior to wildfire. However, other important factors such as topography (elevation; aspect; landscape location – hillslope, ridge, riparian), proximity to developed areas, road density, fuel loads, rock type, and seasonal climatic information can be considered prior to fire occurrence. Indeed, some of these factors have been investigated with machine learning. Zald and Dunn (2018) used a random forest ensemble model and determined that daily fire weather was the most important predictor variable followed by stand age, ownership, and topographic position in an area impacted by the 2013 Douglas Complex Fire in southern Oregon. Wells *et al.* (2023) found that fuel loads and conditions (e.g. leaf-on chlorophyll content), prefire weather, and topography were important predictors of burn severity for two fires in north-central Colorado. Klimas *et al.* (2025) used a machine learning model and found that vegetation productivity, elevation, and canopy fuels were the most important predictor variables in forested land in Utah. Further development of machine learning approaches and other methods to estimate fire severity are promising to improve postfire debris-flow likelihood predictions prior to wildfire.

Although our goal was to assess potential debris-flow hazards for all of California, some caution should be applied when using the debris-flow likelihood and volume models (Table 1) in areas outside the original calibration area in Southern California. For example, debris-flow sediment sourcing (dry ravel, landslide, in-channel storage, hillslope rilling), sediment characteristics (grain size, shape, volume of available sediment, etc.), storm behavior (convective, atmospheric river, etc.) vary in California. These differences are currently not accounted for in the debris-flow likelihood and volume models, even though they may produce different debris-flow behavior and characteristics. An expanded database of debris-flow triggering conditions and volume is required to fully validate the models for all of California. These data are currently being collected and we expect that future versions of the debris-flow likelihood and volume models will include these data in their development.

Additionally, we note that the goals and methods of this study relate to the prediction of postfire debris-flow hazard prior to a hypothetical future fire. As such, any predictions produced as part of this study that lie within recently burned areas reflect the debris-flow likelihood that may be induced by the simulated burning of vegetation that may not represent actual postfire conditions. To assess the current debris-flow hazard in recently burned areas, we recommend consulting the USGS hazard assessment produced using observed and field-verified burn severity maps (http://landslides.usgs.gov/hazards/postfire_debrisflow). Similarly, as the data products used in our modeling approach are current as of August 2022, changes in EVT and/or fire probability that have occurred after that date (likely by recent fire) are not reflected in our model output.

Additional limitations of this study are outlined below. The climate products from NOAA Atlas14, though currently the most comprehensive estimate of rainfall-intensity climatology in the study area, quantify only the past climatology in the area rather than future climate. As a result, they may not capture changes in rainfall climatology that may result from an ongoing climate change. Additionally, many of the gage records used in the computation of the Atlas14 product are less than 50 years in duration, meaning that the 50-year 15-min product is based on extrapolation rather than true quantification of the 50-year recurrence interval storm. Furthermore, the link between drought and short-duration rainfall intensities important for runoff-generated debris-flow occurrence is poorly understood and provides an opportunity for future climate modeling work that may improve prefire predictions.

The FSim fire probability product also has several limitations. Similar to Atlas14, the weather component of the fire probability simulation is based on past climate records rather than future climate predictions. The model is also calibrated only on fires >100 ha in size, though the authors acknowledge that the role of fires smaller than this threshold on overall fire probability is likely negligible. Also, the latest statewide release of FSim is valid from August 2022, so the decreases in future fire probability present in areas burned between August 2022 and the release of this study are not captured in our products.

Conclusion

We presented a consistent methodology to model postfire debris-flow hazards in California prior to wildfire using simulated differenced Normalized Burn Ratio (dNBR) data calibrated from 2020 to 2021 fire data, NOAA Atlas 14 rainfall data, and fire probability data developed by Pyrologix. The dNBR and other data were used to predict debris-flow likelihood and volume for a 15-min rainfall intensity of 24 mm h^{-1}. The largest source of uncertainty in predicting postfire debris-flow likelihood and volume is due to the difficulty in predicting dNBR, a proxy for soil burn severity, prior to wildfire. Our approach tended to produce regionally consistent simulated dNBR while actual fires will produce a wider range in dNBR. Some areas will experience lower burn severity while other areas will experience higher burn severity. Areas that burn at high soil burn severity will experience higher debris-flow likelihood relative to debris-flow likelihoods presented here. Because the debris-flow likelihood and volume predictions are for a fixed rainfall intensity and assume that a fire has occurred, we also calculated the annual probability that a wildfire and the 15-min triggering rainfall intensity for a debris-flow likelihood of 50% will occur using NOAA Atlas14 rainfall recurrence data, the debris-flow likelihood model, and the Pyrologix fire probability product. This debris-flow product can be used to identify regions that are most likely to experience postfire debris flows. Once these regions are identified, our debris-flow likelihood and volume products can be used to target specific basins that would benefit from prefire mitigation efforts, such as improvements to stream crossings. Ultimately, these products of postfire debris-flow prediction prior to wildfire should aid prefire efforts to mitigate debris-flow risks.

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16. ABSTRACT

Currently Caltrans is searching for a methodology to determine sediment bulking specific to Northern California, In Southern California, there are specific, existing methods and equations in use by Caltrans. Due to increased wildfire occurrence and severity in northern and southern California, a regionalized sediment bulking method for California watersheds would allow Caltrans to design better hydraulic and stormwater facilities. This prepares Caltrans for climate change and the resulting increase wildfire potential to create a more sustainable roadway design.

The research will benefit Caltrans by having roadways that are more resilient and safer. The methodology can be used by local and state agencies to create safer and more sustainable infrastructure. Also, this research will provide a defensible justification and method for sizing drainage facilities that account for sediment bulked associated with wildfires.

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Regional Sediment Bulking Methods for California in Support of Post Wildfire Flood Mitigation

- Final Report -

Authors

G Mathias Kondolf, John Radke, Adrienne Dodd, Minho Kim, Anna Serra Llobet, Anthony Falzone, Vladimir Ulyashin

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1. Introduction

1.1. Background Information

Post-fire debris flows/floods are extremely dangerous geo-hazards due to their sudden onset, high velocity, and destructive power (Cui et al., 2018), and are a growing threat in California as changing climatic patterns lead to higher risk of high-burn-severity wildfires and intense rains (Silver Jackets, 2020). High soil burn severity can lead to the creation of hydrophobic soils, which increase the risk of landslides and flood hazards as the soil repels water, reducing infiltration and increasing the volume of runoff in a watershed (VanDine et al., 2005). This increased runoff reduces the rainfall threshold needed to trigger debris flows. In addition, burnt material has lower internal friction angle and cohesion, which makes it more easily mobilized (Cui et al., 2018), and loss of vegetation to fire reduces the stabilizing effect of roots and infiltration of water, increasing runoff and debris flow generation potential (Wall et al., 2020). As a result, when intense rains occur on recently burned hillslopes, debris flows and flash floods may occur (Rengers et al., 2016) Risk of erosion and post-fire debris flow decreases as vegetation recovers. Time since the last burn is an important factor affecting risk of post-fire debris flow (Hoch et al., 2021). Sediment yields from burned watersheds are highest within the first two years since the fire, after which they typically decrease by an order of magnitude, though recovery rates differ across regions and ecosystems (Robichaud et al., 2010). These realities make it important that infrastructure is designed to account for potential post-fire flood flows, whether they be normal flow, hyperconcentrated flow, or debris flow.

To account for increasing concentrations of sediment in streamflow, modelers often use bulking methods with which to increase discharge above the expected normal flow by the volume of sediment added to the flow (West Consultants, 2011; Gusman et al., 2009; Highway Design Manual: Chapter 810 - Hydrology, 2020 *Highway Design Manual: Chapter 810 - Hydrology*) Figure 1 shows a flow classification scheme based on sediment concentration and bulking factor adopted from Gusman et al. (2009). Bulking factors have been estimated based on historically observed sediment concentrations, but the data to support these estimations have been limited (Highway Design Manual: Chapter 810 - Hydrology, 2020). Bulking factors are important to predict the potential flow volume and impact area of a watershed in a flood after fire situation. There is no single, agreed upon method for identifying the bulking factor appropriate for a watershed (West Consultants, 2011), or what design event should be used to calculate sediment concentration and bulking factor. Better understanding wildfire processes and debris flow/flood processes can help to inform decision making. Burn severity is recognized to be a principal variable influencing the hydrologic effects of wildfire, so we have focused part of our work on predicting burn severity.

Flow Classification	Sediment Concentration by volume (specific gravity = 2.65)	Bulking Factor
Normal Streamflow	0 - 20	0 - 1.25
Hyperconcentrated flow	20 - 40	1.25 - 1.67
Debris/Mud flow	40 - 55	1.67 - 2.5

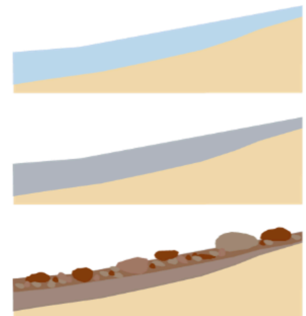


Figure 1: Flow classification by sediment concentration and bulking factors (adapted from Gusman et al., 2009)

Fire Response in Northern vs Southern California

To date, bulking factors have been applied to Southern California, as this region has long experienced wildfires and resulting debris flows, debris floods, and generally higher sediment loads, as a result of the extremely steep topography, easily erodible rocks, and high-intensity rains such as those associated with atmospheric rivers. The phenomenon of "flood after fire" has long been well documented in the San Gabriel Mountains (Munns 1920, DeBano et al 1981), and public works agencies have built debris basins, concrete channels, and other structures to manage the high runoff and sediment loads from burned watersheds. As wildfires occurred predominantly (but not exclusively) in southern California in the 20th century, bulking factors were developed for this part of the state by various agencies (US Army Corps LA District, Los Angeles County Public Works, as well as San Bernardino, Riverside, and Ventura Counties, as reviewed by WEST (2011).

With the increased extent and frequency of large wildfires in northern and central California, CalTrans has recognized the need for methods to estimate bulking factors for northern California (i.e., areas north of Santa Barbara County), which has motivated this study. Unfortunately, there have been few studies documenting post-fire runoff and sediment bulking effects in northern California, so there is still large uncertainty in predicting post-fire effects on runoff and sediment bulking in these parts of the state. As more data are compiled, we anticipate that these relations can be better specified. In the meantime, we can consider factors leading to debris flows and sediment-bulked runoff in general, and how these differ from southern to northern California. Empirically, we can see from the limited data that post-fire runoff response in Southern California tends to be twice that documented in Northern California.

Among the key factors are differences in topography and lithology (rock type and condition), differences in vegetation cover, and intensity of rainfall. The Transverse Ranges of Southern California (e.g. the San Gabriel and Santa Inez Ranges) occur at the 'Big Bend' of the San

Andreas Fault system and are thus subject to extreme compression (Crowell, 1979). As a result, these are among the most rapidly uplifting mountains in the world, with uplift rates exceeding 3 mm/y (Johnson et al., 2020). The rocks (predominantly sedimentary in the western Transverse Ranges and granitic in the eastern) are shattered from faulting and tectonic movement, making them highly erodible.

The Southern California hillslopes are dominantly covered by chaparral vegetation, which does not provide consistent shading of the ground surface. When chaparral landscapes burn, they typically burn more thoroughly than the forested slopes characteristic of northern California (DeBano et al 1981), leaving a ‘moonscape’. While there is less vegetation in the chaparral to burn, it’s common to see virtually all of the chaparral vegetation consumed by wildfire. Moreover, severely burned soils under chaparral commonly develop a hydrophobic layer that repels water and leads to increased runoff, which in turn can trigger debris flows.

Rainfalls associated with atmospheric rivers in southern California can be intense. For example, in the Santa Ynez Range above Montecito, rainfalls of over 15 mm over 5 min (3 mm/min) and over 25 mm over 15 min were recorded at two sites during the January 09, 2018 storm (Oakley et al., 2018). When the erodible rocks of these steep mountains are subjected to intense rainfalls, especially after slopes have recently been burned, the result is rapid erosion and mass wasting, including debris flows, as illustrated in Montecito in 2018, and which has occurred repeatedly, with 15 large debris flows documented over the past 200 years in Montecito alone (Serra-Llobet et al., 2023).

By contrast, the landscapes of northern California, while tectonically active, are not so extreme in their deformation rates as the Transverse Ranges. The central California Coast Ranges have uplift rates generally less than 1 mm/y (McGregor and Onderdonk, 2021), still active but not so much as the Transverse Ranges. The lithologies are not typically as shattered as those of the Transverse Ranges (though there are exceptions) and thus tend to be less inherently erodible. The slopes are generally forested, and while there is more fuel loading in the forest, these forested slopes generally do not burn as thoroughly as chaparral slopes. In most cases, there is some remnant of forest trees standing post-fire. These dead trees provide some protection for the soil against intense rains, some slope stabilization, and their roots provide pathways for infiltration. Finally, rainfall intensities are rarely comparable to the extreme rates generated by the steep orographic lift resulting from moisture-laden winds blowing from the sea up the slopes of the Transverse Ranges. Thus, all these factors tend to make debris flow production less likely in northern than in southern California. However, at this time there is little data on bulking of post-fire runoff from northern California burns, and thus inadequate empirical data upon which to base estimates of sediment bulking factors independent of the rich data set available for southern California. Thus, the approach we propose here relies on watershed characteristics first, incorporating factors that influence sediment production statewide.

1.1.1. Research scope

The CalTrans Highway Design Manual (Highway Design Manual: Chapter 810 - Hydrology, 2020) includes an approach to setting bulking factors for post-fire runoff in southern California.

The approach is described in the HDM Section 810, and outlined in a flow chart on pp.810-61 to 810-62 (*Highway Design Manual: Chapter 810 - Hydrology*, 2020). This project builds upon the existing guidance to develop a framework for estimating sediment bulking factors for design of road crossings in northern California.

Our framework includes additional physically-based variables that have become recently available statewide. The deliverables include the narrative report explaining the proposed approach, datasets in ArcGIS that can be readily accessed by district engineers, and a program developed to be a decision-support tool that automatically interrogates statewide data sets for relevant information for a given road crossing site and computes relevant variables, indicating likely flow type, while still requiring the district engineer to use professional judgment to estimate a sediment bulking factor for the site.

1.1.2. Other factors affecting post-fire floods

In addition to increased post-fire sediment loads, post-fire runoff is affected by increased clear water runoff, and non-sediment debris such as large wood and trash. The scope of our project was limited to providing guidance only for assessing *sediment bulking*, but district engineers should be aware of these other factors in the design of road crossings.

Post-fire runoff can be greater than normal runoff due not only to sediment loads, but also due to the altered hydrologic response of soils post-fire. 2-year rainstorms falling on fresh burn scars have been documented to produce runoff 10-30 times higher than would be predicted without the effects of wildfire. But of this increase, the component of bulking potentially attributable to sediment is limited to a bulking factor of 2.0 or 2.5, because of physical limitations in how much sediment can be carried by a given volume of water. The balance of the increase in runoff is attributable to hydrologic effects of reduced infiltration and consequently increased runoff.

Moreover, blockage and/or failure of stream crossings below burn scars is commonly caused by debris jams, as trash, logs, and entire trees can hang up on bridge piers or culvert intakes, trapping further debris, and ultimately plugging the culvert or bridge opening, forcing flow over or around the structure. Woody debris has been a perennial challenge for managers of bridges and culverts generally (Diehl 1997, Lassettre and Kondolf 2012); these challenges become infinitely greater in burned landscapes due to the volumes of woody debris that can be generated and transported into the stream system via debris flows and other mass movements.

Our study has focused only on bulking attributable to higher sediment loads, not the hydrologic effect of increased runoff post-fire, nor the effects of debris accumulation at culverts and bridges.

Road crossings, whether culverts or bridges will always have residual risk to flows beyond their design event. While predictions can be made for the scale of post-fire floods that could occur across culverts and bridges, in many cases it may be unrealistic to construct a culvert or bridge to the dimensions needed to pass the maximum possible bulked flows. In these circumstances, other design techniques can be used to ‘harden’ the road crossing so that even if the crossing is overtopped, the fill prism of a culvert (or the structure of a bridge) is not lost; it may be buried and require excavation post-event, but it can be restored to functionality fairly easily. A simple example would be rocking the fill prism such that an overtopping debris flow will not destroy the crossing, termed a rock-armored 'vented' crossing (Figure 2) (Cafferata et al, 2017). These crossings should be designed with a pronounced dip to effectively convey sediment and debris-charge flows without causing flow diversion or channel avulsion.

Figure 2: Examples of culvert design interventions to manage debris flow (Source: Caffereta et al., 2017. Designing Watercourse Crossings for Passage of 100-Year Flood Flows, Wood, and Sediment (Updated 2017))

1.2. Current Caltrans HDM Guidance

1.2.1. Existing bulking factor estimation process

California Department of Transportation's 2020 Highway Design Manual describes methods to identify bulking factors for debris flow modeling in Chapter 810-Hydrology. The Caltrans Highway Design Manual notes that smaller rain events, such as a 10- or 25-year rain event will require a higher bulking factor compared to larger rain events such as a 100-year storm, as there is a higher concentration of sediment (*Highway Design Manual: Chapter 810 - Hydrology*, 2020). The Highway Manual provides a flow chart laying out how district engineers should identify a bulking factor for their project area. This flowchart defines 6 steps. A simplified version of this flowchart is shown in Figure 3. The first step is for district engineers to identify "relevant watershed data" for their project area, including past debris flow events, geologic maps, soils data, aerial photos, fire history, flood history, seismic/volcanic activity, and watershed geometry. The second step, "field reconnaissance", asks district engineers to identify sediment producing features they can identify on site. The third step, "Debris Flow Likelihood", directs the engineers to consider rock type, slope, and location of site in relation to an alluvial fan. The fourth step asks district engineers to identify flow type and BF based on engineering judgment considering steps 1, 2, and 3 (normal streamflow 1-1.3, hyperconcentrated flow 1.3-1.7, debris/Mud flows 1.7-2.0). The fifth step is to follow the local agency method to calculate debris flow; if the project site is located in a region that does not have a designated method, district engineers are directed to use the LA District Method due to its use of the adjustment-transposition factor. Finally, step six directs district engineers to select a design bulking factor based on: these prior steps, project budget, and highway safety considerations (Highway Design Manual: Chapter 810 - Hydrology, 2020).

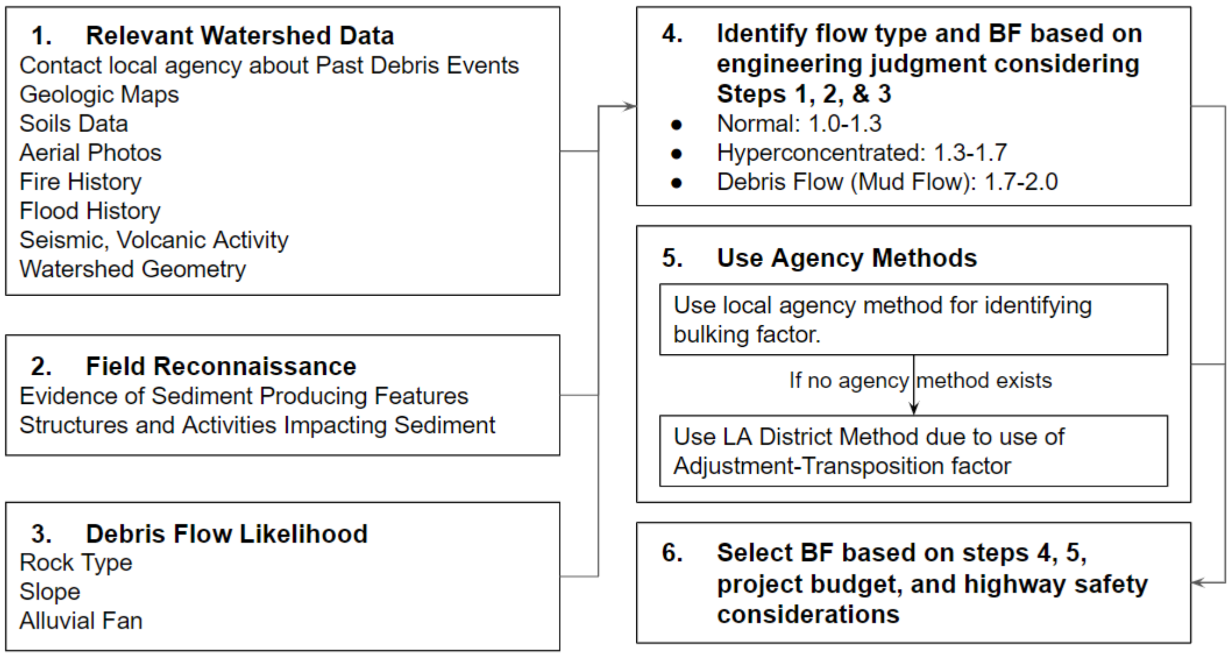


Figure 3: Current methodology given for district engineers to follow in the Caltrans HDM (adapted from Highway Design Manual: Chapter 810 - Hydrology, 2020)

1.2.2. Current limitations of existing process

The current method outlined in the HDM calls district engineers to collect datasets from various sources. The datasets are not compiled nor necessarily easy to find. Providing statewide data sets in a more readily-used format could facilitate the work of the district engineer in determining bulking factors for use in road crossing design. In addition, while the important landscape features and datasets are pointed out in the current HDM, there is no clear path forward for how district engineers should assess these datasets, what thresholds are important within these datasets, and how they should assess these many variables together to identify a single bulking factor. In addition, in the current method, after district engineers are asked to compile data in steps 1 through 3, and determine a flow type in step 4, they are asked to also complete an agency method in Step 5, and finally in step 6 take into consideration their results from both Steps 4 and 5 in addition to project budget and highway safety considerations, to decide upon a single bulking factor. There is a need for an updated method that builds on the current logic and science outlined in the HDM, with more direction on how the variables can be used together to identify an estimated sediment bulking factor.

1.3. How to Use this Report

The purpose of this report is to introduce to Caltrans decision makers and engineers a method for identifying sediment bulking factors for road crossing design with post-fire debris flow risk in mind. The report includes a literature review, proposed bulking factor estimation method, and case studies highlighting practical use of the method. The literature review introduces major concepts behind sediment laden flow and bulking factors to lay the framework for what sediment bulking factors can and can not represent. The proposed bulking factor estimation method provides a step by step walkthrough of the method, the datasets it uses, and a description of each variable used and their thresholds that influence post-fire flows. This method is designed to provide insight and direction in how landscape features and basin geometries can be analyzed to inform probable peak flow types, and estimated bulking factors. The method provides structure for how multiple variables can be assessed together, while requiring engineering judgment. This section also provides insight on the program we created to aid district engineers in gathering, processing, and downloading data for use, as well as aid in completing the analysis quickly. The case study section provides two examples of this method being used: one from Southern California, and one from North Central California. The case studies are provided to help contextualize the method, and the various opportunities for engineering judgment and refinement.

2. Literature Review

Sediment-laden flows are usually distinguished based on the concentration of sediment and its caliber. Flows can behave very differently, from a normal Newtonian fluid (flowing water carrying some sediment) to Non-newtonian flows transporting as much sediment as water. Mudflows and debris flows are perhaps the best known types of sediment-laden flows, both consisting of a flowing muddy matrix capable of suspending larger particles (including boulders). They are distinguished based on the caliber of grains in the flow. If at least half of the grains are larger than sand, it's termed a debris flow, if finer, a mudflow. Both debris flows and mudflows require steep slopes to initiate and to flow, and both eventually 'run out' as they slow on more gentle slopes. In some cases debris flows may come to rest on relatively dry land, where the matrix-supported deposits may 'set up', preserving the distinctive stratigraphy of the debris flow. But more often, the debris flow is followed by water-dominated flow, which can mobilize gravel, sand, and finer grains in the flow and transport them farther downstream, fluvially sorting them in the process, and leaving a distinctively stratified but poorly sorted, framework-supported, deposit. This type of flow is increasingly termed a 'debris flood'.

Church and Jakob (2020) define debris floods as "floods during which the entire bed, possibly barring the very largest clasts, becomes mobile for at least a few minutes and over a length scale of at least 10 times the channel width." The concept of the debris flood is important because downstream of steep mountainous reaches, we are less likely to encounter debris flows themselves and more likely to find debris floods carrying the sediment load farther downstream. Thus many highways are more likely to be exposed to debris floods than debris flows

Various classifications of sediment-laden flows have been proposed, typically ranging from fluvial transport, hyperconcentrated flow (especially with high concentrations of mud), debris floods, mud and debris flows. The types of flow most relevant for post-fire flooding are debris flow, mud flow, and debris flood. Debris flows are defined as a very rapid, to extremely rapid flow of saturated debris in a steep channel with a plasticity index less than 5% (Jakob and Hunger, 2005). If at least half of the grains are larger than sand, the flow is considered a debris flow. Mud flows are finer-grained, defined as a very rapid to extremely rapid flow of saturated debris in a channel with a plasticity index over 5% and significantly greater water content relative to sediment (Jakob and Hungr, 2005). Debris floods are defined as a very rapid flow of water in a steep channel that is "heavily charged with debris" (Jakob and Hungr, 2005). A debris flood has free flowing water present, while still containing floating debris.

In terms of management, a key feature of debris flows is their ability to transport large boulders due to the density of the flowing mud. Boulders are commonly carried in the 'snout' of the debris flow, which is followed by a slurry of mud and debris, and in many cases, by flowing water, still transporting sediment but at lower concentrations (Takahashi 1981). The bouldery snout can be exceptionally destructive of structures it encounters, and individual boulders can exceed the size of openings in bridges and culverts, causing blockages, which can then force flow out of the channel and around the obstruction, potentially destroying the structure in the process.

Church and Jakob (2020) provide a more detailed definition of a debris flood, identifying three types of debris floods based on their triggering mechanisms: 1. A debris flood caused by exceeding a shear stress threshold required for mobilizing D84 bed material; 2. A debris flood caused by dilution of a debris flow; and 3. A debris flood caused by outbreak floods from natural or artificial dams. Church and Jacob (2020) further identify subcategories based on the forces water flow imposes on the bed, but in general define debris floods as a flood where the entire bed, outside of the largest clasts, is mobilized for at least a few minutes and flows downstream a distance that is at least 10 times the channel width. A debris and sediment-laden flow can change between these specific types of flow as it passes downstream in the river system or in one location over time (Church and Jakob, 2020).

There is a specific terminology around the path of the debris flow, starting with the initiation zone, transport zone, and deposition zone (Jakob and Hungr, 2005). Debris flow initiation is often caused by slope failure, generally in areas with steep slopes between 20° to 45°. In these situations, there can be a specific location identified where the debris originated. But post-fire debris flow initiation can be caused by runoff and enhanced erosion from burned slopes. In a post-fire situation, there is an increase in sedimentation rates and runoff rates throughout the burned watershed due to burned biomass, loss of ground cover, and, depending on the fire, hydrophobic soils (McGuire et al., 2021). These conditions also increase the risk of slope failure on top of increased erosion rates.

A great deal of literature on debris flow initiation relates to the failure of colluvial wedges in hilly terrain, where sediment builds up in colluvial hollows (draws) until (usually on a time scale of multiple decades) it fails during an intense rainfall, initiating a debris flow. The US Geological Survey and other agencies devoted a great deal of research effort in the 1970s and 1980s to identifying rainfall intensities that would trigger such failures and debris flow initiation. However, in addition to this classical debris-flow generation mechanism, intense rains on recently burned soils can rapidly run off, bringing large loads of sediment and debris down slopes and into channels. It is this latter mechanism that is of greater interest for our study.

3. Proposed Bulking Factor Estimation Method

3.1. Overview of Proposed Method

The proposed method has five main steps (See Figure 4): (1) Identify the Asset's Coordinates, (2) Delineate Contributing Basin and basin Characteristics, (3) Identify flow type and corresponding bulking factor ranges, (4) Refine the Bulking Factor Estimation, and (5) Calculate Bulking Factor. While this method is a framework that can be processed using geospatial software (e.g., ArcGISPro), we developed a decision-support tool to help streamline and accelerate the GIS processing and calculation steps by generating a bulking factor estimate within minutes. In the Appendix, we provide extensive technical documentation, detailed explanations on installation and implementation, and other relevant metadata and specifications. The case studies in Sections 4.2 were produced using this decision-support tool and we provide the datasets, source code, documentation, and a video explaining how to run the code.

Guiding Engineering Judgment for Estimation of a Suitable Bulking Factor Using GIS Data

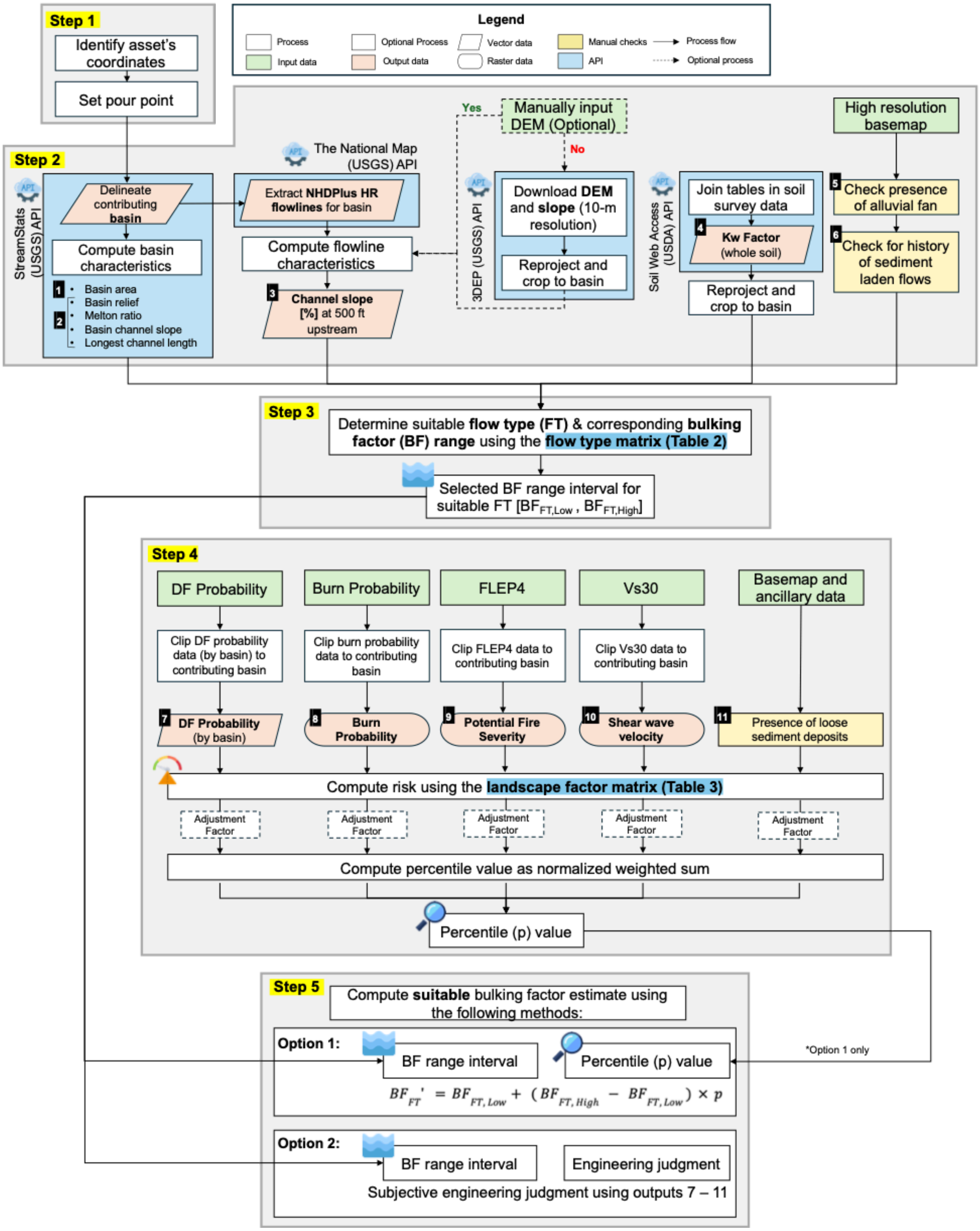


Figure 4. Flowchart of the proposed method

3.2. GIS Datasets and Input Variables

3.2.1 Basin area

Staley et al. (2016) conducted studies of post-fire debris flows in Southern California and the intermontane western US, all of which had contributing basin areas of 0.02 to 8km^2, which is the range seen as most likely to see debris flows. Recently, Ebel (2024) identified an upper limit of basin area for post-fire floods after assessing 61 post-fire debris flows and 119 post-fire floods. While these cases were measured from around the world, the majority were from western United States. This study highlights the importance of contributing basin area in informing magnitude of expected peak flow as well as in informing expected flow type in a post-fire flood scenario. In addition, Ebel (2024) found that while unburned watersheds can have an upper limit of ~100km^2, the upper limit of the basin area for post-fire floods based on an envelope regression estimation was 23 to 34km^2, with a decline with areas >23km^2 according to a power law relation (Ebel, 2024). Cannon et al. (2010) saw similar basin areas in their assessment of 64 post-fire debris flows in the Western United States, none of which had basin greater than 30km^2. Due to these considerations, we use >23km^2, 8-23km^2, and 0.02-8km^2 as the basin area threshold for normal flow, hyperconcentrated flow, and debris flows.

There is an important caveat to consider when using drainage area as a variable, especially for larger basins. There is broad agreement, reflected in research to date (e.g., Cannon et al. 2010, Staley 2016, Ebel 2024) and in comments from the Technical Advisory Committee, that drainage area is an important variable for analyzing debris flow potential. As noted by multiple authors, most debris flows initiate in basins of less than 8 km^2. However, this does not imply that the debris flow vanishes at the point that the drainage area reaches 8km^2. Rather, we see a 'run-out' from the debris flow downstream. Commonly the debris flow will mix with fluvial flow from another tributary and transition into a debris flood (hyperconcentrated flow), which may continue flowing downstream for some distance if the slope is sufficient. The runout from the debris flow/flood may continue downstream to points where the drainage area may exceed 23 km^2, and thus a site whose drainage area exceeds 23 km^2 may still receive a debris flow (or more likely debris flood) from upstream. This is illustrated by our case study on Big Creek (Monterey County) after the Dolan Fire (See Section 4.3).

3.2.2 Channel slope

The slope of the stream channel is important because it tells us about potential runout. As noted in West Consultants (2011), the National Research Council (1996) identified slopes of 10-14% as the downstream limit of higher concentration, coarse debris flows, and 3.5-5.3% as the downstream limit of dilute debris flows. Similarly, and also noted by West Consultants (2011), Stock and Dietrich (2003) identified slopes of 3-10% to be the approximate downstream limit for general debris flows. Taking these factors into consideration, we chose the threshold of a 3% channel slope as defining the end of any potential sediment-laden flows. While runout can occur on upwards of 5 to 10% slopes, we took the lowest slope as our threshold. In our method, slopes above 3% could potentially see any type of flow, and are not limited to normal flow, while slopes <3% are identified as likely to see normal flow. Slope is calculated as a percent by taking the change in elevation divided by the distance (so-called “rise over run”) and multiplying it by 100.

$$S = (dh / dl) \times 100$$

where S is slope as a percent, dh is the change in elevation, and dl is the distance over which the elevation drops.

3.2.3 Melton ratio and watershed length

Wilford et al. (2004) identified the Melton ratio used in combination with watershed length as the most important factors to distinguish between flood, debris flow, and debris flood prone basins. The Melton Ratio is the basin relief divided by the square root of the basin area, while the watershed length is the straight-line distance from the watershed outlet to the most distant point. The basin relief is the difference in elevation between the highest and lowest points in the watershed, and is considered within the melton ratio calculation. Wildford et al. (2004) conducted experiments in British Columbia, Canada and identified class limits that help distinguish what type of flow basins are prone to, with a Melton ratio <0.3 indicating a basin is more prone to normal flooding, a Melton ration between 0.3-0.6 or >0.6 with length >1.677 miles indicates a basin more prone to debris floods, and finally a Melton ratio >0.6 with a watershed length <1.677 miles indicates a basin is more prone to debris flows (Wilford et al., 2004; Jackson, 1987; Bovis and Jakob, 1999). In our method, we compute the watershed length as the largest straight-line distance from the point of interest (where the asset is located) to the farthest located point on the watershed boundary.

3.2.4 Kw factor

As defined in the National Soil Survey Handbook, Kw factor is a soil erodibility factor that quantifies potential soil erosion due to runoff and rain splash. Kw factor considers the whole soil, even larger particle sizes, while Kf factor only considers fine-earth particles less than 2.0mm. Kw factor values range from 0.02 to 0.69, the lower the value the less susceptible to detachment and erosion, the higher the value the more susceptible to detachment and erosion. According to the National Soil Survey Handbook, the most important properties in the K-factor variables are texture, organic matter content, structure size class, and the saturated conductivity of the subsoil. In this method, we direct Caltrans district engineers to use the Kw factor as a variable to help determine potential flow type, as the erodibility of the soils in a contributing basin informs the amount of sediment available for transport. We use the following thresholds for low, moderate, and high erodibility:

$$\text{low} \;\; \leq 0.2 \leq \;\; \text{moderate} \;\; \leq 0.4 > \;\; \text{high}$$

(USDA-NRCS-MICH, 2002). While these values have not been directly linked to a flow type, we suggest using these thresholds for normal flow, hyperconcentrated flow, and debris flow for the time being. That being said, the thresholds used can be altered and changed by district engineers based on engineering judgment and new information. In our method, we compute the Kw factor of the dominant component and use the average value found in the contributing basin for subsequent calculations.

3.2.5 Alluvial fans

In general, alluvial fans are evidence from past sediment laden flows of the region of deposition and runout. If the project location for a culvert or bridge is directly upstream of or on an alluvial fan, we can assume that the sediment laden flows that formed the alluvial fan must have passed the site of the culvert or bridge, and that comparable, future flows would likewise pass through the site of the road crossing.

3.2.6 History of sediment laden-flow

Similar to the alluvial fan variable, which is itself lasting physical evidence of a history of sediment laden flow on the landscape, this variable is up to the district engineer to identify and manually define. Outside of alluvial fans, is there evidence of a history of hyperconcentrated or debris flows in the project site? We would not expect to find an alluvial fan form in a canyon (because the canyon wall constriction prevents the flow expansion essential to fan formation), so we must look for other evidence of past flows. These could include maintenance records, news articles of past debris flows at the site, other field evidence, or anecdotal reports from residents or experienced engineers (who may be retired but available to share their experience). If there is no evident history of sediment laden-flows, that does not necessarily rule out past events. Rather, in assessing the potential for sediment-laden flows, this variable can be skipped (as 'ND', no data). If there is a known history, this variable will add more value to hyperconcentrated or debris flow.

3.2.7 Debris flow likelihood model

The Post-Fire Debris Flow Likelihood (PFDFL) data is created by using the logistic model developed in Staley et al. (2016), which integrates slope (>23 degrees), soil burn severity (moderate and high via differenced Normalized Burn Ratio), and soil erodibility (rock-free K-Factor). While the training dataset used in Staley et al. (2016) is predominantly from southern California and may overestimate risk in Northern California, we assume that the PFDFL dataset can be a useful measurement to help gage a level of risk. California Geological Survey (CGS) has identified classified probabilities within the PFDFL data, dividing the probability percents by equal intervals across five classes from 1 to 5; 1 = 0-20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80%, and 5 = 80-100%. In discussion with CGS, and following their categorization of debris flow likelihood, we use the following thresholds for low, medium, and high probability of debris flows: P<40%, 40% ≤ P < 60%, and P>60%, with the classified probability groups 1 and 2 being low, 3 being medium, and 4 and 5 being high. We use the PFDFL predictions for 15-min 24mmh at basin scale and average them to generate a single value for subsequent calculations. PFDFL predictions are made by USGS after major fires using observed burn severity data, but these are limited to areas that have already burned. To allow for future predictions to be made ahead of potential wildfires, CGS has created a synthetic burn severity dataset for the state, and a predictive PFDFL dataset for the state. We recommend using this dataset created by CGS for this analysis in order to assess possible bulking factors in areas that have not yet burned.

3.2.8 Burn probability

Following a wildfire, burned fuels and debris can lead to hydrophobic soil conditions and an increased risk of debris flow when triggered by intense rainfall (Jakob et al., 2005). To account for the likelihood of a fire occurring and the potential to increase debris flow risk, we use burn probability computed from thousands of stochastic simulations of various fire-climate scenarios using a physics-based fire spread simulation model called Fire Simulation (i.e., FSim) (Finney et al., 2011) provided as statewide datasets by the USFS (Short et al., 2020; Scott et al., 2024). Burn probability represents an annual likelihood of a fire's occurrence at a given location (i.e., chance of burning in any given year) and is a function of vegetation and wildland fuels from LANDFIRE, historical fire data, terrain, and weather parameters. The burn probability dataset is produced at 270m spatial resolution and upsampled to 30 m, and for California, annual burn probability ranges from 0 to 12%. We use thresholds of 0-5%, 5-10% and >10% as ranges for low, moderate, and high burn probability ranges. Further, we average the burn probability values in the contributing basin for subsequent calculations.

3.2.9 Potential fire severity

The amount of moderate to high severity burn is a key variable in many post-fire debris flow likelihood models that connects wildfires and subsequent debris flow occurrence. As a proxy measure of potential fire severity, we used 4ft flame length exceedance probability (FLEP4) data produced as an output from FSim (Finney et al., 2011), which represents the likelihood a given location will have flames larger than 4 feet in length (Short et al., 2020; Scott et al., 2024). Yu et al. (2023) used FLEP4 with burn probability to model the probability of wildfires causing moderate to high severity burns in regional watersheds. This metric ranges from 0 to 100% and we use thresholds of 0-25%, 25-50% and >50%. Further, we average the FLEP4 values in the contributing basin for subsequent calculations.

3.2.10 Shear wave velocity in the upper 30m (Vs30)

Shear wave velocity is a measure of the speed at which body waves move through the earth. This velocity is dependent upon the characteristics of the rock and soil, such as particle density, bulk density, packing arrangement, number of particle contacts, and ambient stress conditions (Moss and Lyman, 2022). Shear wave velocity has long been used to predict impacts of seismic shaking, and liquefaction, looking at how stiff, or solid rock and sediment are and how resistant they may be or prone they may be for liquefaction. The higher the velocity, the denser the sediment is, while the lower the velocity the looser the sediment is leading to it being more prone to liquefaction, lateral spreading, flow failures, and other ground failures (Moss and Lyman, 2022). Moss and Lyman (2022) test the use of Vs30 as a proxy for sediment shear stiffness in the Staley debris flow likelihood model, replacing Kf factor with Vs30 to see how this variable impacts prediction reliability. They found that Vs30 variables provide similar results as the original Staley method which uses the Kf factor, showing the potential of Vs30 to inform debris flow predictions. Wills et al. (2015) created a shear wave velocity dataset for California which we use in our method to inform soil and rock conditions. The range of Vs30 values in this dataset for California is 0-733.4 m/s. There are no standard thresholds for determining low, moderate, or high shear wave velocity. We use 0-250, 250-500, and >500 m/s as ranges for low, moderate, and high Vs30 ranges, with the higher ranges relating to more stable soils and rocks with less vulnerability to failure. These thresholds can be modified by the district engineer. In our method, we use the updated Vs 30 dataset provided by Thompson (2018) which provides data at a higher resolution of 3 arcseconds instead of 7.5 arcseconds. We average the Vs30 values in the contributing basin for subsequent calculations.

3.2.11 Presence of Loose Sediment

Presence of loose sediment deposits in a contributing basin means there are easily erodible sources of sediment that can bulk flows. Examples of such deposits include landslides, mass wasting, alluvial fans, debris basins, reservoirs, elevated railroad beds, and mining operations. In this method, the presence of loose sediment is a variable assessed by the district engineer who will determine if there are loose sediment deposits, and if so, decide if the amount of loose sediment deposits will likely impact the bulking or not. If “Yes”, that means the sediment deposits are likely to impact flow and will direct the district engineer towards the higher end of the bulking factor range. This variable can also be left out of the assessment and not influence bulking factor refinement if there are no or so little sediment deposits it is unlikely to impact flow, or if district engineer choses to leave it out. Reasons for the variable to be left out may include lack of sufficient data, or lack of confidence in the data. Assessment of this variable may require a site visit to the contributing basin, and/or a desktop assessment of aerial images, landslide databases, mining databases, railroad databases, or other data depending on how the district engineer choses to do their assessment.

3.2.12 Limitations of Using Ancillary Data Generated By Third Parties

There are a number of caveats to consider when using spatial data generated by third parties. For example, a 30 meter DEM from a USGS data site will simplify the slope of a stream channel and may bias the variables generated from this data. This is a common problem of data fusion where data is coming from various third parties who generated it under different specifications to solve unrelated problems. DEMs are a good example of this as they often range from 1 to 30 meter resolution. In this example, our process and facilitating software allows for the substitution of higher spatial resolution input data, such as a DEM generated from Lidar, to be integrated into the solution if an engineer, from field observation, feels the downloaded DEM from the USGS does not best represent the surface used to calculate the slope of a stream channel.

Each year the gathering and processing of data measuring the landscape is becoming more accurate and better at representing the physical characteristics of the earth. In short, the GIS based data is becoming available at higher spatial resolutions. As a result, the calculation of bulking factor estimates will likely improve over time using our method.

3.3. Spatial Analytical Process Using GIS data

3.3.1. Step-by-step walkthrough

Step 1. Identify Asset's Coordinates

The first step for the Caltrans District Engineer is to identify the coordinates of their asset or road crossing.

Step 2. Delineate Contributing Basin and Basin Characteristics

The second step is to delineate the contributing basin for the asset and the basin's key characteristics: relief, area, slope, watershed length, and Melton Ratio. Once the basin is delineated and a shapefile is created for the basin, the district engineer will be able to download all needed data for the basin region itself.

Step 3. Identifying flow type and corresponding bulking factor ranges

The third step is to identify expected peak flow type, which will give district engineers a bulking factor range to work with. We have identified six variables for use in informing expected peak flow type at the project location: 1. Basin area, 2. Channel slope, 3. Melton Ratio with Watershed Length, 4. Soil erodibility Kw factor (Table 2), 5. presence of an Alluvial Fan at project location, and 6. history of sediment laden flows. In this method, each variable (v_i) has thresholds corresponding to an expected flow type: normal flow, hyperconcentrated flow, or debris flow. District engineers will assess all six variables in their project basin and what peak flow type each variable directs them to. The average is then calculated to identify probable flow type for the project location considering all six variables. To calculate the average flow type of all six variables, a score (α_i) is given to each variable based on if that variable's threshold points to normal flow, hyperconcentrated flow, or debris flow. A score of 1 is given to normal flow, a score of 2 is given to hyperconcentrated flow, and a score of 3 is given to debris flow.

Table 1: Scores allocated to each flow type and corresponding bulking factor range

Score (α_i)	Flow type	Bulking Factor Range *Upper and lower bound values can be changed
1	Normal flow	0 - 1.25*
2	Hyperconcentrated flow	1.25 - 1.67*
3	Debris flow	1.67 - 2.00*

Once scores are given to all six variables, the average is calculated to identify the final flow type score for the project location. This is done by dividing the sum of the scores by the total number of variables. In some situations, it is possible that not all variables will be used in the assessment, if that is the case the total number of variables can be less than 6. Three of the variables, channel slope, presence of an alluvial fan at project location, and history of sediment laden flows, have the potential to direct one to "any flow type possible", in which case that variable will not be considered. Once the average score is identified, it is used to determine the estimated peak flow type. The standard procedure is to round the final averaged score to the closest integer: 1 meaning normal flow, 2 meaning hyperconcentrated flow, and 3 meaning debris flow; and then use the expected BF range for that flow type. But, if a district engineer gets a final score of, say, 2.5, and wants to use a BF range between hyperconcentrated and debris flow instead of rounding directly up to debris flow, they can choose to do that.

$$Flow\ Type = \frac{1}{n}\sum_{i=1}^{n} \alpha_i$$

Table 2. Variables and thresholds for determining suitable flow type and bulking factor range. The bulking factor range shown in the table is retrieved directly from the HDM.

#	**Flow Type**	**Any flow type possible**	**Normal Flow**	**Hyperconcentrated Flow/ Debris flood**	**Debris Flow**
	Bulking Factor Range (E.g., HDM)	**-**	**0 - 1.25**	**1.25 - 1.67**	**1.67 - 2.00**
	Score for Normalized Sum Calculation	**-**	**+1**	**+2**	**+3**
1.1	**Area of Basin**	-	>23km^2	8 - 23km^2	0.02 - 8km^2
1.2	**Channel Slope (500ft upstream of asset)**	≥3%	<3%	-	
1.3	**Melton Ratio and Watershed length**	-	Melton <0.3	Melton 0.3-0.6; or >0.6 with watershed length >1.677 mi	Melton >0.6 with watershed length <1.677 miles
1.4	**Kw Factor**	-	≤0.20	>0.2;≤0.4	>0.4
1.5	**Alluvial fan** ***Manual entry**	None	-	Upstream / on	
1.6	**History of Sediment laden flow** ***Manual entry**	Unknown/None	-	Yes	

Example:
For instance, these are the scores each variable would get with the following site conditions: (1) Area of basin of 8-23km^2, this variable will get a score of 2; (2) a channel slope greater than 3%,

you will ignore that variable and not include it in the average as this threshold directs you to any flow type; (3) a Melton ratio >0.6 with a watershed length <1.677miles, this variable will get a score of 3; (4) has a Kw factor between 0.2 and 0.4, this variable will get a score of 2; (5) is on an alluvial fan, this variable will get a score of 3; and (6) has a history of sediment laden flow, this variable will get a score of 3. In this scenario, five variables are used, and you have scores of 3, 2, 3, 3, 2. The sum of all these variable scores is 13. Divide this sum by the total number of variables, 5, which gives you the average, 2.6. This average rounded to its closest integer is 3, directing you to a debris flow as the peak probable flow type based on these landscape features. The district engineer can decide the bulking factor range based on this probable flow type information.

Step 4. Refine the Bulking Factor Estimation

Once a probable flow type is identified in Step 3 and the district engineer has a Bulking Factor range, they must decide which value within the selected range is appropriate for use at their site. Step 4 leads the user through five variables that can inform the scale of sediment bulking in a basin. The five variables (x_i) are: 1. Post Fire Debris Flow Likelihood (PFDFL), 2. burn probability, 3. potential fire severity, 4. Shear wave velocity (Vs30) in basin, and 5. Presence of loose sediment deposits in basin (Table 3). The first four variables are connected to spatial datasets that are automatically created for the study area when using the program developed for this method. The fifth variable must be researched by the district engineer and manually entered.

In Step 4, a method is laid out for combining these variables as a weighted average, and then using the result as a percentile for identifying a bulking factor in Step 5. The district engineer can use this quantitative method to assess these variables, or can choose to assess the variables using engineering judgment to decide on the bulking factor in Step 5, or a combination of both.

The conceptual logic behind this step is similar to the calculation for the flow type in Step 3; however, since we have already identified the flow type and therefore the bulking factor range, here, each variable is given a threshold defining low, medium, and high risk as opposed to flow type. Adjustment factors can be used to change the risk value higher or lower based on engineering judgment (adjustment factors less than 1 lower the risk of that variable, adjustment factors over 1 increase that risk). Then, we consider the average of the *weighted* sum of the variables and use the resulting value as a *percentile* to calculate a specific Bulking Factor from the range identified in Step 3.

Our method assesses each variable (x_i) and records a score (β_i) based on thresholds of “risk” defined in Table 2:

$$\beta_i = \begin{cases} \mathbf{1}\ if\ Low\ Risk \\ \mathbf{2}\ if\ Moderate\ Risk \\ \mathbf{3}\ if\ High\ Risk \end{cases}$$

Similarly to Step 3, we use integer values of 1, 2, and 3 for the scores, though these scores represent low, medium, and high risk of sediment laden flows instead of flow type. These scores are calculated for all "*n*" variables based on the thresholds shown in Table 3. To further refine the estimation, users have the option to add adjustment factors (w_i) to each of the variables. These adjustment factors can be set by the district engineer if they want the scores to be lowered or raised due to site knowledge, or specific site conditions the datasets are not sensitive to, thus providing a flexible parameter for further engineering judgment. The adjustment factors can be any value between 0 and 3. Once each variable is given a score, and multiplied by their adjustment factor, they are combined as a weighted sum then divided by the total number of variables to find the average. This average is then divided by the highest possible score (β_{max}) to normalize the result and make it into a percentile (p) from 0-1 as described in the following equations:

$$A = \frac{1}{n}\sum_{i=1}^{n} w_i \times \beta_i$$

$$p = \frac{A}{\beta_{max}}$$

Where:

A is the average of the weighted sum

n is the total number of variables included in the assessment

w_i is the adjustment factor (weight) for each variable

β_i is the score for each variable

p is the percentile as a value between 0 and 1

β_{max} is the highest score possible, which is 3 in this method

These two equations can be simplified into one equation as shown below. Here we find the percentile (p) directly by calculating the normalized average of the weighted sum.

$$p = \frac{1}{n \times \beta_{max}}\sum_{i=1}^{n} w_i \times \beta_i$$

The resulting percentile (p) will be a number between 0 and 1, and can then be used as a percentile to identify a refined bulking factor in Step 5. 1 is the maximum value for the percentile. If the percentile is anything above 1, it will be set to 1.

Table 3. Variables considered for bulking factor refinement. Weights are shown as uniform in the table, but are modifiable as long as the sum of all adjustment factors equals the total number of variables used.

#	**Feature**	**Adjustment Factors**	**Low (+1)**	**Moderate (+2)**	**High (+3)**
2.1	**Post-fire debris flow likelihood (P)**	w_1	P < 40%	40% ≤ P < 60%	P > 60%

2.2	**Burn probability**	w_2	P < 5%	5% ≤ P < 10%	P > 10%
2.3	**Potential fire severity (FLEP4)**	w_3	P < 25%	P ≤ 25% < 50%	P > 50%
2.4	**Vs30m shear wave velocity to 30m depth (1:24,000 scale)**	w_4	>500 m/s	250-500m/s	<250 m/s
2.5	**Presence of Loose Sediment deposits in basin** ***Manual entry**	w_5	-	-	Yes

Example: We can calculate the percentile for a site with the following conditions where we use an equal weighting of 1 for each variable: 2.1 Post-fire debris flow likelihood of 40% ≤ P < 60%, would be a score of 2; 2.2 Time since last fire <10, would be a score of 1; 2.3 burn probability of 50, would be a score of 2; 2.3 Potential fire severity of high, would be a score of 3; 2.4 Shear Wave velocity of 250-500m/s would be a score of 2; and 2.5 Presence of loose sediment determined to be moderate, would be a score of 2. Here we use all six variables with weighted scores of 2, 1, 2, 3, 2, 2, the sum of which is 12. Plugin this into the equations above, we get 2.4 for the average weighted score, and 0.8 for the percentile.

$$A = \frac{1}{5}12 = 2.4$$
$$p = \frac{2.4}{3} = 0.8$$

Step 5. Calculate Bulking Factor

In Step 5 you identify the refined bulking factor value (BF_{FT}') from the BF range identified in Step 3. In step 5 the user can use engineering judgment to assess the variables and result of step 4, and identify a bulking factor for themselves, or they can directly use the equation provided. The normalized average of the weighted sum from Step 4 is a percentile (p) used for relative scaling. The percentile (p) from Step 4 informs you on how severe the sedimentation may be in your project location based on the landscape features and conditions. Find what that percentile (p) is in your bulking factor range ($BF_{FT,Low}$ to $BF_{FT,High}$) to identify an estimated bulking factor. You can use the following equation to identify what that refined bulking factor (BF_{FT}') would be:

$$BF_{FT}' = BF_{FT,Low} + (BF_{FT,High} - BF_{FT,Low}) \times p$$

where:

BF_{FT}' is the refined Bulking Factor value

$BF_{FT,Low}$ is the minimum value in the BF range

$BF_{FT,High}$ is the maximum value in the BF range

p is the desired percentile

Example: If your expected flow type is Debris Flow, and your BF range is 1.67-2.00, and your average weighted sum from Step 4 is 2.4, which is 80% of 3, then your normalized average weighted sum is the percentile (p) 0.8, and your final BF value will be the 0.8 percentile of 1.67-2.00 which is a bulking factor of 1.93, as shown in the following equation:

$$BF_{FT}' = 1.67 + (2.00 - 1.67) \times (.8) = 1.93$$

As the decision maker, I may choose to use the bulking factor calculated: 1.93, or I may choose to take this as a consideration, and alter it based on engineering judgment.

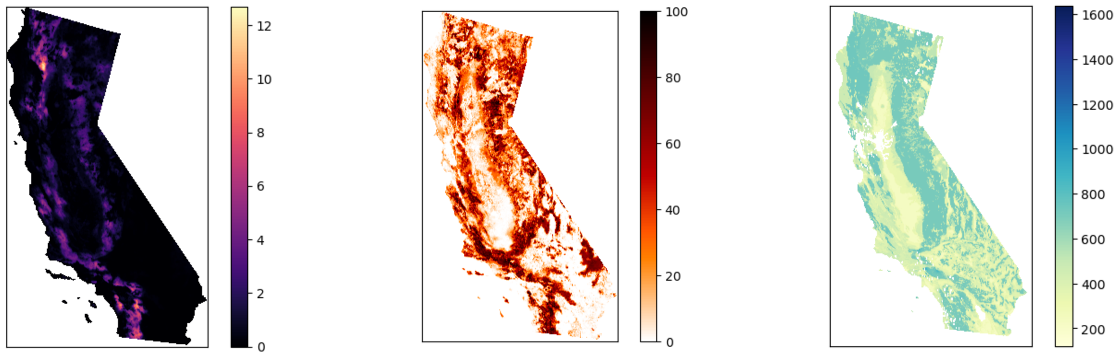
3.3.2. Data collection

(1) Input data

Statewide datasets are downloaded and can be stored locally while very large datasets (eg. high resolution DEMs and slope raster datasets) are not stored locally. Instead, we download these large datasets in real-time from their corresponding web service as preprocessed datasets for a specific region of interest (e.g., case study of a basin of interest). In Table 4, we organized these datasets and their applications in deriving variables used in our method. We also show their file formats and original data sources. To note, the “Deliverable” column indicates the “statewide” datasets shown below in Figure 5, and are provided together with the coded program. “Case study” datasets are downloaded and preprocessed in real-time using the APIs for specific basin extents. For users who do not use the coded program, DEM, slope, and Kw Factor can be obtained from their respective original sources, as linked in Table 4.

Table 4. Main datasets used in our coded program

#	Statewide Dataset	Applied Variables	Format	Deliverable	Original Source
1	DEM	• 3.2.1: Basin area • 3.2.3: Melton ratio	Raster (.tif)	Case study	USGS
2	Slope	• 3.2.2: Channel slope	Raster (.tif)	Case study	USGS
3	Slope [%]		Raster (.tif)	Case study	USGS
4	Kw Factor	• 3.2.4 Kw Factor	Shapefile (.shp)	Case study	USDA (SSURGO)
5	Burn probability	• 3.2.9: Burn probability	Raster (.tif)	Statewide	USFS
6	Potential fire severity	• 3.2.10: FLEP4	Raster (.tif)	Statewide	USFS
7	Shear wave velocity	• 3.2.11: Vs30	Raster (.tif)	Statewide	USGS (Thompson, 2018)



Burn probability [%]

Potential fire severity [%]

Shear wave velocity (Vs30) [m/s]

Figure 5. Provided statewide datasets

(2) Case study data

Aside from statewide datasets, for case studies, we also need datasets and information regarding specific regions of interest (i.e., contributing basin). These datasets include point information (i.e., latitude and longitude) of the asset of interest and PFDFL data (See Section 3.2.7). PFDFL data is computed for a select number of past wildfires as part of emergency assessments of post-fire debris flow hazards by the Landslide Hazards program in USGS. PFDFL data can be accessed on their website: https://landslides.usgs.gov/hazards/postfire_debrisflow/.

Users can input a preprocessed or refined shapefile of the contributing basin to substitute for the automatically generated one by the StreamStats API. Similarly, a preprocessed or refined shapefile of the flowlines can also be inputted to substitute for the flowlines extracted from the NHDPlus high resolution dataset. This substitution is important when automatically extracted shapefiles of the contributing basin and their flowlines may not be fully representative or accurate.

(3) Application Programming Interfaces (APIs)

We use Application Programming Interfaces (APIs) in the program we developed to help ease and accelerate data collection, as shown in Table 5. We used the StreamStats API to delineate the contributing basin, compute basin characteristics, and compute flow statistics. In addition, we use *HyRiver*, an established Python package designed with APIs to web services, for the collection of large hydrology and climatology datasets (Chegini et al. 2021). First, we use this package to obtain up to 12 different topographic data variables from 3DEP web services. Our program specifically uses this package to download DEM, slope (measured in degrees), and slope percentage, which are automatically downloaded, reprojected, and cropped to the given extent and coordinate reference system. Second, we use this package to download flowline data from The National Map web services. We use the NHDPlus high resolution flowlines dataset, which is available statewide and was built using the National Hydrology Dataset High

Resolution data at 1:24:000 scale, 3DEP topographic data at 10-m resolution, and the Watershed Boundary Dataset. The NHDPlus high resolution flowlines is an upgrade over the previous version (NHDPlus Version 2), providing much more detail and millions of additional flowline vector features. Lastly, we use *pysda*, a public python package included as a part of the USGS' National Cooperative Soil Survey's collection of repositories. We use this package to query and access soil survey data (Kw factor) from the Soil Data Access web services provided by USDA's Natural Resources Conservation Service.

Table 5. Main datasets from global datasets (see Table 4) acquired via APIs

API	Usage	Source
py3DEP (HyRiver)	DEM and slope	https://github.com/hyriver/py3dep
pyNHD (HyRiver)	NHDPlus High resolution flowlines	https://github.com/hyriver/pynhd
pysda	Kw factor from SSURGO	https://github.com/ncss-tech/pysda/

3.3.3: Data outputs

Our program outputs raster (.tif) and vector (.shp) GIS datasets at the basin and channel scale. All rasters are produced using a coordinate reference system of NAD83 / Conus Albers (EPSG code: 5070) to facilitate measurement calculations and minimizes distortion by facilitating a projection for the entire state. Vector shapefiles are also provided in NAD83 / Conus Albers.

Table 6. Output GIS datasets

Variable	Units	Format	Download Method	Dataset Source
DEM	m	Raster (.tif)	Downloaded via web services API Chegini et al. (2021)	USGS
Slope Percent (basin)	%			
Slope Degrees (basin)	Degrees			
Slope Percent (channel)	%			
Slope Degrees (channel)	Degrees			
Vs30	m/s		Thompson, E.M., 2018	
Burn probability	%		Scott et al., 2024	USDA
FLEP4	%		Scott et al., 2024	USDA
Contributing basin	-	Shapefile (.shp)	Downloaded via web services API (StreamStats)	USGS
Point of interest	-		-	-
Upslope channel at 500ft	-		-	-
Flowlines	-		Downloaded via web services API Chegini et al. (2021)	USGS
Kw factor	-		Downloaded via web services API (SSURGO)	USDA
Summary table of results	-	Comma separated values (.csv)	-	-

4. Case Studies

4.1. Background and Purpose of Case Study Application

We chose two case study sites to run this method on as examples of the workflow. One site is the Murphy Creek culvert in the 2021 Dixie fire footprint along the Feather River in Plumas County, California. The post-fire flood occurred in November, 2022 and overwhelmed the culvert. The other site is the Big Creek bridge in the 2020 Dolan fire footprint along Big Creek in Big Sur, California. The post-fire flood occurred in January 2021, but the bridge was not damaged. We have chosen these locations to run a preliminary pilot study and show what this method looks like when used to specify the bulking factor for a culvert and a bridge.

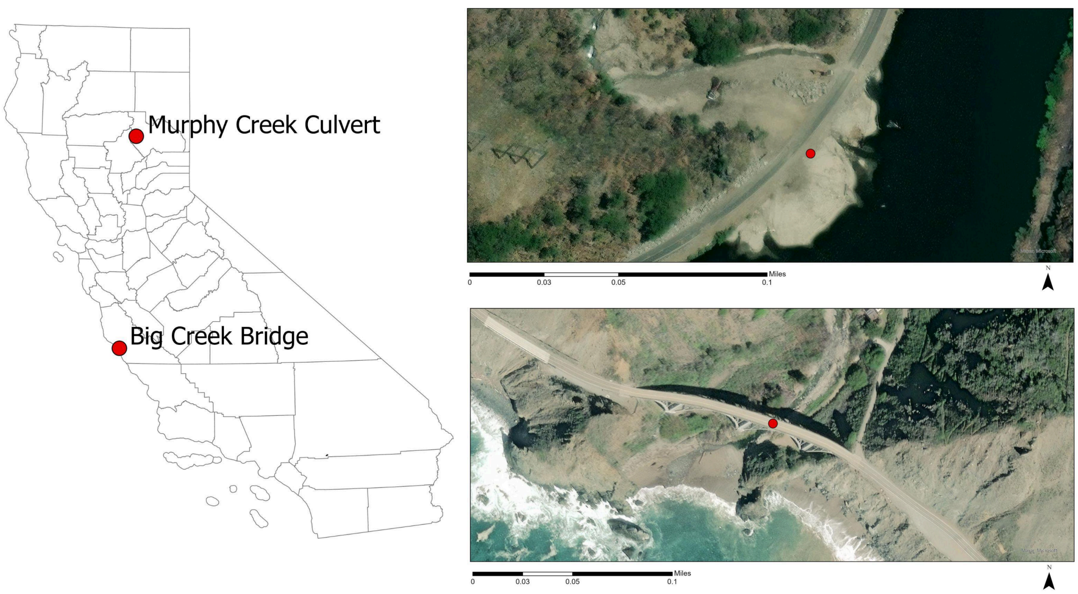


Figure 6. Case Study locations: Murphy Creek culvert and Big Creek bridge

4.2. Assessing Murphy Creek, Hwy 70

Step 1. Identify Asset's Coordinates

Step 1 is to identify the asset's coordinates. Murphy Creek culvert along Route 70 is located at 121.2804053°W 39.9918156°N. The post fire flood brought debris down through the tributary and took out the culvert, as can be seen in the aerial image of the site in Figure 7.

Figure 7. Murphy Creek Culvert

Step 2. Delineate Contributing Basin and Basin Characteristics

Step 2 is delineating the contributing basin, and gathering the data that describe the basin characteristics. In this step we generate the base GIS datasets needed to compute the variables required for expected flow type estimation and bulking factor refinement in Steps 3, 4, and 5. First, we extract the contributing basin using the StreamStats API and compute basin characteristics and flow statistics (Figure 8). Then, we compute the DEM and slope datasets from the 3DEP API (Figure 9). We have the option of downloading these datasets and opening them in ArcPro ourselves, or running the analysis through the program provided. Once we know the contributing basin and have its shapefile, we can download all the data necessary for our basin that will be used in the following steps.

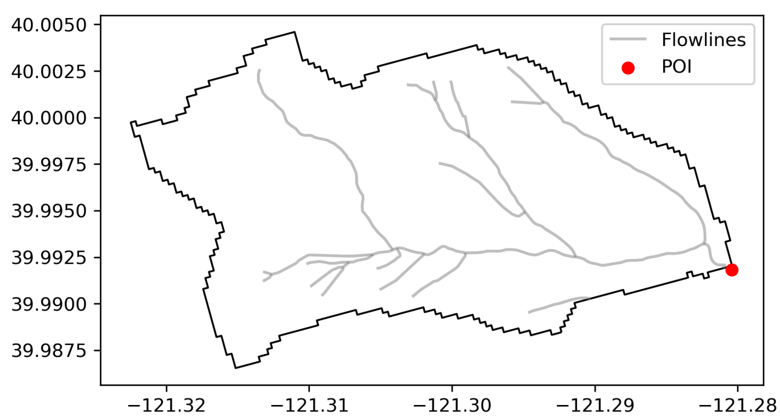


Figure 8. Basin and flowline characteristics calculated using the StreamStats API

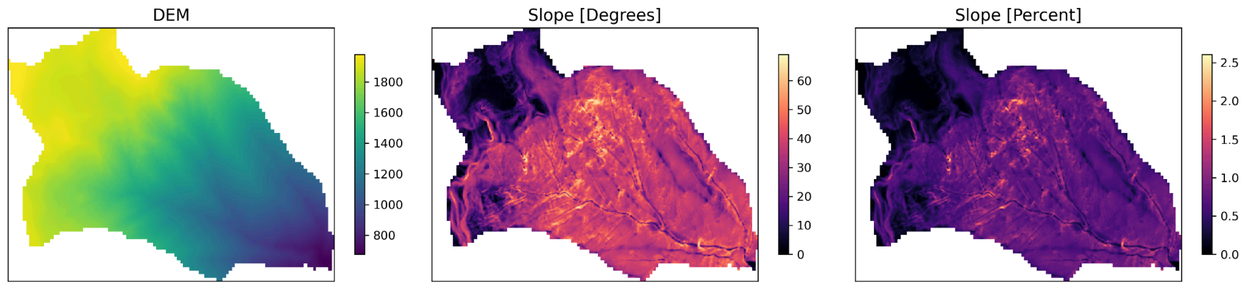
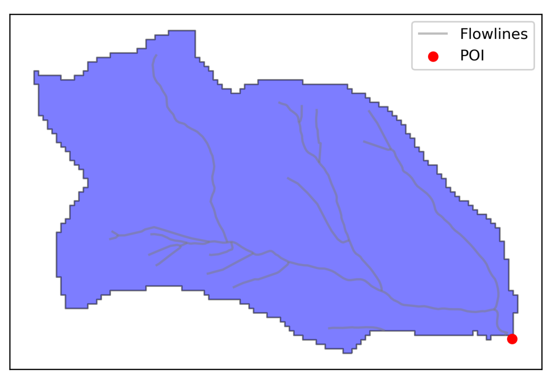
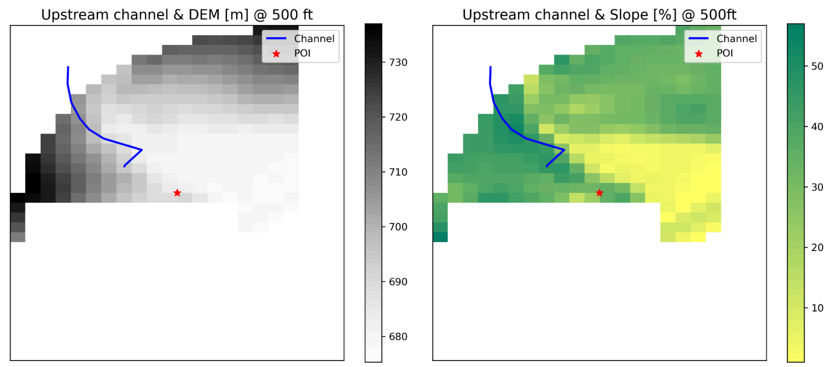
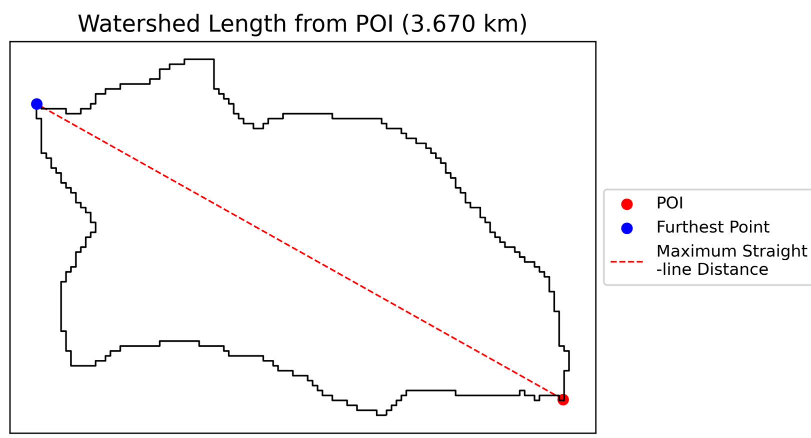
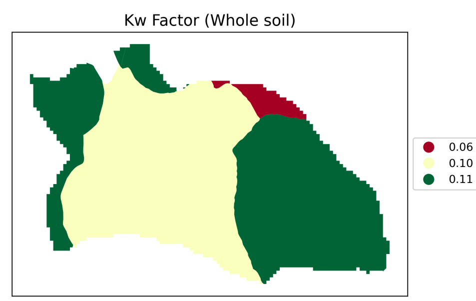


Figure 9. Topographic data clipped to the contributing basin

Step 3. Identifying flow type and corresponding bulking factor ranges
In Step 3 we identify the probable peak flow type for Murphy Creek culvert. We gather the data for each of the six variables used to determine probable flow type: 1. Basin area, 2. Channel slope, 3. Melton ratio and watershed length, 4. Erodibility Kw factor, 5. Alluvial Fan, and 6. History of sediment laden flow. Spatial datasets are used to assess the first four variables, but the last two variables: the presence of an alluvial fan and history of sediment laden flow, is determined by the user and requires a manual entry. When using the program we developed, the spatial datasets are automatically downloaded, preprocessed and stored to your local machine and can be visualized as shown in Table 7.

Table 7. Variables used in Step 3 for Murphy Creek and a visualization of the datasets produced by the program

#	Variable	Visualization
3.2.1	Basin area	

3.2.2	Channel slope	
3.2.3	Melton ratio and watershed length	
3.2.4	Kw Factor	
3.2.5	Alluvial fan	Manual
3.2.6	History of sediment deposits	Manual

An assessment of these variables can be seen in Table 8. The basin area is 4.39km^2 , which falls within the threshold for a debris flow, with a score of 3. The Channel slope is 37.28%, which falls within the threshold of any flow type possible, meaning this variable is not considered. The melton ratio is 0.62 and the watershed length is 3.67km, which falls within the threshold for a hyperconcentrated flow, with a score of 2. Kw factor is 0.1, which falls within the threshold of normal flow, with a score of 1. Manual assessment of the presence of an alluvial fan at the project location was that the culvert was in fact on top of an alluvial fan, which falls within the threshold for either hyperconcentrated or debris flow, with a score of 3. The final variable, history of sediment laden flow, was unknown, leading to this variable not being considered. In total, 4 of the 6 variables were used in this case.

Table 8. Results of the Step 3 Murphy Creek Culvert Variable Assessment

#	Flow Type	Any Flow Type Possible	Normal Flow	Hyperconcent-rated Flow	Debris Flow	Results
	Bulking Factor Range (E.g., HDM)	**-**	**0 - 1.25**	**1.25 - 1.67**	**1.67 - 2.00**	
	Score for Normalized Sum Calculation	**-**	**+1**	**+2**	**+3**	
3.2.1	Basin area	-	>23km^2	8 - 23km^2	0.02 - 8km^2	4.39 km^2
3.2.2	Channel Slope (500ft upstream of asset)	≥3%	<3%	-		37.28%
3.2.3	Melton Ratio & Watershed length	-	Melton <0.3	Melton 0.3-0.6; or >0.6 with watershed length >1.677 mi	Melton >0.6 with watershed length <1.677 miles	0.62 & 3.67 km
3.2.4	Kw Factor	-	≤0.20	>0.2;≤0.4	>0.4	0.10
3.2.5	Alluvial fan	None	-	Upstream / on		Yes
3.2.6	History of Sediment laden flow	Unknown/None	-	Yes		None

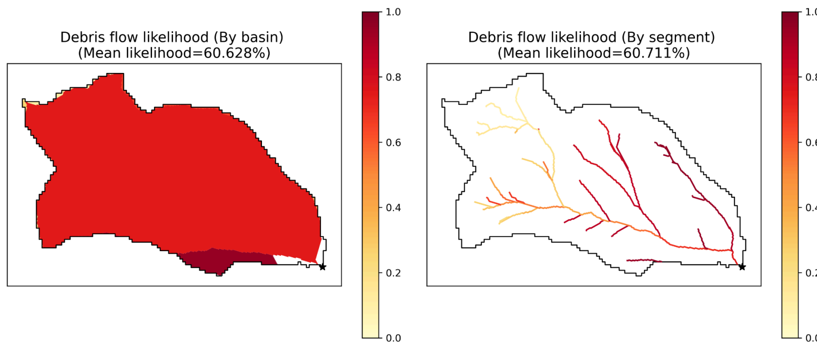
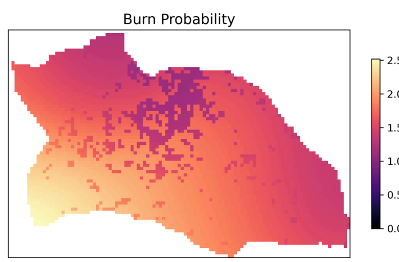
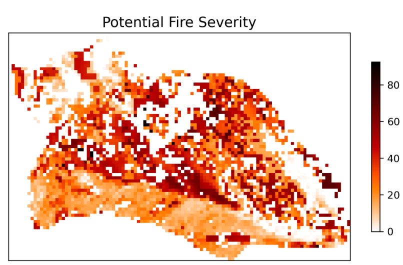
The average of these scores is then calculated to identify the flow type and corresponding bulking factor range interval. The average score for this site is 2.25, which is rounded down to 2, which directs us to expect a hyperconcentrated flow. In this assessment we are considering a Q100 event, and use a bulking factor range of 1.25-1.67 for hyperconcentrated flows. The calculations for this can be seen below. When using the program we developed these calculations will be done automatically once all the variables are set, but the calculation can be done manually as well if preferred by the district engineer.

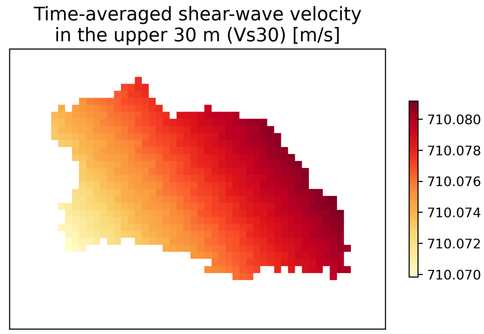
Calculation:
(3) Calculate Average Flow Type score
$Flow\,Type = (3 + 2 + 1 + 3) / 4 = 2.25$
Suitable flow type: Hyperconcentrated
Corresponding bulking factor range interval: [1.25, 1.67]

Step 4. Refine the Bulking Factor Estimation

In step 4 we use five more variables to identify a refined bulking factor from the range identified in Step 3. Five variables are used in this step: 1. Post Fire Debris Flow Likelihood, 2. Burn Probability, 3. Potential Fire Severity, 4. Shear wave Velocity of 30m (Vs30), and 5. Presence of loose sediment deposits. The first four variables are based on spatial datasets and are created automatically for the study site by the program. The final variable, presence of loose sediment, requires the user to assess for themselves and provide a manual entry of the result. You can see the data created and used in this step in Table 9.

Table 9. Variables used in Step 4 for Murphy Creek and a visualization of the datasets produced by the program

#	Variable	Visualization
3.2.7	PFDFL	
3.2.8	Burn probability	
3.2.9	Potential fire severity	

3.2.10	Vs30m shear wave velocity	
3.2.11	Presence of loose sediment deposits	Manual

The assessment of each variable can be seen in Table 10. In this step, each variable can be given an adjustment factor to scale their importance. This adjustment factor serves as a way to scale the variable according to engineering judgment. This provides an opportunity for engineering judgment to be used. For this scenario we are using equal adjustment factors for each variable. The post-fire debris flow likelihood for this basin is 60.63%, falling within the high risk category, with a score of 3. The burn probability variable is 1.70%, falling within the low risk category, with a score of 1. The potential fire severity variable is 21.52%, falling within the low risk category, with a score of 1. The shear wave velocity variable is 710.08m/s, falling within the low risk category, with a score of 1. The presence of loose sediment deposits variable is a manual entry, our assessment found no loose sediment deposits in the basin, meaning this variable was skipped in the calculation.

Table 10. Results of the Step 4 Murphy Creek Culvert Variable Assessment

#	Variable	Adjustment Factor	Low (+1)	Moderate (+2)	High (+3)	Results
3.2.7	Post-fire debris flow probability (P)	1	P < 40%	40% ≤ P < 60%	P > 60%	60.63%
3.2.8	Burn probability	1	< 5%	5 % < P < 10%	> 10%	1.70%
3.2.9	Potential fire severity	1	< 25%	25% < P < 50%	> 75%	21.52%
3.2.10	Vs30m shear wave velocity	1	>500 m/s	250-500m/s	<250 m/s	710.08 m/s
3.2.11	Presence of Loose Sediment deposits in basin	1	-	-	Yes	None

Next, we calculate the percentile as shown below, resulting in a percentile of 0.5.

Calculation:
(2) Calculate percentile (p) using β scores for each variable:

$$p = ((1 \times 3) + (1 \times 1) + (1 \times 1) + (1 \times 1)) / (4 \times 3) = 0.5$$

Step 5. Calculate Bulking Factor

In the final step, we calculate the refined bulking factor using the percentile from step 4 to identify what value from the bulking factor range should be used. In step 3 we identified the probable flow type to be hyperconcentrated, with a given Q100 BF range of 1.25-1.67. For Murphy Creek culvert we get a bulking factor of 1.46. The calculation can be seen below.

Calculation:
(3) Calculate BF:

$$BF = 1.25 + (1.67 - 1.25) \times 0.5 = 1.46$$

Final bulking factor estimate = 1.46
Total elapsed time = 122.3 seconds (2.04 minutes)

4.2.1 Impact of Engineering Judgment: Adjusting the Weights for Murphy Creek

We can adjust the relative weight of each variable in Step 4 based on engineering judgment around the risk that variable represents for our site. For instance, if we see that in general PFDFL overpredicts for northern California, we may want to reduce the level of risk this variable shows by giving it an adjustment factor less than 1. But, the sum of all adjustment factors must equal the total number of variables used. So, if we lower the PFDFL adjustment factor to 0.8, we need to increase other adjustment factors by 0.2. In this case, we know that Vs30 is an important variable for rock strength, and so we can increase the risk that Vs30 variable shows by changing its adjustment factor to 1.2. This would lead to a percentile of 0.466, and a slightly lower bulking factor than if we did not change the adjustment factors.

Table 11. Results of the Step 4 Murphy Creek Culvert Variable Assessment

#	Variable	Adjustment Factor	Low (+1)	Moderate (+2)	High (+3)	Results
3.2.7	Post-fire debris flow likelihood (P)	0.8	P < 40%	40% ≤ P < 60%	P > 60%	60.63%
3.2.8	Burn probability	1	< 5%	5 % < P < 10%	> 10%	1.70%
3.2.9	Potential fire severity	1	< 25%	25% < P < 50%	> 75%	21.52%
3.2.10	Vs30m shear wave velocity	1.2	>500 m/s	250-500m/s	<250 m/s	710.08 m/s
3.2.11	Presence of Loose Sediment deposits in basin		-	-	Yes	None

Calculation:
(2) Calculate percentile (p) using β scores for each variable:

$$p = ((0.8 \times 3) + (1 \times 1) + (1 \times 1) + (1.2 \times 1)) / (4 \times 3) = 0.466$$

4.3 Assessing Big Creek, Hwy 1

The area of the contributing basin for Big Creek bridge is over 57km^2. Using the thresholds derived from the literature and discussed with the TAC, such a basin would be expected to produce only normal fluvial flows. And due to the large basin area, this case study is probable to have a long watershed length, and low Melton ratio, indicating a low likelihood of a sediment-laden flow. Yet we know that following the Dolan Fire (August 2020), an intense winter rain (Jan 2021) produced a debris flood that passed under the Hwy 1 bridge, leaving a 2-3m thick deposit of stratified sand and gravel, characteristic of debris floods. We were able to observe this deposit after conducting a field visit to the site. Looking into why the method does not predict such an event sheds light on the limitation of the widely-used morphology criterion for predicting debris flows likelihood.

During the January 2021 storm, debris flows initiated in the downstream-most tributaries above the bridge: Cathedral Creek, which drains about 2km^2 and whose confluence with Big Creek is about 2.9 km upstream of the Hwy 1 bridge, and Brunette Creek, which drains about 2.6km^2 and which joins mainstem Big Creek about 1.6 km upstream of the bridge (Figure 10). In this case, debris flows were generated on small, steep tributary basins, and the sediment flowed downstream as a debris flood to reach the bridge. As of summer 2021, there were 2-3-m thick deposits of mostly stratified sediments flanking the lower 2 km of Big Creek, classic debris-flood deposits (Dodd, 2021; DeWit et al., 2022; Olsen, 2023).

As illustrated by our case study application, neither our method – nor relations published by other researchers relating drainage area to debris flow occurrence – predict a sediment laden flow at the bridge. The Big Creek experience highlights the importance of engineering judgment when determining flow type and the final bulking factor. It further highlights the importance of looking into the history of any documented past sediment-laden flows, as important background information for the district engineer’s evaluation. With this history in mind, we can run through the Big Creek case study.

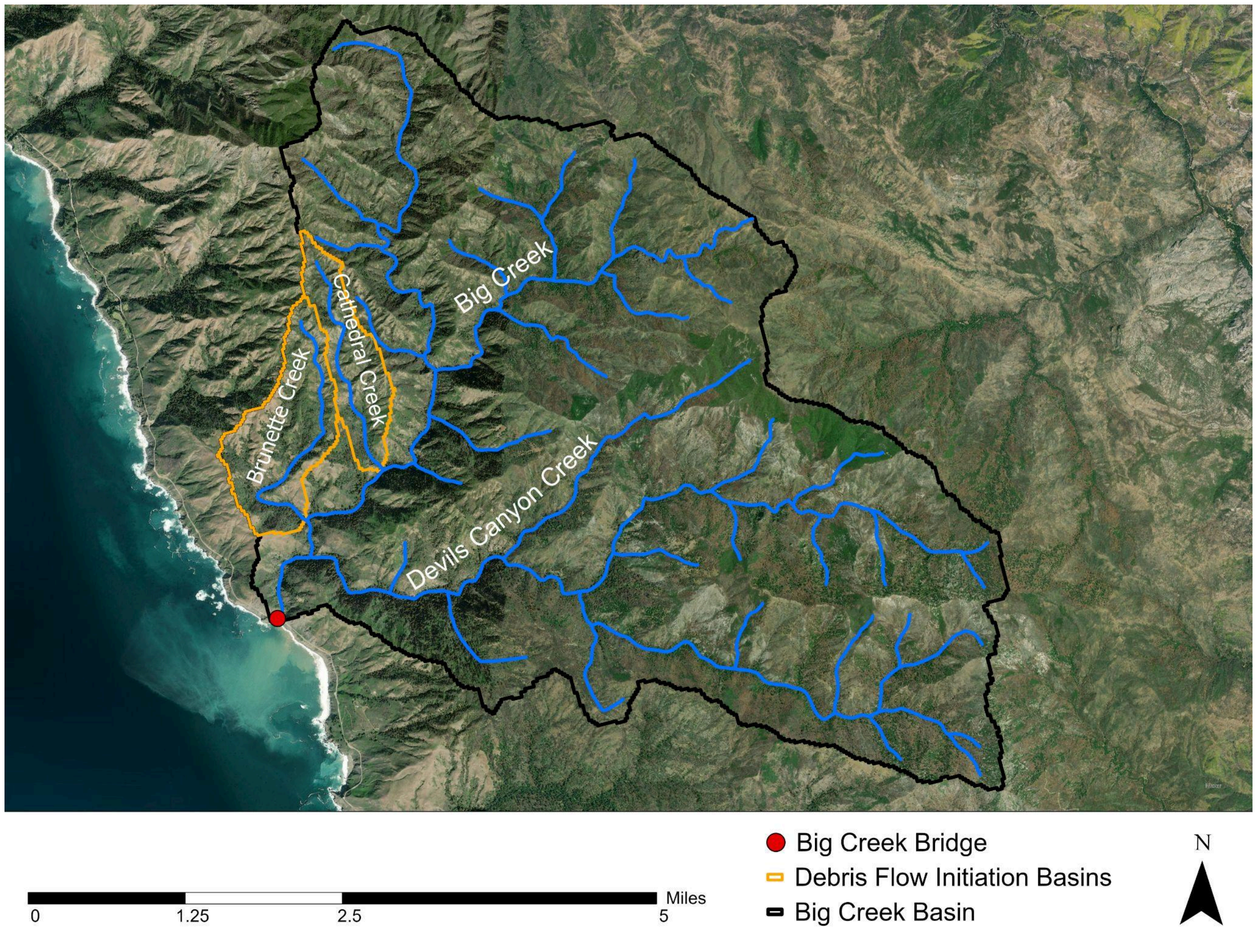


Figure 10. Big Creek Bridge Contributing Basin and the Basins in which debris flows were initiated.

Step 1. Identify Asset's Coordinates

Step one is to identify the asset's coordinates. The Big Creek crossing is located at 21°35'57.2"W, 36°04'13.1"N as seen in Figure 11. The post-fire flood brought debris from the recently burned basin, but this bridge is 65 ft high and over 500 ft long, so it was not impacted by the debris flow and flood.

Figure 11. Big Creek Bridge

Step 2. Delineate Contributing Basin and Basin Characteristics

Step two is delineating the contributing basin, and gathering the data that describe the basin characteristics. In this step we generate the base GIS datasets needed to compute the variables required for expected flow type estimation and bulking factor refinement in Steps 3, 4, and 5. First, we extract the contributing basin using the StreamStats API and compute basin characteristics and flow statistics (Figure 12). Then, we compute the DEM and slope datasets from the 3DEP API (Figure 13). We have the option of downloading these datasets and opening them in ArcPro ourselves, or running the analysis through the program provided. Once we know the contributing basin and have its shapefile, we can download all the data necessary for our basin that will be used in the following steps.

Note that following the convention of other studies and our proposed method, we do not calculate debris flow probability separately for each small subwatershed, only for the aggregate drainage area draining to the bridge crossing. But as we know the debris flows in Cathedral and Brunette Creeks were able to run-out downstream as far as the Hwy 1 bridge, we can see that the actual physical process is not well represented by the calculations conducted over the entire 57km^2 basin.

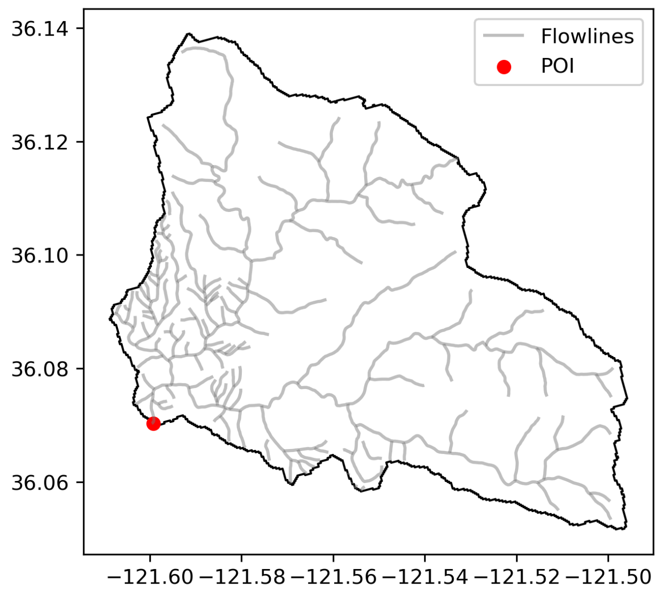


Figure 12. Basin and flowline characteristics calculated using the StreamStats API

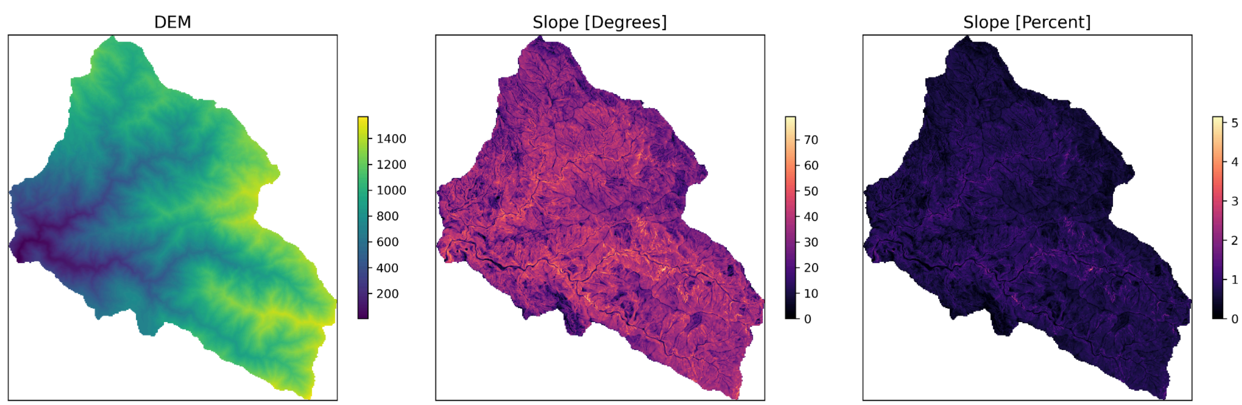
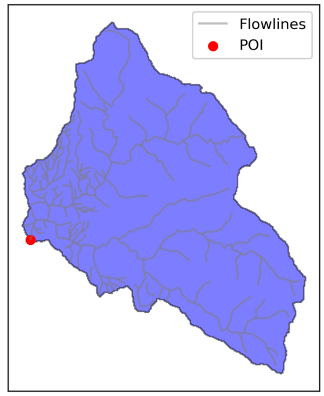
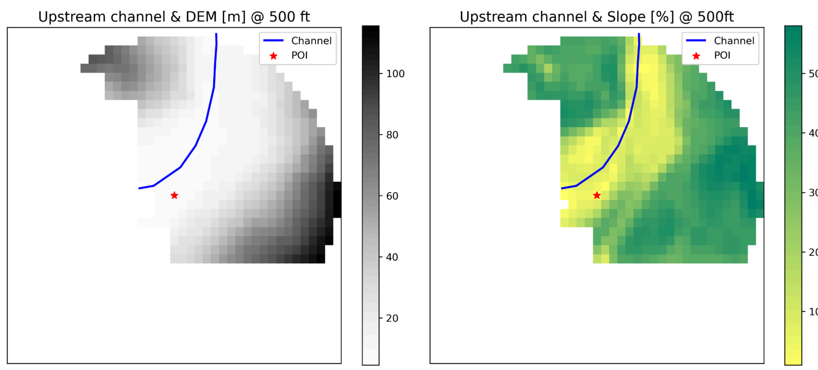
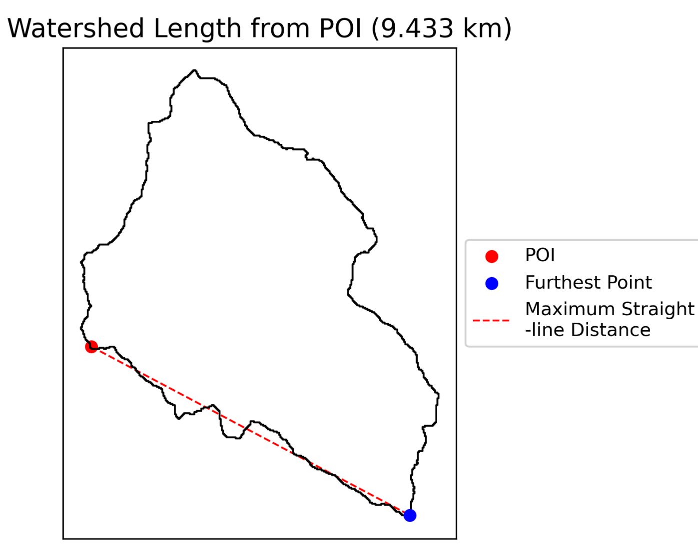


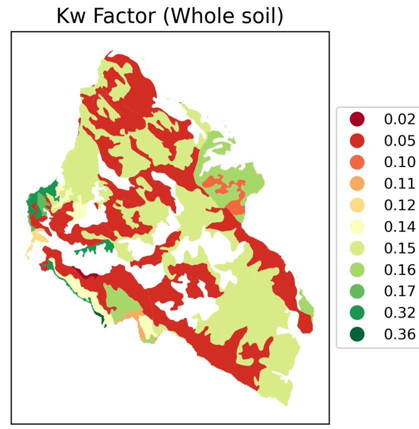
Figure 13. Topographic data clipped to the contributing basin

Step 3. Identifying flow type and corresponding bulking factor ranges

In Step 3 we identify the probable peak flow type for the Big Creek crossing. We gather the data for each of the six variables used to determine probable flow type: 1. Basin area, 2. Channel slope, 3. Melton ratio and watershed length, 4. Erodibility Kw factor, 5. Alluvial Fan, and 6. History of sediment laden flow. Spatial data is used to assess the first four variables, but the last two variables: the presence of an alluvial fan and history of sediment laden flow, is determined by the user and requires a manual entry. When using the program we developed, the spatial data is automatically created and downloaded to your computer as can be seen in Table 12.

Table 12. Variables used in Step 3 for Big Creek Bridge and a visualization of the datasets produced by the program

#	Variable	Visualization
3.2.1	Basin area	
3.2.2	Channel slope	
3.2.3	Melton ratio and watershed length	

<table>
<tr><td>3.2.4</td><td>Kw Factor</td><td>
</td></tr>
<tr><td>3.2.5</td><td>Alluvial fan</td><td>Manual</td></tr>
<tr><td>3.2.6</td><td>History of sediment deposits</td><td>Manual</td></tr>
</table>

An assessment of these variables can be seen in Table 13. The basin area is 57 km^2 , which falls within the threshold for a normal flow, with a score of 1. The Channel slope is 21.00%, which falls within the threshold of any flow type possible, meaning this variable is not considered. The melton ratio is 0.21 and the watershed length is 9.43km, which falls within the threshold for a normal flow, with a score of 1. Kw factor is 0.12, which falls within the threshold of normal flow, with a score of 1. The variables 'presence of an alluvial fan' and 'history of sediment laden flow' were unknown, leading to them not being considered. (Big Creek passes in a confined canyon all the way to its mouth, thus there would be no open valley bottom providing an opportunity for the creek to develop an alluvial fan.) In total, 3 of the 6 variables were used in this case.

Table 13. Results of the Step 3 Big Creek Bridge Variable Assessment

#	Flow Type	Any Flow Type Possible	Normal Flow	Hyperconcent-rated Flow	Debris Flow	Results
	Bulking Factor Range (E.g., HDM)	-	0 - 1.25	1.25 - 1.67	1.67 - 2.00	
	Score for Normalized Sum Calculation	-	+1	+2	+3	
3.2.1	Basin area	-	>23km^2	8 - 23km^2	0.02 - 8km^2	57.52km^2
3.2.2	Channel Slope (500ft upstream of asset)	≥3%	<3%	-		21.00%

3.2.3	Melton Ratio & Watershed length	-	Melton <0.3	Melton 0.3-0.6; or >0.6 with watershed length >1.677 mi	Melton >0.6 with watershed length <1.677 miles	0.21 & 9.43 km
3.2.4	Kw Factor	-	≤0.20	>0.2;≤0.4	>0.4	0.12
3.2.5	Alluvial fan	None	-	Upstream / on		None
3.2.6	History of Sediment laden flow	Unknown/None	-	Yes		None

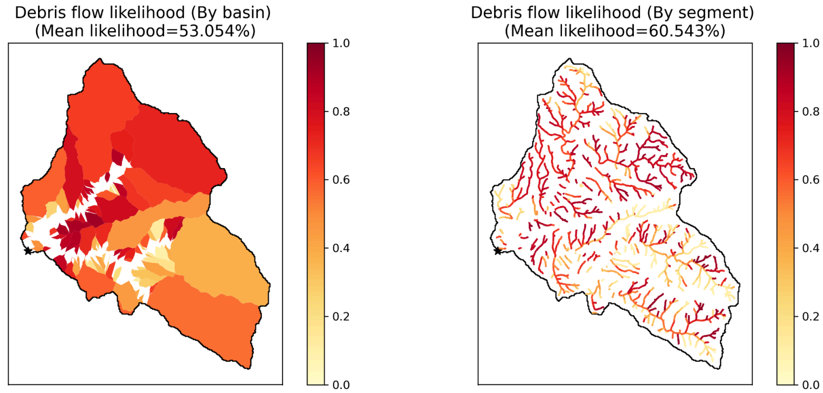
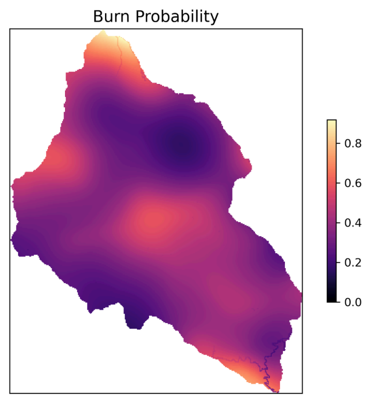
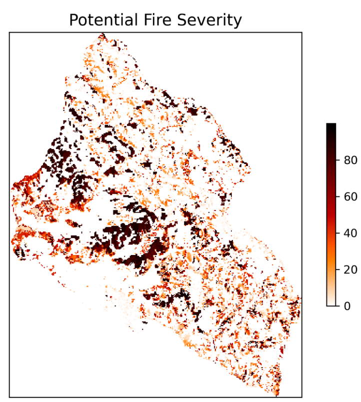
The average of these scores is then calculated to identify the flow type and corresponding bulking factor range interval. The average score for this site is 1, which directs us to expect a normal flow. In this assessment we are considering a Q100 event, and use a bulking factor range of 0-1.25 for normal flows. The calculations for this can be seen below. When using the program we developed, these calculations will be done automatically once all the variables are set, but the calculation can be done manually as well if preferred by the district engineer.

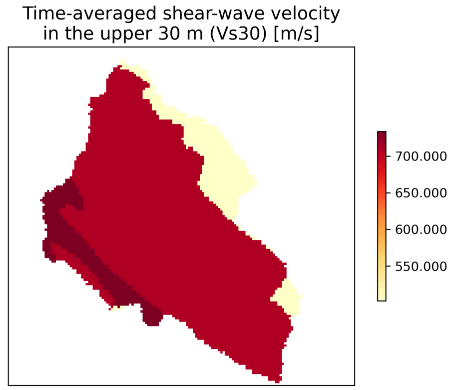
Calculation:
(3) Calculate Average Flow Type score
$Flow\,Type \;=\; (1 + 1 + 1)\,/\,3 \;=\; 1$
Suitable flow type: Normal
Corresponding bulking factor range interval: [0, 1.25]

Step 4. Refine the Bulking Factor Estimation
In step 4 we use five more variables to identify a refined bulking factor from the range identified in Step 3. Five variables are used in this step: 1. Post Fire Debris Flow Likelihood, 2. Burn Probability, 3. Potential Fire Severity, 4. Shear wave Velocity of 30m (Vs30), and 5. Presence of loose sediment deposits. The first four variables are based on spatial datasets and are created automatically for the study site by the program. The final variable, presence of loose sediment, requires the user to assess for themselves and provide a manual entry of the result. You can see the data created and used in this step in Table 14.

Table 14. Variables used in Step 4 for Big Creek and a visualization of the datasets produced by the program

#	Variable	Visualization

3.2.7	PFDFL	
3.2.8	Burn probability	
3.2.9	Potential fire severity	

3.2.10	Vs30m shear wave velocity	
3.2.11	Presence of loose sediment deposits	Manual

The assessment of each variable can be seen in Table 15. In this step, each variable can be given an adjustment factor, or weight, to scale their relative importance. This provides an opportunity for engineering judgment to be used. For this scenario we are using equal weighting for each variable, meaning we do not want to adjust the scores of these variables. The post-fire debris flow likelihood for this basin is 53.05%, falling within the moderate risk category, with a score of 2. The burn probability variable is 0.38%, falling within the low risk category, with a score of 1. The potential fire severity variable is 14.19%, falling within the low risk category, with a score of 1. The shear wave velocity variable is 686.53m/s, falling within the low risk category, with a score of 1. The presence of loose sediment deposits variable is a manual entry, our assessment found no loose sediment deposits in the basin, meaning this variable was skipped.

Table 15. Results of the Step 4 Big Creek Bridge Variable Assessment

#	Variable	Adjustment Factor	Low (+1)	Moderate (+2)	High (+3)	Results
3.2.7	Post-fire debris flow probability (P)	1	P < 40%	40% ≤ P < 60%	P > 60%	53.05%
3.2.8	Burn probability	1	< 5%	5 % < P < 10%	> 10%	0.38%
3.2.9	Potential fire severity	1	< 25%	25% < P < 50%	> 75%	14.19%
3.2.10	Vs30m shear wave velocity	1	>500 m/s	250-500m/s	<250 m/s	686.53 m/s
3.2.11	Presence of Loose Sediment deposits in basin	1	-	-	Yes	None

Next, we calculate the percentile using the calculation shown below, resulting in a percentile of 0.417.

Calculation:
(2) Calculate percentile (p) using β scores for each variable:

$$p = ((1 \times 2) + (1 \times 1) + (1 \times 1) + (1 \times 1)) / (4 \times 3) = 0.417$$

Step 5. Calculate Bulking Factor
In the final step, we calculate the refined bulking factor using the percentile from step 4 to identify what value from the bulking factor range should be used. In step 3 we identified the probable flow type to be normal flow, with a given Q100 BF range of 0-1.25. For the Big Creek crossing we get a bulking factor of 0.521. The calculation can be seen below.

Calculation:
(3) Calculate BF:

$$BF = 0 + (1.25 - 0) \times 0.417 = 0.521$$

Final bulking factor estimate = 0.521
Total elapsed time = 211.8 seconds (3.53 minutes)

4.3.1 Impact of Engineering Judgment: Adjusting the Basin for Big Creek

In order to address the possible problem of sediment-laden flow potential being hidden by the geometries of a large watershed, when working within a large watershed district engineers have the option of running the method again on smaller basins within their project's contributing basin. We provide an example of this using the Big Creek Bridge case study as an example. We made a sub-basin within the Big Creek bridge watershed for Brunette and Cathedral Creeks (Figure 14). Using this sub-basin, we re-ran the case study to see what the results would be considering just these nearest tributaries along Big Creek.

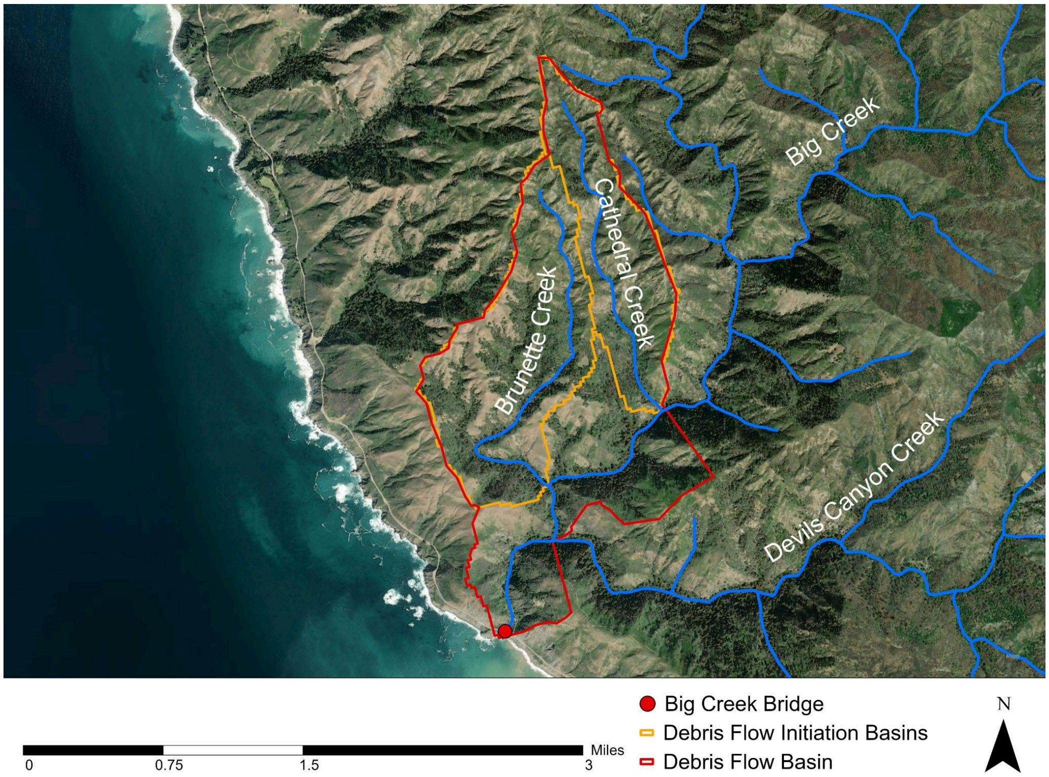


Figure 14. Sub-basin for tributaries of Big Creek created for further assessment.

Step 2. Delineate Contributing Basin and Basin Characteristics

Step 1 was the same, but in Step 2, we created the new sub-basin in ArcPro using the basins created in StreamStats for Brunette Creek, Cathedral Creek, and Big Creek tributary to create the outline. Then we used our manually created basin shapefile in the program to calculate the watershed geometries and download all needed datasets. The sub-basin shapefile and its flowlines can be seen in Figure 15.

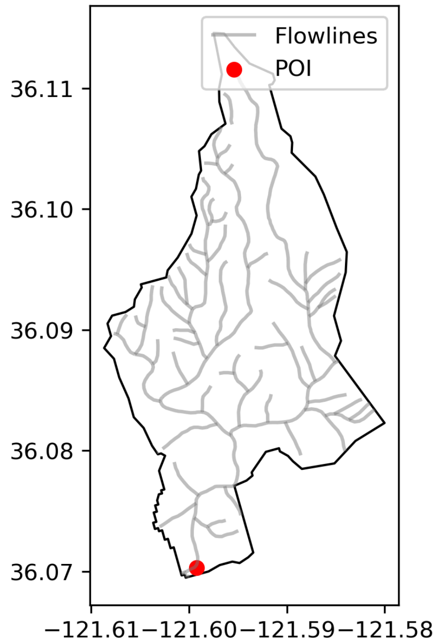


Figure 15. Manually created Basin along with the flowline characteristics calculated using the StreamStats API

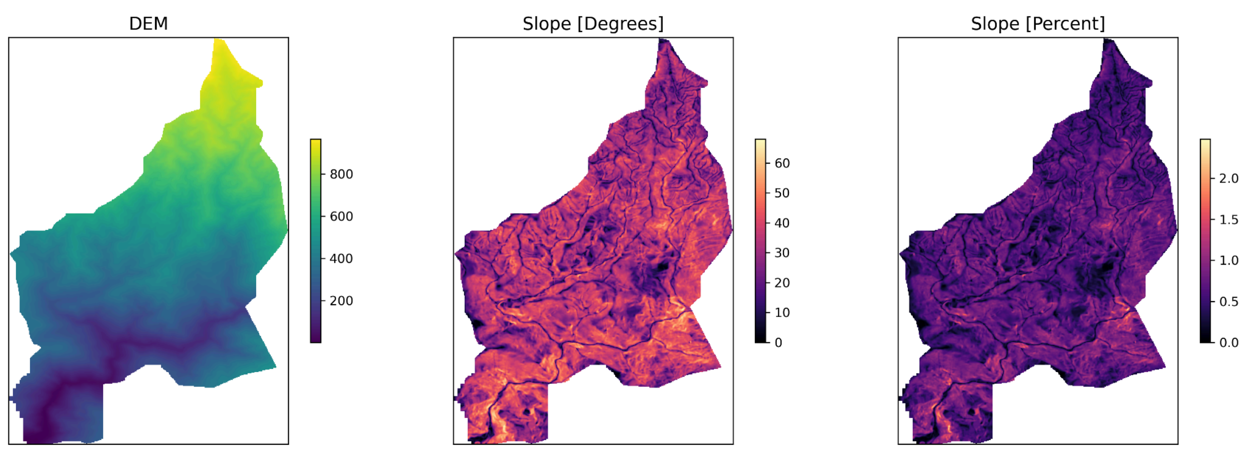


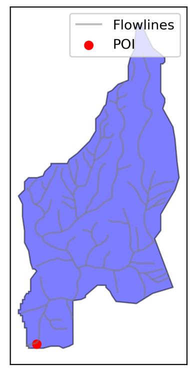
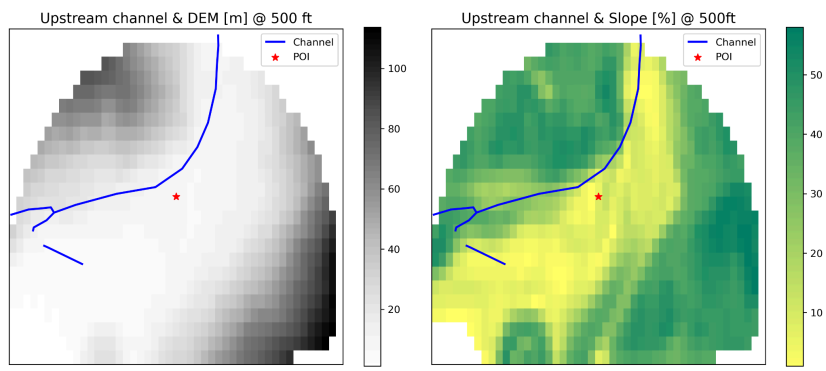
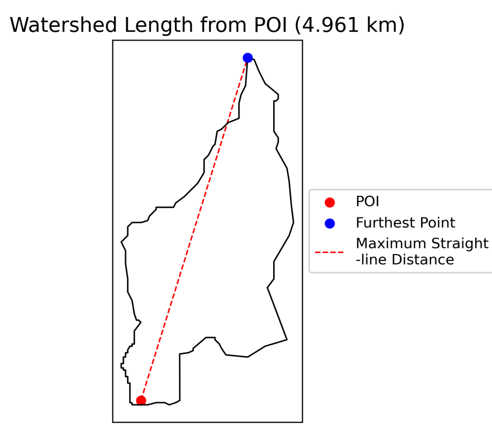
Figure 16. Topographic data clipped to the contributing basin

Step 3. Identifying flow type and corresponding bulking factor ranges

The new variable visualizations can be seen in Table 16. The results of the analysis can be seen in Table 17. The sub-basin area is 6.143km^2 , which falls within the threshold for a debris flow, with a score of 3. The Channel slope is 45.05%, which falls within the threshold of any flow type possible, meaning this variable is not considered. The melton ratio is 0.389 and the watershed length is 4.961km, which falls within the threshold for a hyperconcentrated flow, with a score of 2. Kw factor is 0.14, which falls within the threshold of normal flow, with a score of 1.

The variables ‘presence of an alluvial fan’ and ‘history of sediment laden flow’ were unknown, leading to them not being considered (Big Creek passes in a confined canyon all the way to its mouth, thus there would be no open valley bottom providing an opportunity for the creek to develop an alluvial fan). In total, 3 of the 6 variables were used in this case.

Table 16. Variables used in Step 3 for Big Creek Bridge Sub-Basin and a visualization of the datasets produced by the program

#	Variable	Visualization
3.2.1	Basin area	
3.2.2	Channel slope	
3.2.3	Melton ratio and watershed length	

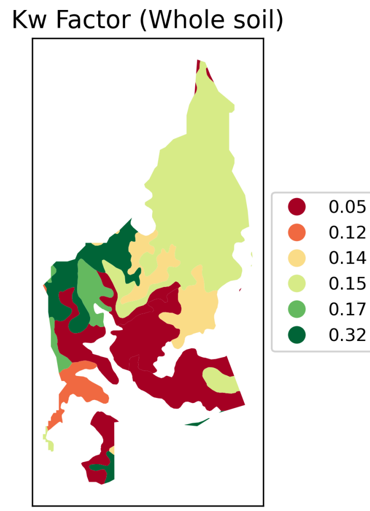
3.2.4	Kw Factor	
3.2.5	Alluvial fan	Manual
3.2.6	History of sediment deposits	Manual

Table 17. Results of the Step 3 Big Creek Bridge Sub-Basin Variable Assessment

#	**Flow Type**	**Any Flow Type Possible**	**Normal Flow**	**Hyperconcent -rated Flow**	**Debris Flow**	**Results**
	Bulking Factor Range (E.g., HDM)	**-**	**0 - 1.25**	**1.25 - 1.67**	**1.67 - 2.00**	
	Score for Normalized Sum Calculation	**-**	**+1**	**+2**	**+3**	
3.2.1	Basin area	-	>23km^2	8 - 23km^2	0.02 - 8km^2	6.143km^2
3.2.2	Channel Slope (500ft upstream of asset)	≥3%	<3%	-		45.05%
3.2.3	Melton Ratio & Watershed length	-	Melton <0.3	Melton 0.3-0.6; or >0.6 with watershed length >1.677 mi	Melton >0.6 with watershed length <1.677 miles	0.389 & 4.961 km
3.2.4	Kw Factor	-	≤0.20	>0.2;≤0.4	>0.4	0.14

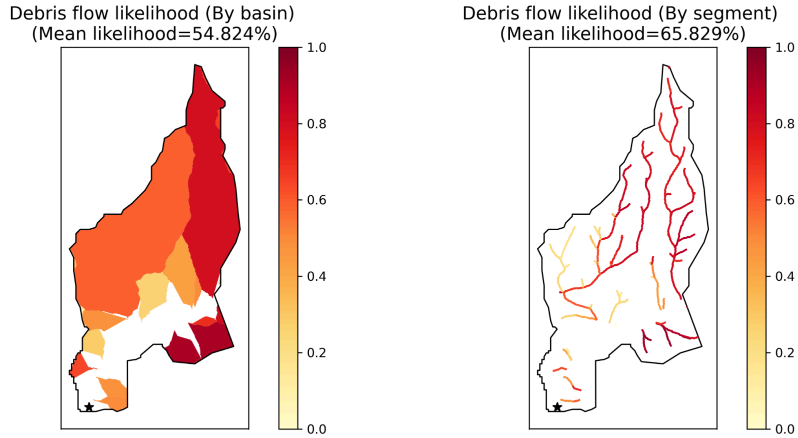
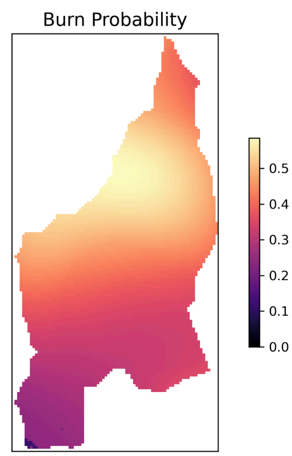
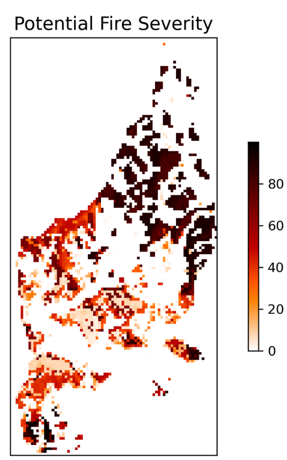
3.2.5	Alluvial fan	None	-	Upstream / on	None
3.2.6	History of Sediment laden flow	Unknown/None	-	Yes	None

The average of these scores is then calculated to identify the flow type and corresponding bulking factor range interval. The average score for this site is 2, which directs us to expect a hyperconcentrated flow. In this assessment we are considering a Q100 event, and use a bulking factor range of 1.25-1.67 for hyperconcentrated flows. The calculations for this can be seen below. When using the program we developed, these calculations will be done automatically once all the variables are set, but the calculation can be done manually as well if preferred by the district engineer.

Calculation:
(3) Calculate Average Flow Type score
$Flow\ Type = (3 + 2 + 1) / 3 = 2$
Suitable flow type: Hyperconcentrated
Corresponding bulking factor range interval: [1.25, 1.67]

Step 4. Refine the Bulking Factor Estimation
The visualization of the sub-basin datasets for step 4 can be seen in Table 18. The assessment of each variable can be seen in Table 19. For this scenario we are again using equal weighting for each variable. The post-fire debris flow likelihood for this basin is 54.82%, falling within the moderate risk category, with a score of 2. The burn probability variable is 0.41%, falling within the low risk category, with a score of 1. The potential fire severity variable is 22.17%, falling within the low risk category, with a score of 1. The shear wave velocity variable is 719.64m/s, falling within the low risk category, with a score of 1. The Presence of loose sediment deposits variable is a manual entry, our assessment found no loose sediment deposits in the basin, meaning this variable was skipped.

Table 18. Variables used in Step 4 for Big Creek sub-basin and a visualization of the datasets produced by the program

#	Variable	Visualization
3.2.7	PFDFL	
3.2.8	Burn probability	
3.2.9	Potential fire severity	

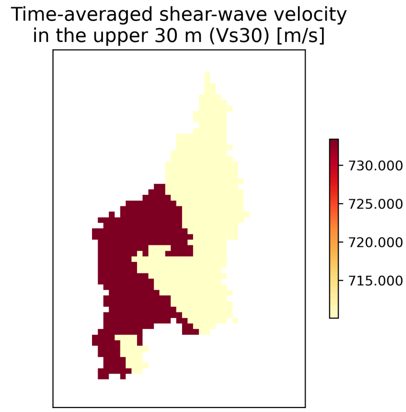
3.2.10	Vs30m shear wave velocity	
3.2.11	Presence of loose sediment deposits	Manual

Table 19. Results of the Step 4 Big Creek Bridge sub-basin Variable Assessment

#	Variable	Adjustment Factor	Low (+1)	Moderate (+2)	High (+3)	Results
3.2.7	Post-fire debris flow probability (P)	1	P < 40%	40% ≤ P < 60%	P > 60%	54.82%
3.2.8	Burn probability	1	< 5%	5 % < P < 10%	> 10%	0.41%
3.2.9	Potential fire severity	1	< 25%	25% < P < 50%	> 75%	22.17%
3.2.10	Vs30m shear wave velocity	1	>500 m/s	250-500m/s	<250 m/s	719.64 m/s
3.2.11	Presence of Loose Sediment deposits in basin	1	-	-	Yes	None

Next, we calculate the percentile using the calculation shown below. The percentile result was the same as for the entire basin, resulting in a percentile of 0.417.

Calculation:
(2) Calculate percentile (p) using β scores for each variable:

$$p = ((1 \times 2) + (1 \times 1) + (1 \times 1) + (1 \times 1)) / (4 \times 3) = 0.417$$

Step 5. Calculate Bulking Factor

In the final step, we calculate the refined bulking factor for the sub-basin using the percentile from step 4 to identify what value from the bulking factor range should be used. In step 3 we identified the probable flow type to be hyperconcentrated flow, with a given Q100 BF range of 1.25-1.67. For the Big Creek crossing sub-basin we get a bulking factor of 1.425. The calculation can be seen below.

Calculation:
(3) Calculate BF:

$$BF = 1.25 + (1.67 - 1.25) \times 0.417 = 1.425$$

Final bulking factor estimate = 1.425
Total elapsed time = 38.4 seconds

5. Conclusion

Post-fire flooding is a growing risk in California, with implications for urban settlements and transportation infrastructure. Southern California has a long history of wildfires and post-fire flash floods and debris flows, especially in the Transverse Ranges. To account for the increased volume of flow resulting from the sediment load added to floods by debris flows and debris floods (hyperconcentrated flows), public works agencies in southern California (Santa Barbara County and South) have developed sediment bulking factors with which to estimate how much larger they should design infrastructure to accommodate the larger flows draining burnt slopes (West Consultants, 2011). With the recent increase in wildfire throughout northern California, there is a recognized need for bulking factors that can be used in northern California as well.

While we anticipate that sediment bulking (and hydrologic response more generally) will be less extreme in northern California due to differences in relief, lithology, vegetative cover, and rainfall intensity, to date there is very few empirical data with which to develop relationships.

This project was intended to focus on sediment bulking only, and did not directly consider related factors such as increased clearwater runoff, and bulking from woody debris and trash.

After conducting a literature review (submitted Spring 2023), we investigated numerous variables correlated with sediment laden flow. From these we selected relevant variables that are publicly available in statewide GIS datasets. Building on the current bulking factor approach in the HDM, we developed a framework for assessing likely flow type and taking relevant information into account to estimate bulking factors. The framework can be applied manually, following the current approach detailed in the HDM. However, as much of this work can be tedious, we also developed an optional decision-support tool to aid bulking factor estimation in an automatic and flexible way. Use of this decision support tool is explained in our report, an appendix, and in a video going over the tool's use step by step. To illustrate application of the tool, we provide two detailed case studies in this report, and have completed four other case studies, whose release is pending review by CGS.

The framework proposed here is more comprehensive than the framework in the current HDM, but is very much in line with the spirit of the HDM approach in giving district engineers leeway in determining appropriate sediment bulking factors. As more data are compiled in future years following future fires, the approach can be improved by drawing upon more complete data sets, especially with respect to northern California conditions. We highlight that CGS is currently preparing a new, revamped model for debris flow likelihood, which should improve predictions of bulked runoff.

The decision support tool is widely applicable across the state, but should be regarded as only one source of information upon which the district engineer should make a determination of appropriate bulking factor for a given site. The calculated bulking factor is not purported to be the “true” value, but it supports an iterative process towards finding a suitable sediment bulking factor. We have used the best available data sets in our method, and provided code that automatically retrieves the relevant data for the drainage basin above a given asset (culvert, bridge).

Sediment bulking is limited by the physical processes of how much sediment a given flow of water can carry, such that sediment bulking cannot exceed 2 or 2.5. It is useful to keep in mind that post-fire runoff has been documented to be 10-30 times greater than pre-fire runoff, attributable to hydrologic effects such as reduced infiltration. Thus sediment bulking, the focus of our study, is only one factor in increasing post-fire runoff. Another important factor is the effect of large woody debris and trash in blocking culverts and bridge openings (which has been termed 'dynamic bulking'). Our approach does not address the effects of large wood or trash.

The case studies illustrate the application of the approach generally and the decision support tool. An important caveat with the case studies is that whether a debris flow occurs or not depends not only on the 'static' factors assessed in debris flow probability models (and the variables considered in our framework), but also the weather: whether an intense rain occurs soon after a severe burn. Thus, when reviewing case studies, we cannot use the occurrence (or non-occurrence) of a sediment-laden flow as a 'test' of the method, as the intensity of rain during the vulnerable post-fire period is a wildcard.

The Murphy Creek example illustrates use of the approach and the decision support tool. In this case study we also illustrate the potential for the district engineer to use professional judgment in determining bulking factor by adjusting weights given to different variables. For this example, we assume that a debris flow (or at least a debris flood) occurred here following the Dixie Fire in light of the appearance of the creek and the road crossing on aerial imagery. However, we were unable to visit the site so could not observe sedimentology and stratigraphy of the fan deposit, so cannot confirm the flow type with certainty. Nonetheless, the framework predicts a sediment-laden flow (debris flow or debris flood), and one occurred that was large enough to close the highway for some time.

The Big Creek example is perhaps most interesting for its cautionary note about using drainage area as a variable to determine flow type. While drainage area has frequently been used as a variable predicting the likelihood of a debris flow or flood, and larger drainage areas are assumed to be incapable of producing such flows, Big Creek illustrates how two small, steep tributaries that join mainstem Big Creek only 2.9 and 1.6 km above the creek mouth can 'load' the mainstem with sufficient sediment to produce a debris flood down to the Hwy 1 bridge. The case study also illustrates how running the decision support tool model with a redefined drainage area of only the lower basin (encompassing Cathedral and Brunette Creeks, and adjacent local drainage to Big Creek) could yield different predictions of sediment laden flow (and thus bulking factors).

It is hoped that this updated method can assist Caltrans district engineers in quickly gathering data and assessing variables that inform the risk of sedimentation in possible post-fire flooding to logically identify an estimated sediment bulking factor.

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FLOOD AFTER FIRE CALIFORNIA TOOLKIT

A RESOURCE FOR TECHNICAL SPECIALISTS TO ASSESS FLOOD AND DEBRIS FLOW RISK AFTER A WILDFIRE

September 2020

Version 1

Cover Photos courtesy of Ventura County:

CENTER:

Flooded road

OUTSIDE, CLOCKWISE:

Bird's eye view of the Thomas Fire

A culvert plugged by debris

A car lifted by a debris flow

Large rocks deposited in a road

A gate holding back debris

This Flood After Fire: California Toolkit is a collaborative, living document written by the California Silver Jackets Team. Silver Jackets is a partnership program that brings together Federal, State, local, and Tribal agencies to find collaborative solutions to complex flood risk management issues.

Agencies that contributed to this guide include:

Bureau of Land Management
California Department of Forestry and Fire Protection
California Department of Transportation
California Department of Water Resources
California Geological Survey
California Office of Emergency Services
County of Lake, California, Water Resources
Federal Emergency Management Agency
National Aeronautics and Space Administration
National Ocean and Atmospheric Administration
National Park Service
National Weather Service
Natural Resources Conservation Service
Santa Barbara County, California
U.S. Army Corps of Engineers, Engineer Research and Development Center
U.S. Army Corps of Engineers, Sacramento District
U.S. Forest Service
U.S. Geological Survey
Ventura County, California, Public Works Agency

What is in This Toolkit?

- A collection of tools, methods, and other resources – grouped into chronologically distinct periods of a flood after fire response timeline – to help assess the risks associated with flooding and debris flow after a fire.
- Basic checklists and generalized procedures, written to encourage an interdisciplinary response to post-fire modeling and analysis.
- Appendices to help guide those who do not frequently respond to fire events. For more experienced emergency response officials or those who become familiar with this toolkit, the matrices provided can act as a "quick reference" to commonly used models and data.
- References and discussions on the roles different agencies of varying levels of government may have in response to wildfire.
- Technical resources that are useful for well-trained and experienced technical specialists, not the general public or communities impacted by wildfires and the floods and debris flows that could follow them. The information provided is specific to California.

Who is This Toolkit For?

- GIS specialists, hydrologists, hydraulic engineers, or those with similar backgrounds.
- Geohazard specialists, geologists, mitigation planners, soil scientists, or other natural resource professionals may find this toolkit informative, but of limited use.
- Wildfire support staff such as Emergency Managers and those above who are responding to wildfires in the State of California.

How is This Toolkit Used?

- This toolkit is designed to be used on a computer, and uses links to accompanying documents, files, and websites/data sources that are built into the text. However, a hardcopy can be printed and referenced if the user has ample and adequate access to data.
- For maximum benefit, this toolkit should be reviewed during the offseason (Chapter 2), or when there is not an emergency, so the reader becomes familiar with its structure and content. That said, this toolkit can be used during an emergency by relying heavily on the table of Contents and headings to take the reader to the most relevant sections.
- Those who do not frequently assess flood risk after a wildfire should follow the chapters and sections in order, beginning with Chapter 3 (Fire Event and Pre-Flood).
- Experienced emergency response officials or technical support staff can use the toolkit in the order they judge to be appropriate, based on what period of the fire response timeline they are in and what risk(s) they need to analyze and identify.
- Experienced modelers familiar with how interagency teams in California cooperate and respond to wildfires may find that the appendices are a useful "quick reference". In that case, much of the main text of the toolkit could be skipped, but used as a refresher.

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List of Acronyms and Abbreviations

ac..Acre
AAR..After Action Report (or Review)
ADH..Adaptive Hydraulics Model
AGWA..Automated Geospatial Watershed Assessment
AOI..Area of Interest
BAER..Burned Area Emergency Response
BARC..Burned Area Reflectance Classification
BIA..Bureau of Indian Affairs
BLM..Bureau of Land Management
BMP..Best Management Practice
CAL FIRE..California Department of Forestry and Fire Protection
Cal OES..California Governor's Office of Emergency Services
Caltrans..California Department of Transportation
CGS..California Geological Survey
CN..Curve Number
DEM..Digital Elevation Model
DHS..Department of Homeland Security
dNBR..differenced Normalized Burn Ratio
DOD..Department of Defense
DOI..Department of the Interior
DWR..California Department of Water Resources
ERMiT..Erosion Risk Management Tool
ESR..Emergency Stabilization and Rehabilitation
FAF..Flood After Fire
FEMA..Federal Emergency Management Agency
FOUO..For Official Use Only
FRAP..Fire and Resource Assessment Program
GIS..Geographic Information System
GISS..GIS Specialist
H&H..Hydrologic and Hydraulic
HEC..Hydrologic Engineering Center, U.S. Army Corps of Engineers
HEC-GeoHMS................Hydrologic Engineering Center-Geospatial Hydrologic Model System Extension
HEC-HMS..Hydrologic Engineering Center-Hydrologic Modeling System
HIFLD..Homeland Infrastructure Foundation-Level Data
HMS..Hydrologic Modeling System
HUC..Hydrologic Unit Code
ICP..Incident Command Post
IFSAR..Interferometric Synthetic Aperture Radar
JFO..Joint Field Office
LiDAR..Light Detection and Ranging

NBI .... National Bridge Inventory
NHD... USGS National Hydrography Dataset
NID...National Inventory of Dams
NIFC.. National Interagency Fire Center
NLD .... National Levee Database
NOAA.. National Oceanic and Atmospheric Administration
NPS..National Park Service
NRCS..Natural Resources Conservation Service
NWS .... National Weather Service
RCS...Rowe, Countryman, Storey
RI .... Recurrence Interval
RWQCB .... Regional Water Quality Control Board
SBS ....Soil Burn Severity
SRA... State Responsibility Area
TNM .... The National Map
USACE.. United States Army Corps of Engineers
USDA .... United States Department of Agriculture
USFS .... United States Forest Service
USFWS .... United States Fish and Wildlife Service
USGS... United States Geological Survey
UTM .... Universal Transverse Mercator
VAR ....Values-at-Risk
WBD..Watershed Boundary Dataset
WEPP...Water Erosion Prediction Project
WERT.. Watershed Emergency Response Team
WUI ....Wildland Urban Interface

1. Introduction

Across the globe, the risk of large wildfires continues to increase. In the United States, it is estimated that wildfire potential in the Mountain West could increase six-fold by mid-century (Figure 1; NOAA, 2015). In California, the length of fire season is estimated to have increased by 75 days across the Sierra Nevada (CAL FIRE, 2019a) and the threat of catastrophic fire is high in many of the highly-populated parts of the State (Figure 2). The intensity of wildfires is also increasing (Figure 2). For example, the 2018 Camp Fire in Northern California's Butte County – the deadliest fire in California history – was only active for 17 days, but killed 85 people, destroyed 18,804 structures, burned over 150,000 acres (CAL FIRE, 2019b), and cost an estimated $16.5 billion in firefighting costs and infrastructure (Pike, 2019).

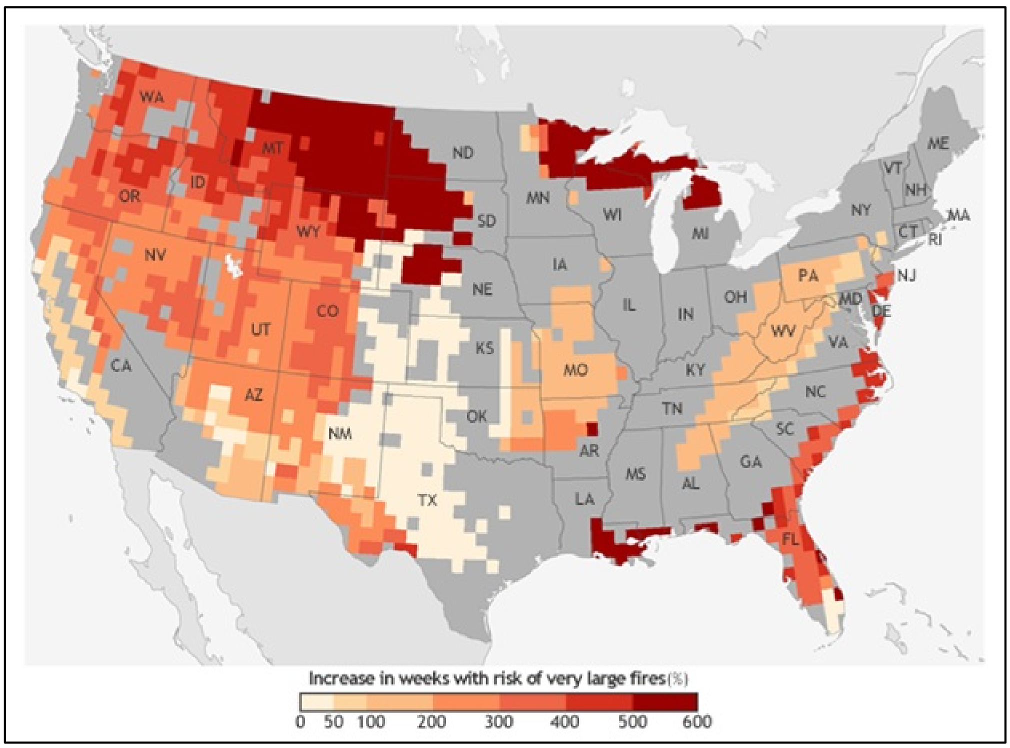

Figure 1. Increase in Fire Risk by Mid-Century (NOAA, 2015).

Extended droughts, increases in wildfire fuels, climate change, and expanding wildland-urban interfaces (WUI) are but a few contributors to global increases in wildfires and their destructiveness. Although wildfires are a disaster on the minds of many Californians, the well-known fire-flood sequence is sometimes overlooked, even though the risk of flooding after the fire remains for several years. Late autumn and winter wildfires further necessitate the need for pre-fire planning, including the development of tools and resources for geologic hazards and engineering evaluations. In California, these late season fires create a challenging situation for emergency managers as storms may impact a burned area while emergency response to wildfire is still in progress.

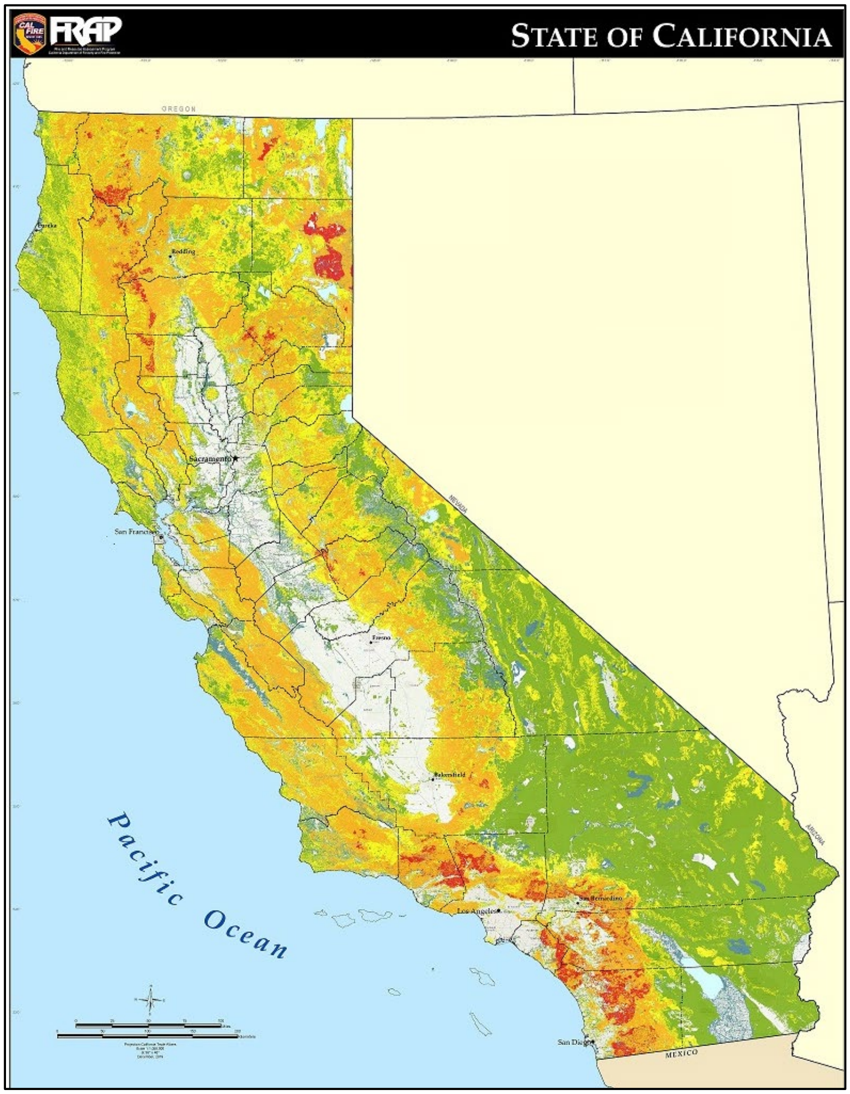

Figure 2. California fire threat map. Colors represent wildfire risk. Red – extreme; orange – very high; yellow – high; green – moderate; blue – low; white – unmapped areas.

The Thomas Fire dealt this challenge to Ventura and Santa Barbara counties. It started on December 4, 2017, and burned 281,893 acres, with full containment declared on January 12, 2018, after a storm and catastrophic debris flow event on January 9. As early as January 3, while the fire was still burning, the National Weather Service (NWS) communicated the potential for a strong storm in the coming week to the local emergency management and flood control partners (Laber, 2018). On January 6, the NWS issued a flash flood watch for the burn area given anticipated 1-hour rainfall rates of 0.5 to 1.0 inch/hour (12.7 to 25.4 mm/h) (Laber, 2018). At this time, an upper-level trough approached and deepened along the California coast and developed into a closed low-pressure system offshore of Point Conception. As the storm moved on shore the morning of January 9, intense rainfall passed through eastern Santa Barbara County and western Ventura County, triggering debris flows and sediment-laden flows on steep burned slopes within the Thomas Fire perimeter.

Debris flows issued from numerous watersheds within the Santa Ynez and Topatopa Mountains killed 23 people and caused severe damage to infrastructure, including 558 structures, 162 of which were considered destroyed (CAL FIRE, pers. comm.). Of the destroyed structures, 79 had complete structural damage including 41 structures that were swept off their foundations (Kean et al., 2019). Debris accumulated in low sections of Highway 101 (US 101), a major transportation corridor, rendering the section through Montecito impassable by vehicle for 13 days. Between January 9 and 22, first-responder personnel conducted search and rescue operations, provided life safety – and life sustaining – support. Before and during the event approximately 1,300 individuals were evacuated, and 700 sheltered-in-place (SBCOEM, 2018).

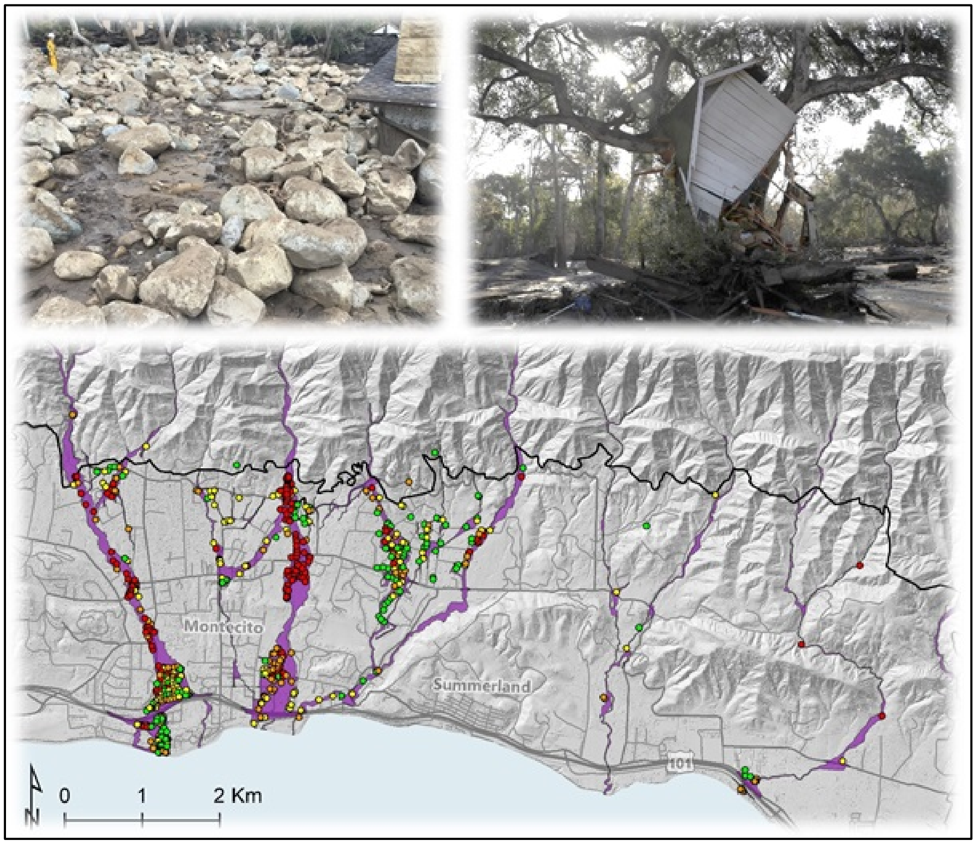

Figure 3. Debris flows after the 2018 Thomas Fire (top left and top right); locations of structures damaged by debris flows (bottom half). Colors represent state of damage as identified by the CALFIRE-led damage assessment team. Green – slight; yellow – moderate; orange – high; red – destroyed. Map modified from Kean et al. (2019)

This toolkit is one of the first attempts to provide a summary of the many technical principles and methodologies that are increasingly being used to prepare for flooding after a wildfire. These methods are becoming more common as professionals working in the Geographic Information Systems (GIS), engineering, geologic (geohazards), and hydrologic & hydraulic (H&H) engineering fields frequently join post-wildfire response teams. This document uses the term "flood" throughout to describe the full spectrum of post-wildfire flash flooding; from streamflows to hyper-concentrated flows to debris flows (Table 1).

Table 1. General classification of flow behavior (modified from Lancaster et al., 2015).

Flow Type	**Sediment Load**	
	By Weight	By Volume
Streamflow	1 – 40%	0.4 – 20%
Hyperconcentrated flow	40 – 70%	20 – 60%
Debris flows	70 – 90%	>60%

The purpose of this toolkit is to act as a "playbook" that presents options to help select appropriate methods, models, or actions when working with a given set of data and/or circumstances after a wildfire. This toolkit is the culmination of decades of collective experience in wildfire response in California. It was written by a diverse group of experts from multiple government agencies across all levels of government; their experience in fields of geology, GIS, hydrology, hydraulics, engineering, soil science, flood risk management, and emergency response guided the primary subjects of this toolkit.

What is in This Toolkit?

This toolkit contains a collection of tools, methods, and other resources that can be used when assessing the risks associated with flooding after a wildfire event in California. While it does provide some references and discussion on the roles different government agencies may have, it is not a replacement of those agencies' programs or emergency response procedures. This toolkit is targeted to data management, scientific, and engineering professionals, rather than the general public or individual members of communities impacted by wildfires and resulting floods. The information provided is targeted to the Western United States, but it uses details and examples that are specific to California.

The toolkit is organized into three generally recognizable periods: Fire Offseason, Fire Event/Pre-Flood, and Post-Flood Event (Flood-After-Fire). This can help a user of this toolkit more easily locate what portions of the toolkit they should review based on the period of time in which they are working. The toolkit also provides some checklists and generalized step-by-step procedures, and strives to integrate this information to encourage an interdisciplinary response to the risk of flood after fire. The toolkit can also be thought of as a "playbook" that provides multiple methods, tools, and resources that could be used to address flooding after fire.

What this toolkit does not provide is a comprehensive one-size-fits-all guide for responding to wildfires or addressing the risk of floods after a wildfire. All wildfires exhibit unique characteristics that contribute to the risk of flooding. The need for post-fire flooding and debris flow assessment will vary greatly, depending on the fire event's magnitude, location relative to population and infrastructure impacts, topography, soil burn severity, etc. Not all wildfires will need post-fire assessment for flood risk or flood flows, so users of this toolkit must approach each wildfire with flexibility. In that regard, this toolkit does not recommend, or intend to supersede, policies or prescribed actions for communities or agencies to undertake. Likewise, this toolkit does not recommend a particular software or methodology. It does provide some discussion on software, methods, tools, and other resources in the context of the information this toolkit's user has on hand.

Who is This Toolkit For?

Because this toolkit is focused on the flood-after-fire threat, it is not directed at those responding to the fire event itself. It is also not designed as a guide for the general public. The key audience for this toolkit includes emergency managers, geohazard specialists, soil scientists, GIS specialists (GISS), and H&H engineers. The key audience also includes people with a background in the technical nature of working with spatial data, modeling flood risk and/or debris flows, or providing technical reports to emergency response officials. To that end, those who do not frequently respond to flood after fire events may find the appendices to be especially useful. The appendices provide methods, tools, and resources to use in a given set of circumstances. Experienced emergency response staff or officials may find that the appendices act as a quick reference that can support their efforts.

This toolkit focuses on assessing flash flood and debris flow risk after wildfires in California. This toolkit is appropriate for use in California's steep lands that frequently burn, have abundant sediment supply, and are situated upstream of populated areas at risk. Those who use it outside of California, or for other types of emergency response, may find that it does not suit their situation. However, if incorporated into a multi-hazard response plan, or as part of a larger disaster response effort, then this toolkit is likely to be helpful in supporting the appropriate response for potential post-fire flood events. Not all fires are equal – the response will ideally depend on the fire context. Fire location (proximity of affected communities), sheer size, fires with relatively steep terrain, and fires with a higher proportion of moderate and high burn severity are likely to trigger a higher level of post-fire flood and debris flow concern.

1.1. Fire Timeline and Response

Regardless of a community's level of fire preparedness, once the fire occurs, multiple agencies respond. They apply varying focus, tools, methodologies, and timelines of involvement to fulfill or perform their responsibilities and task objectives. Local government, usually via local law enforcement, may focus on residential evacuation while fire and utility crews are simultaneously arriving to fight the fire and repair critical infrastructure. Community needs will change from before the fire is contained, immediately after containment, and during the extended period following fire containment (see the After Wildfire Guide; Silver Jackets, 2019). All of this typically occurs before the risk of flood after the fire increases. As time and data collection progress, community response will also progress. Focus may change from egress and suppression to infrastructure protection, soil mass wasting mitigation, and preparation for possible flood and debris flow risk evaluation damages and response concerns.

This toolkit simplifies the multilevel, multi-agency timeline of activity and emergency response (see Appendix 6.1, the Resource Timeline Matrix) to flood-after-fire (FAF) into three time tiers. Each time tier is a generalized temporal snap shot of activities throughout a FAF response. Each time tier is distinguished by varying levels of data availability, agency responsibility, and timing. Figure 4 depicts a simple categorization of time tiers and stakeholder involvement.

Activities of stakeholders in each time tier are discussed throughout the document and outlined in greater detail in the Resource Timeline Matrix (Appendix 6.1). The Resource Timeline Matrix details stakeholder needs, methods, and tools. For example, post-fire flood and erosion analyses typically do not occur until a Burned Area Reflectance Classification (BARC) map is available sometime during Time Tier 1. A flood flow estimate made during pre-containment/immediate post-containment (Time Tier 1) may be optimized during Time Tier 2 to augment and produce higher fidelity flood risk prediction products and response management strategies. In general, most post-fire responses will move through these time tiers as part of the overall response. How post-fire response moves through these time tiers can be dependent on the fire event's magnitude and values at risks, the latter of which being somewhat dependent on the WUI. For example, a large fire in a remote area with no impact to population or infrastructure – meaning the WUI is small – may not proceed past Time Tier 1. In contrast, a smaller fire posing immediate risk or contributing to flood impacts to a densely populated area (i.e., large WUI) may go through all time tiers, possibly faster than the typically time periods shown in Figure 4.

Figure 4. A generalized timeline of fire response

2. Pre-Fire (Offseason)

The wildfire offseason refers to winter and spring seasons when large wildfires are typically unlikely events, conventionally December or January thru March or April. Over the last decade, the offseason has shortened in California, and in some years has been non-existent. Thus most but not all years have an offseason. Regardless of whether a fire occurs, the winter and spring are the fire training and preparedness season, particularly for Federal agencies. The term pre-season is also common, literal shorthand for preparedness-season. It has become crucially important for experts in both GIS and H&H disciplines to also prepare for the upcoming fire season. This means having data updated and organized, software licenses current, training reinforced, and new analytical techniques explored. New innovations in cartographic display and messaging should also be explored. And, of course, it means taking lessons learned from previous seasons and deployments, and integrating that knowledge as preparedness actions.

2.1. GIS Preparedness

GIS preparedness for an upcoming fire season is about being ready to react to a wildfire event on short notice. For a GISS, this may require an array of different strategies depending on the resources involved and the intended purpose or level of response. Regardless, preparedness is mostly about data: inventory, collection, and organization. Packaging the data library and copying it to a portable hard drive for deployments should be included as a necessary step (see Section 2.1.3 and Appendix 6.2, the Spatial Data Matrix). Other aspects of GIS preparedness include software updates, exploring new tools and analytical techniques, attending trainings, reviewing policy papers, and collaborating with colleagues through webinars or conferences. Offseason analysis and cartographic products may be prepared for situational awareness to agency management and the general public. This may include preparedness by Federal Burned Area Emergency Response (BAER) teams and state Watershed Emergency Response Teams (WERT) that will typically perform rapid (Time Tier 1) responses – necessitating thorough planning of GIS resources. The rapid responses are provided to agencies and private sector firms performing site-specific evaluations for mitigation engineering or broad-area evaluations with the purpose of long-term planning for mitigation and recovery. In these cases, the GIS data requirements may be similar, however, there are several distinctions depending on which phase of FAF response is being planned for. These include:

- Preparation of GIS data in the offseason
- Preparation of GIS data during the fire including field team applications using tablet-based software
- After the fire and pre-flood preparation including software needed to support geohazards and H&H specialists, including the incorporation of new spatial data such as LiDAR, aerial and satellite imagery

- After the fire and post-flood preparation including inundation mapping field team applications using tablet-based software, collection and incorporation of new field team data, new post-event spatial data such as LiDAR and imagery

Preparation of GIS data in the offseason may include the collection of spatial data for an area of intended operation. For example, at the Federal level there may be regions of operation that are logical boundaries for compiling data (e.g., National Forests - US Forest Service (USFS) Region 5, USACE South Pacific Division, or Federal Emergency Management Agency (FEMA) Region IX). At the State and local response level, logical boundaries might include CAL FIRE Units or Regions, counties, or groupings of counties. From this geographic basis spatial data may then be organized into different data type categories.

In addition to data organization, it is important that GIS professionals conduct regular offseason meetings with past deployment groups such as geologists, engineers, and other-agency GIS counterparts to gather feedback on what additional data and product refinements are recommended for future deployments. For example, if field applications are being used by field staff, it's important to share lessons learned and refine GIS data and editable attribute fields to streamline field operations on the next deployment.

Review of new GIS tools for assessments, analysis, and cartographic products should also be explored.

2.1.1. Spatial Data and Products Library: Organization

An organized format is the first requirement of a data and products library. Figure 5 shows an example of data organization that uses folders for base data and event data. Within the base data folder, additional folders for various data categories are created.

- Fire
- Hydrography
- Topography (Terrain)
- Climate (Meteorological)
- Land Cover
- Soils
- Biology
- Infrastructure
- Transportation
- Cadastral
- Imagery (or Remote Sensing)
- Org_Boundaries (Organizational and Political Boundaries)

The event data folder contains data, map products, tables, and other documents. Like in the base data folder, the event data folder has sub-folders for spatial data types (such as those shown in

Appendix 6.2, the Spatial Data Matrix), as well as for H&H modeling inputs and outputs (such as those shown in Appendix 6.3, the H&H Model Matrix). The data that are collected and placed here are specific to a wildfire or post-fire flood event, and can be further organized by affected watersheds or defined impact areas.

The structure shown in Figure 5 is just one example for organizing a data library. Other formats may use folders for data file types, like vector and raster. Another option is the creation of a geodatabase with feature datasets for the categories. The important value of a having good and consistent structure that works for the individual user is that datasets can be easily accessed, and the format can be easily understood and implemented by other users. Response to disaster events usually employs multiple personnel executing various GIS tasks, necessitating an organized spatial hub. Additionally, many agencies have the personnel respond on emergency deployments of a set duration. This means a transfer of knowledge must occur as the first responding staff end their tour and handoff to follow up personnel.

Base Data

A collection of standard, widely applicable data should always be maintained as base data. Priority may be placed on regional-scale spatial data such as satellite imagery, soils and geology, landslide inventories, or hillshade products from LiDAR (10 m or better). These and other infrastructure data – like locations of utilities, drinking water supplies, or critical facilities – can be considered base data for emergency readiness. If these data are not readily available at the beginning of the fire response, it will likely be the responsibility of GIS staff to focus on collecting them, which could delay the actions needed to prevent further post-fire damage and potentially put lives at risk. See Section 2.1.2 for a discussion on common ways to compile and store available base data.

Event Data

Event data are those data specific to a fire or flood after fire event. This includes information gathered early during the response timeline, such as the burn perimeter and soil impacts (BARC or soil burn severity mapping). There are rapid response tools for flooding and erosion analysis that can utilize estimates of burn severity and hillside slopes. A GISS will need to appropriately process these data for later use by an H&H engineer so that models can be used to identify areas at risk for flooding, debris flows, or other hazards.

2.1.2. Spatial Data: Collection and Updating

Spatial data collection revolves around describing the watershed's current status, including setting a baseline for pre-event conditions, and establishing the most current accounting for elements that may be impacted by floods and/or debris flows. As a wildfire event occurs, datasets are refined to the event boundaries for the initial assessments and analysis. H&H modeling will require inputs from several of these datasets. Higher modeling fidelity places the most importance on the terrain data. The better the spatial and temporal resolution, the better the quality of model outputs and analysis assessment.

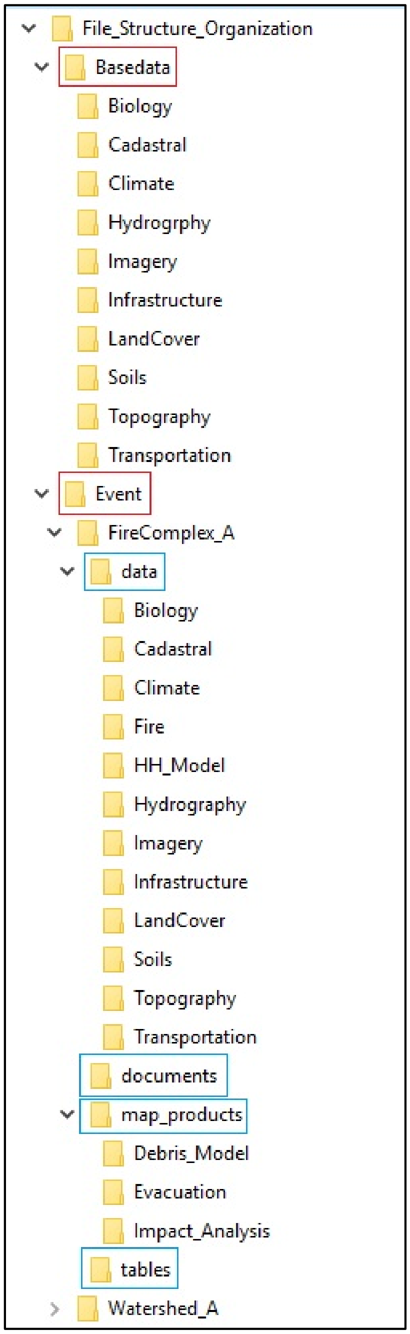

Figure 5. Example organizational hierarchy for GIS data.

A consistent naming convention is recommended such as description name, agency origin, and a date. Using underscores in place of spaces is a best practice. Also, the data name/path name length and number of folder trees can affect spatial analysis tool processing.

Metadata for the datasets acquired through download or electronic transmission should already exist. For datasets that are created or processed for analysis or modeling, metadata should include a good description, projection and coordinate system, value units, key field definitions, data creation methods, and data creation dates or modification dates. Listing contact information and data use restrictions are also strongly recommended.

2.1.3. The "Brick" – A Portable Data Library

During a fire incident, it is common to need several gigabytes of data for initial mapping preparation and later iterations. Incident Command Posts (ICPs) may be built in remote locations, so these data may not be accessible during an emergency if a responding GISS has no sufficient or reliable connection to the internet. It is thus advisable to prepare a workaround for this common scenario.

One such workaround is used by the USFS. USFS GISS personnel maintain an extensive collection of data on external hard drives, typically referred to as the "brick" or "toaster" (i.e., a data black box). The hierarchical data organization of these external hard drives is fairly standardized among Forest Service regions, which aids a GISS with familiarity and reduces time searching for data on the drive. In California, these bricks contain about 1.2 terabytes of data, including data from multiple Federal land management agencies, and select State, County, and City agencies and responsibility areas. Such data includes ownership, boundaries, land cover, topographic and digital orthophoto quadrangles, transportation routes, elevation products, municipal and political districts, fire history, facilities and utilities locations, a wide array of natural and cultural resource data, and a number of contact lists and reference materials. Also included are various necessary software, mapping tools, and printer/plotter drivers that may need to be installed on secondary or rental computers. Some of these data are standard and rarely change, but a significant portion must be updated at least annually. The brick also includes a master data inventory spreadsheet on the drive with metadata, source information, and general update requirements. The master data list and filing structure is too extensive to display here, but it is recommended that if a tool similar to an external hard drive brick is used, it should include all data that could be needed to respond to a fire and prepare for possible flooding. These data should be organized in a consistent manner that follows whatever standard protocol is prescribed by the agency that maintains that external hard drive brick.

This is merely one example that the USFS uses in order to meet blackout data needs, and has been an effective tool in supporting GISS work during wildfire responses. Notably, the external hard drive brick does not have a complete inventory of urban/suburban or other built environment infrastructure data – such as culvert, bridge, and structure locations – because these data are not typically available at the regional or State levels. Most of these data would likely reside at the County or municipal level or with other responsible agencies such as Caltrans. Since these are frequently the features most in harm's way, it is advisable to consider how much of this kind of data should be included in the master dataset and update schedule.

It must be known that some Federal agencies (Department of Homeland Security (DHS)/FEMA and Department of Defense (DOD) in particular) do not allow external devices to be connected to computers to prevent cybersecurity breaches. Security protocols such as these necessitates a different method of data sharing. In principle the limitations and needs among all responding agencies are the same: time is critical during a fire incident or its aftermath, and internet connectivity may not be available. For this reason, data needs should be thought out carefully and be prepared and updated in advance.

2.1.4. Pre-Event Assessment/Analysis and Cartographic Products

In the Preparedness and Pre-Event timeline, assessment and analysis may be requested to provide a general overview of hazards. Cartographic products can provide valuable information for Emergency Managers and serve as a good communication tool for Inter-Agency and public interactions.

Examples of these products are maps of watersheds or areas that are at "High Risk" for wildfire. Spatial data used for the threat determination include current drought intensity, forest density/age, tree mortality, and climate forecasts. Other factors may consider population, high volume roadways, power line proximity, and recreational lands, such as camp grounds and parks. The following dashboard example, Figure 6, is a screenshot taken from an online story map (https://fsapps.nwcg.gov/psp/npsg/). It is a national seven-day forecast produced by the National Interagency Fire Center (NIFC).

Another map product may be identifying watersheds susceptible to debris flows. This usually involves mapping areas that have had significant wildfires in the past five years, and includes an assessment of infrastructure and populations at risk.

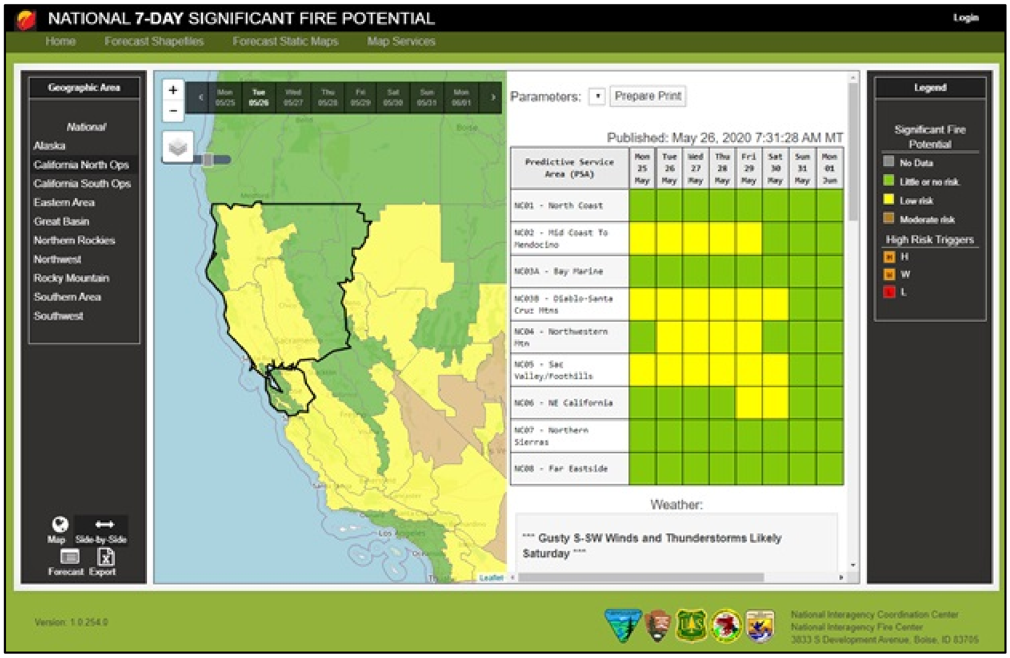

Figure 6. Example NIFC dashboard showing fire potential.

2.1.5. Field Applications

Field applications are typically developed during the offseason for the purpose of being fully vetted and available for field teams during deployment. These may include simple map-based tablet applications such as Avenza PDF maps, Survey 123, or more complex multi-layer applications, such as the Environmental Systems Research Institute's (ESRI) ArcCollector. Field applications may be used in all phases of deployment, such as:

- Documentation of fire damaged structures (damage assessment)
- Soil burn severity
- Values-at-risk and associated emergency protection measures identified during BAER and WERT response
- Documentation of stream channel conditions
- Infrastructure and mitigation measures for post-fire geohazard or H&H characterization
- Post-flood or debris-flow field observations to characterize inundation depths and extent

It is not necessary to identify geographic extent for potential field application deployment in the off-season as refinements can be made once a fire event occurs. Rather, the role of the GIS coordinator will be to work with the field teams to identify a list of required and optional base layers and attributed fields. These data should be prepared for the application and the application should be made ready for immediate deployment. To facilitate this, the GIS coordinator will need to prioritize development and field testing to ensure the agreed upon specifications will be available to field teams. Several cycles of development, testing, and refinement may be necessary.

2.2. H&H Impacts and Response

Fire events in California's steep terrain may have the potential to greatly impact immediate and neighboring communities, depending on the nature of the WUI. Possible impacts on large fires may include:

- Loss of life and infrastructure
- Increased flood risk (increased runoff volume and sediment movement)
- Increased debris flow risk
- Increased risk of rockfall
- Loss of downstream storage (sediment accumulation leading to filling of dams, debris basins, reduced levee freeboard)
- Altered soils (altered structure and infiltration, hydrophobicity, loss of beneficial bacteria)
- Soil erosion (surface sheet erosion, rilling, gullying, mass movement)
- Loss of vegetation and inception canopy
- Degraded water quality
- Impacts to critical species and habitats

It is very important to have base data and emergency response plans in place well before the fire. Involvement with state and local agencies can occur before a fire or fire containment. Coordination with the National Weather Service (NWS) is an example. The NWS establishes qualitative thresholds for flood warning precipitation rates.

Data used for post-fire geohazards, hydrologic, and hydraulic analysis (see Sections 2.1 and Table 3) will vary depending on the timeline and data availability (see Figure 4). During the fire, teams assess affected and downstream burn areas that form the basis for the type of analysis implemented. For example, evaluating changes to floodplain extents or debris flow potential related to infrastructure are estimated by pairing GIS and H&H data. Such data allow for rapid interpretation and will iteratively improve.

As post containment burn severity and soil data (event data) are added to baseline data during Time Tier 2, scientists and engineers will receive and process the event data for a wide range of uses. These uses may include sedimentation analysis for water quality, potential increases in flood inundation, erosion potential, changes in flood timing, and impacts to infrastructure. The preparation of spatial data may include the incorporation of new data such as LiDAR or aerial and satellite imagery. Understanding what baseline and event data are needed depend on the particular analysis and the software tools and methods applied.

2.2.1. Software Updates, Maintenance, and Training

There are a variety of H&H methods and software tools for users across the fire timeline. If the user is deriving a qualitative solution, a rapid response solution, or robust 3D model analysis, each effort will rely on one of three basic considerations:

(1) Timeline and timeframe
(2) Required sensitivity of the solution
(3) User familiarity of available tool/software

In all three considerations, having the software available and licensing up to date is crucial. If a rapid response is needed before or immediately after fire containment (Time Tier 1), event information is limited, and therefore the choice of modeling approaches is limited. If detailed analysis is needed and time is not a limiting factor, the user can select from more complex software options. An agency may appoint a staff member to prepare an H&H analysis and that staff member may be familiar with only one or two of the software options on hand. It is therefore worthwhile to dedicate time during the offseason (if available) to review updates to software and licenses, conduct maintenance on computer hardware, and re-familiarize staff with the software that's available to them, and how to use it.

3. Fire Event/Pre-Flood (Time Tier 1)

As previously mentioned, it is useful to consider fire response in a three-tiered timeline (Figure 4). This tiered timeline fits within and overlaps with the broader flood after fire planning context. These three time frames also dictate a range of resources, agency involvement, and responses. Response may vary depending on the fire location and severity.

The analyses that are needed after a fire can differ by time tier and purpose. During pre-containment (Time Tier 1), data that describe vegetation, soil, and infrastructure conditions may be limited to pre-fire and in-progress remote sensing conditions, BARC imagery, and rapid field-based post-fire observations. This is often when a GISS will begin collecting available data, as they identify infrastructure with BAER and WERT team data via rapid flood and debris flow assessments. Simplified and rapid-response models identifying flood, surface erosion, or debris flow risks are useful. If the fire occurs during California's dry season, this level of analysis may be sufficient, given that flood-triggering storms may be less likely that time of year. It is worth emphasizing, however, that a flood event can occur at any point within the fire timeline between pre-containment and subsequent years, therefore monitoring of weather conditions should be ongoing. Coordination with the NWS is crucial.

The following sections in this chapter detail the activities that are important during the earliest portions of fire response, to prepare for flood. These actions will be taken by GIS specialists, geologists, soil scientists, civil engineers, and hydrologists. The first section emphasizes the importance of interdisciplinary teams: the Federal BAER teams that are deployed by the US Forest Service and the Department of Interior, and the State WERT that are specific to the State of California.

Each stakeholder will operate under their own agency or contract guidelines and funding. For example, FEMA is activated only after a Presidential Emergency Declaration is made, which could occur as a wildfire is still spreading (Time Tier 1) or after fire containment when debris cleanup becomes a priority (Time Tier 2). FEMA may enlist the US Army Corps of Engineers (USACE) during this cleanup phase. During Time Tier 2, USACE GIS and H&H staff work with FEMA on location at the Joint Field Office (JFO) or remotely from USACE offices. USACE GIS and H&H support is limited to the FEMA funded timeline, which usually lasts approximately one month (occasionally two). Therefore, the fidelity of deliverables is based on a one month timeline, and the funds and data available during this period. During Time Tier 2, BAER and WERT team data are available, which typically allows for higher precision analysis of flood, erosion, sedimentation, and debris flow potential.

Detailed erosion, sedimentation, and debris flow studies are commonly prepared in Time Tier 3. Longer term soil and stream analysis occurs during this timeframe with potentially greater access to data and site monitoring. Mitigation efforts, residential debris, tree clearing, and best management practices (BMPs) are also analyzed during this timeline. A spreadsheet of common stakeholder responses across the timeline are listed in the Resource Timeline Matrix (Appendix 6.1).

Figure 7 depicts the hypothetical fidelity of H&H analytical methods across the response timeline. The modeling categories shown are not exhaustive, nor an endorsement of a particular method, but are reflective of how time and data availability relate to H&H resolution. For example, a stakeholder with an existing H&H model of pre-fire conditions may add value, given adequate time, to adjust the model and incorporate additional post-fire data. Likewise, a hydrologic or hydraulic model, can incorporate a simple bulking method if available data or time does not allow detailed study (e.g., Gusman, 2011). Simpler models and bulking methods can be refined over time. Rapid response and rule of thumb tools may not provide improvements in fidelity with more data or time. Detailed physical modeling and analytical methods are provided in Appendix 6.3, the H&H Model Matrix.

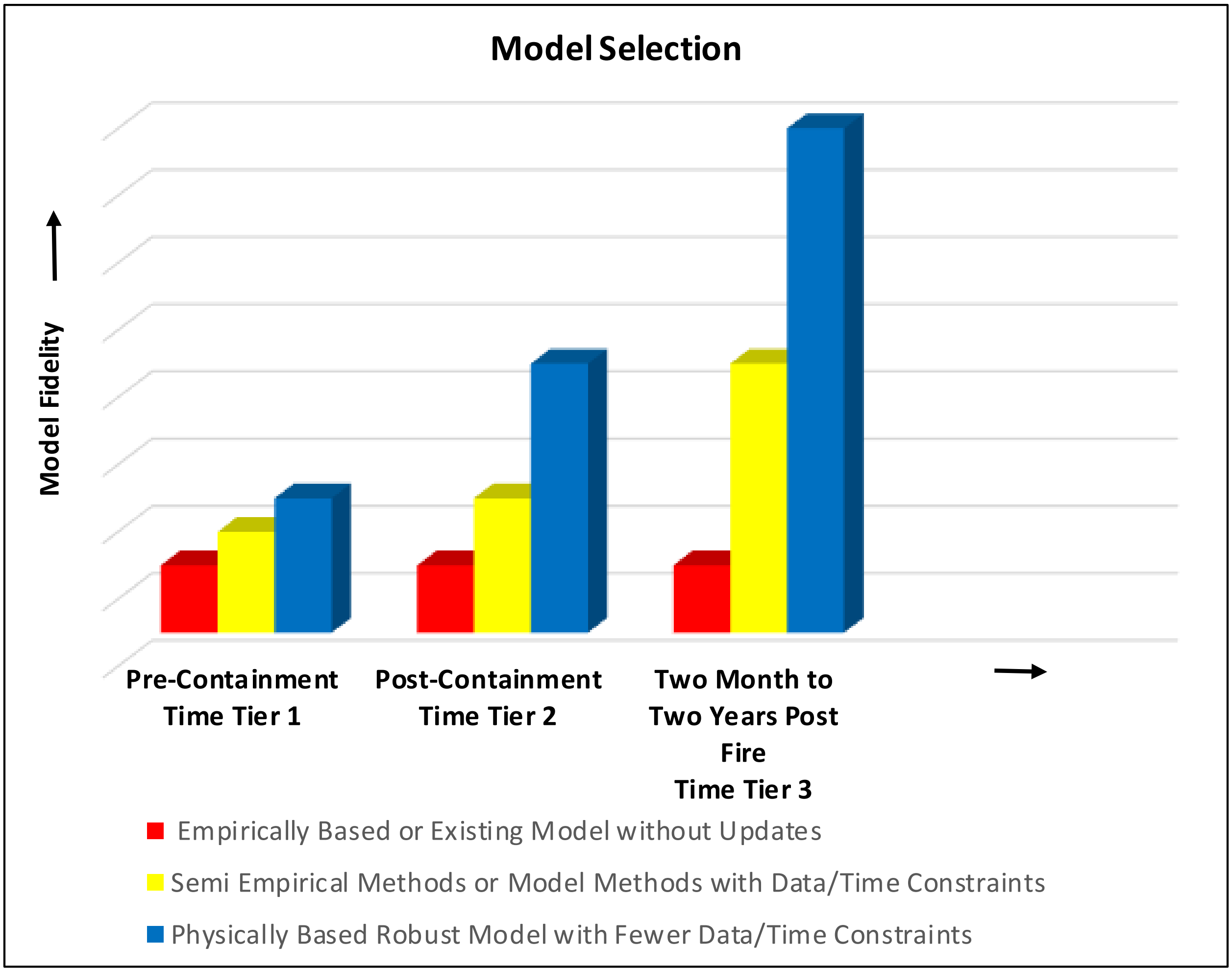

Figure 7. Generalized H&H modeling fidelity across timelines.

3.1. BAER and WERT

Federal BAER teams have been in existence since 1974, and are intended to address post-fire threats to life, property, and critical natural and cultural resources as a result of changed watershed conditions post-fire. The Department of the Interior (DOI) and Department of Agriculture have similar policies for BAER program responsibilities (USFS, 2020; DM 620). BAER is also known as "Emergency Stabilization" in the *Interagency Standards for Fire and Fire Aviation Operations* manual[1]. The objective of a BAER Assessment is to rapidly assess post-fire watershed conditions, identify BAER critical values (on Federal lands and as defined by agency policy), and apply risk assessment procedures for those values to determine if imminent post-fire threats warrant emergency response treatments. The USFS directs that all fires >500 acres, or smaller fires with suspected threats to BAER critical values, should receive some level of assessment. Where appropriate, emergency treatments are prescribed and implemented on Federal lands, with the objective to reduce risks to "acceptable" levels. BAER program responsibility is for Federal lands only, however most BAER teams assess the entire fire area regardless of ownership. Identified threats to non-Federal values are communicated to other appropriate agencies (e.g. NRCS, Caltrans) or other responsible jurisdictions (state, County, City) in an advisory capacity. However, the amount of time and effort spent evaluating non-Federal values downstream or in the wildland-urban interface is largely model-based and cursory compared to state WERT.

WERT have been utilized since 2015 to analyze risks in watersheds after wildfires and recommend actions. Post-fire assessments on non-Federal lands in California have been conducted by CAL FIRE and other State agencies using different approaches since 1956. WERT evaluations are narrower in scope than BAER assessments, and focus on selected wildfires that are anticipated to have significant life-safety and property risks from debris flows, flooding, and rockfall (CAL FIRE and CGS, 2020). WERT inventory values-at-risk (VARs) such as risks to life-safety, property and infrastructure, develop preliminary emergency protection measures, and rapidly conveys VAR locations and protection measures to local agencies (e.g., County department of public works, flood control districts) for implementation in the evaluation area (e.g., see Figure 8).

Often, WERT and BAER teams coordinate and share data on large fires that burn both Federal and State responsibility areas (SRA), each focusing on their respective geographic area (Figure 9). There are many similarities and some differences between the BAER and WERT programs, briefly described below, but both conduct rapid (e.g., 1-2 week) evaluations during Time Tier 1.

[1] https://www.nifc.gov/policies/pol_ref_redbook.html

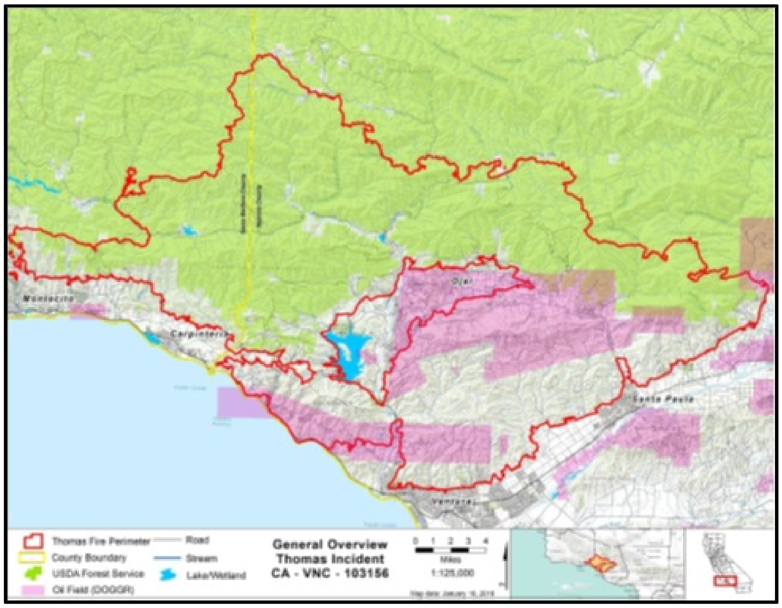

Figure 8. Overview map of the Thomas Fire BAER and WERT evaluation area.

Both WERT and BAER teams include professionals from many disciplines, with the membership dictated by the size and complexity of the fire. Typically, both these teams include geologists, hydrologists, civil engineers, and GISS. BAER teams also include soil scientists, botanists, archaeologists, and optionally wildlife and fisheries biologists and recreation specialists if needed.f

USFA BAER teams are usually composed of USFS employees, with exceptions, while DOI BAER teams are composed of professionals from several different Federal agencies (BLM, NPS, BIA, USFWS, USFS and NOAA). WERT are composed of employees from the California Department of Forestry and Fire Protection (CAL FIRE) and the California Geological Survey (CGS), and usually include staff from the California Department of Water Resources (DWR) and the California Regional Water Quality Control Boards (RWQCBs).WERT and BAER teams both begin the post-fire evaluation process by obtaining BARC maps (Figure 10), which are preliminary maps derived from satellite imagery (i.e., Landsat 8, Sentinel-2). BARC maps are made by comparing satellite-derived data for near- and mid-infrared reflectance values before and after the fire. This "raw data" – called differenced Normalized Bum Ratio (dNBR) – is then classified using specialized algorithms. BARC maps have been available since 2000, and the accuracy of BARC maps have been shown to provide BAER/WERT teams with an excellent starting point for the development of a final soil burn severity (SBS) map (Figure 11), which is used for erosion, peak flow, and debris flow modeling. The next step is to field check BARC maps for unburned/very low, low, moderate, and high soil burn severity using approaches described by Parsons et al. (2010). Final SBS maps can sometimes differ significantly from the BARC map (e.g., compare Figures 10 and 11 for the 2018 Woolsey and Hill fires), because satellites only observe reflectance values, not the more diagnostic belowground soil burn severity indicators.

WERT	USFS/DOI BAER
• Very limited number of fires evaluated with significant SRA • Focused evaluation for fires with life-safety and property risks from debris flows, flooding, and rockfall • Rapid field assessment using current technology to locate VARs • Rapidly develop and convey preliminary measures to local agencies for implementation	• All fires >500 acres in size, or smaller with significant threats • Broader evaluation of post-fire impacts that includes natural and cultural resources • Development of prescriptions for VARs that can be rapidly implemented on Federal land (with funding)

Figure 9. Comparison of WERT, USFS-DOI BAER main objectives.

The higher the soil burn severity, the more susceptible the area is to rapid runoff, surface erosion, flooding, and debris flows. Key field indicators for soil burn severity include post-fire ground cover, soil structure, fine root condition, and soil char depth. Soil water repellency is also tested, but is generally not a reliable indicator for determining soil burn severity, as water repellant conditions are usually highly variable and may or may not correlate well with soil burn severity class on any given fire. Often there are only subtle differences in the characteristics for moderate and high SBS areas. These two categories are often lumped together for post-fire flood and debris flow modeling, but not for surface erosion modeling. If necessary, thresholds for one or more of the soil burn severity categories (i.e., unburned/very low, low, moderate, high) are adjusted within ArcGIS.

For larger fires with distinct climate and vegetation gradients or particular geologic types, the BARC data for different areas may need to be adjusted separately (e.g., by watershed) and re-combined for a contiguous SBS map. Some mistakenly consider the SBS map to be a hazard map or watershed response map, but it is not. It is a key modeling input for other hazard mapping products. Once the final field verified SBS map has been completed, three types of post-fire hazard assessments are typically produced by both the WERT and BAER teams:

- Peak flow/flood response
- Geologic Hazards, including debris flow, rockfall, and hazardous minerals
- Surface soil erosion

These products are in turn used to help determine the threat vector and level of risk to VARs.

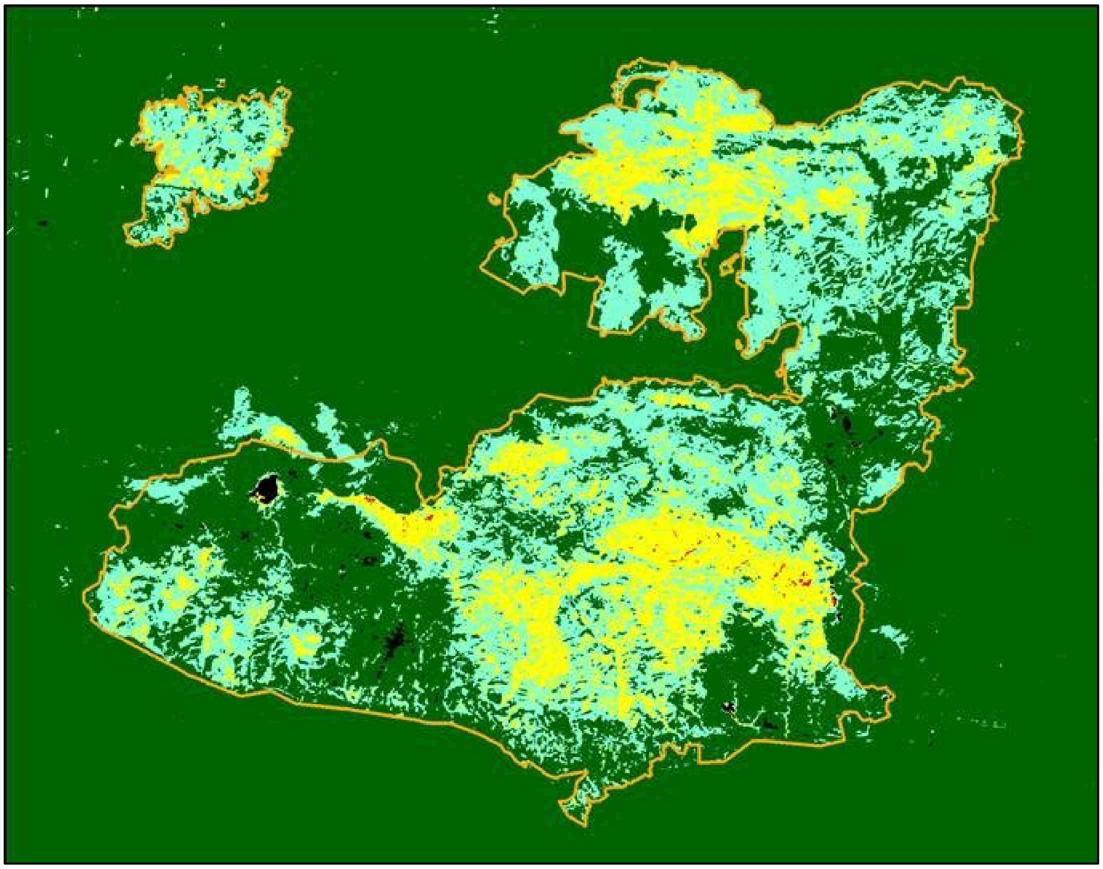

Figure 10. BARC map from the 2018 Woolsey and Hill fires in Ventura and Los Angeles counties, California.

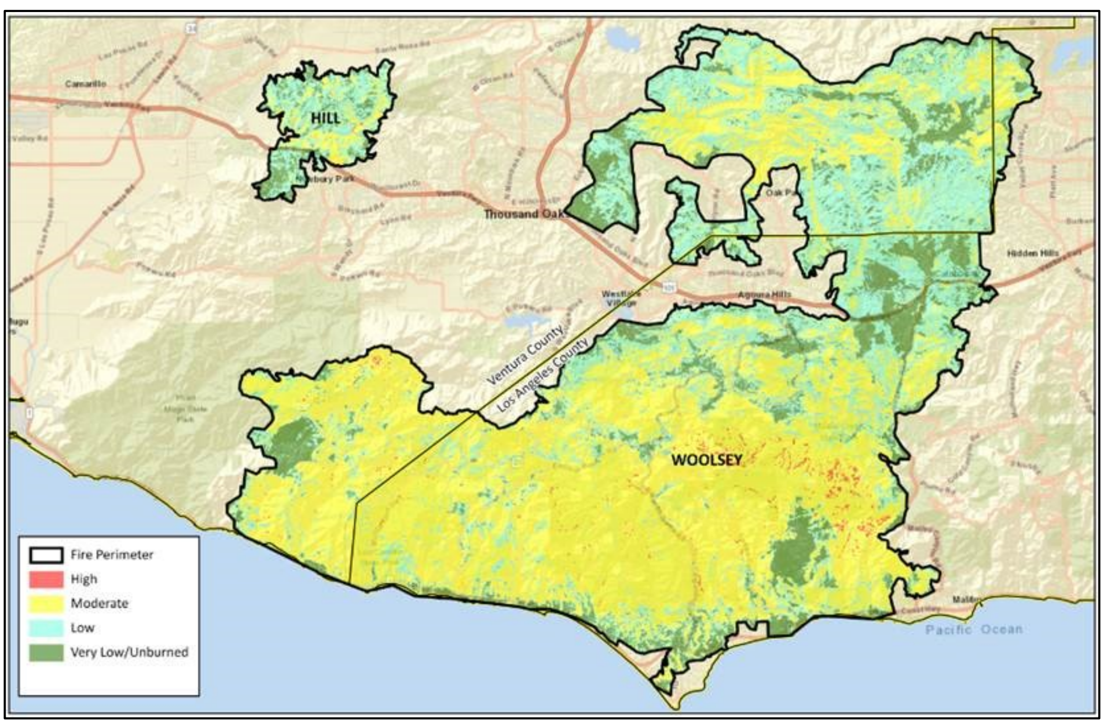

Figure 11. Final SBS map for the 2018 Woolsey and Hill fires in Ventura and Los Angeles counties, California.

Peak Flow/Flood Response Modeling

Post-fire flood response is assessed at watershed scale, commonly 5th field to 8th field Hydrologic Unit Code (HUC), custom sub-watershed, or "pour point" watersheds[2] designated for individual areas or values to determine level of threat or risk at that point. Pour point watersheds are used to obtain a better understanding of the hydrologic response for smaller, individual areas at risk from flooding. If there are a high number of VAR sites in the fire area, pour point watersheds will be used to categorically sample subsets of VAR sites that may be expected to have similar response scenarios. Thus, typically they are not assigned for each and every VAR site. Some pour points are often at or relatively close to the fire perimeter. Some other smaller pour point watersheds within the fire perimeter may be delineated for particular high-value "targets" to determine level of risk, for example where there are life and safety values at potential risk.

Peak flow/flood response is determined by first estimating pre-fire flood flows for selected recurrence interval (RI) rainfall events typical for the local climate. Pre-fire flow estimates can be obtained in multiple ways. One common approach is to rapidly use the USGS StreamStats online tool (https://streamstats.usgs.gov/ss/). StreamStats is a Web application that provides access to GIS analytical tools, and can be used to rapidly delineate pour point drainage areas, obtain basin characteristics, and gather peak flow statistics using the California USGS regional regression equations (Gotvald et al., 2012). Alternatively, if a stream gaging station with a sufficiently long flow record (e.g., >20 years) is within the fire perimeter or a similar hydrological station is located near the fire, a flood frequency analysis can be performed (e.g., USGS PeakFQ program; https://water.usgs.gov/software/PeakFQ/) and the flow transference method (Waananen and Crippen, 1977) method can be used in an Excel spreadsheet. This method adjusts for the difference in drainage areas between the gaged station and the ungauged pour point watersheds to produce flow estimates. Usually only peak flows with relatively low recurrence intervals (RIs) (i.e., 2-year, 5-year, 10-year) are estimated, since flood flow prediction methods have lower confidence with larger recurrence interval events (e.g., 25-year, 50-year, 100-year) (Kinoshita et al., 2014). Also, treatments or protection measures that may be employed to manage risks to VARs become progressively less effective with larger RI events.

To estimate changes in post-fire peak flows, the percent area burned at unburned/very low, low, moderate, and high soil burn severity within each pour point watershed is determined using GIS analysis. Post-fire BAER and WERT peak flow estimates are rapidly generated using several different methods, depending on the fire location and data available. Methods include:

- Rowe, Countryman, and Storey (RCS) tables (Rowe, Countryman, and Storey, 1949 & 1954) for southern California

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[2] Pour points for watersheds can be thought of as the bottom of a funnel – a watershed is delineated to include all uphill slopes that drain down to that particular point. This can be done using hillslope delineator tools in ArcGIS or hand digitized from topographic layers.

- USGS regional regression equations and the flow modifier method (Foltz et al., 2009)
- Moody USGS Analytical Method Equations (Moody, 2012)
- Wildcat5 (Hawkins and Barreto-Munoz, 2016)
- Regional 'rule of thumb' approaches (Table 2)

Recent research conducted by Kinoshita and Wilder at San Diego State University has shown that the RCS methodology is inaccurate for post-fire flow estimation for small watersheds (~750 to 8,650 acres) in southern California. Predictors with the highest importance include peak hourly rainfall intensity, soil burn severity, highest point in the basin, and basin shape (perimeter, circulatory ratio) (Wilder and Kinoshita, 2019). An improved rapid post-fire flow prediction method is under development.

Table 2. Selected BAER and WERT post-fire flow estimation methods (see Kinoshita et al., 2013).

Post-Fire Peak Flow Estimation Approach	Applicable Location in California	Applicable Drainage Area	Advantages	Disadvantages
Rowe, Countryman, and Storey (RCS) (1949, 1954)	Southern California	N/A	Empirical method easy to use; well understood	Large inaccuracy for small watersheds; data not updated
USGS Regression Equations with Flow Modifier (Foltz et al. 2009)	No limitation	Better for large basins (>3200 ac.)	Easy to use; well understood	Must determine appropriate flow modifier (subjective)
Moody USGS Analytical Method Equations (Moody 2012)	No limitation	N/A	30-minute rainfall intensity well correlated to peak discharge	Equations generated with little data from California
Wildcat5 (Hawkins and Barreto-Munoz 2016)	No limitation	<3200 acres	Best performing curve number (CN) method without calibration	User must specify the CN for pre- and post-fire conditions (uncertainty)
Regional 'Rule of Thumb' Methods	No limitation	N/A	Easy to use	Not validated, relies on professional judgment

A bulking factor (Gusman, 2011) is often applied to the post-fire flow estimates generated from the methods listed above, as a conservative approach. Bulking by sediment can be extremely important during the first few post-fire winter periods (LACDPW, 2006a). Due to modeling uncertainties with these rapid approaches, absolute changes in flow volumes or peak magnitude for post-fire flows are usually not provided; rather an estimate of peak flow response is displayed to make a more informed determination on flood hazard. Relative increase of peak flows from one pour point drainage basin to another is judged to be more important for these rapid assessments, rather than the estimated absolute values of the peak flows (i.e., percent change in flows rather than flow rates in cfs). Changes in flood flow recurrence intervals are also commonly reported.

Debris Flow Modeling

Wildfires can significantly alter the hydrologic response of a watershed to the extent that even modest rainstorms can produce debris flows. WERT and Federal BAER teams use the USGS debris flow products to further characterize values-at-risk. When the field verified SBS map is completed by the WERT or BAER teams, it is shipped electronically to the USGS Landslide Hazards Program staff in Golden, Colorado. They rapidly (<24 hours) develop estimates of the probability of debris flows and volume yields that may be produced by a design storm in the burned area. The model uses inputs related to basin shape, slope gradient, SBS, soil properties, and rainfall characteristics (Staley et al., 2016). Debris flow likelihood increases with:

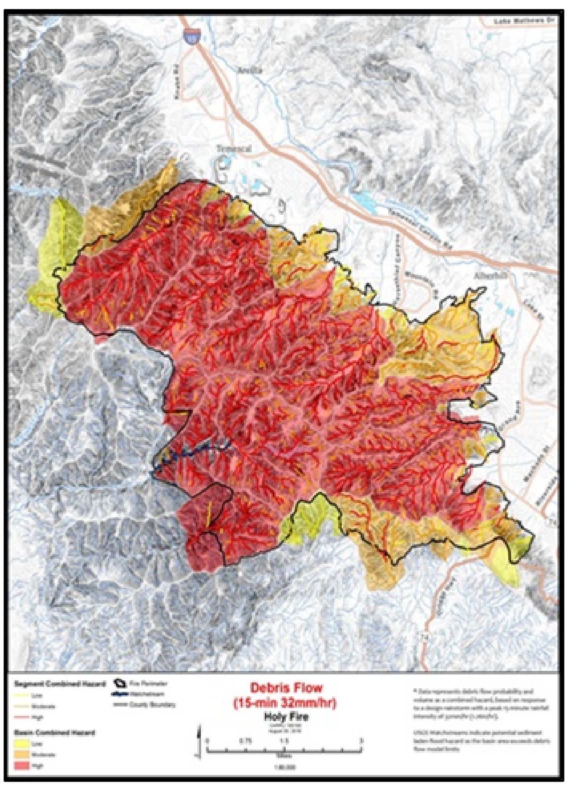

Figure 12. Debris flow model map for the 2018 Holy Fire in Orange and Riverside counties.

(1) Proportion of watershed with slopes greater than 43 percent and burned at moderate and high SBS

(2) Finer textured soil using the soil erodibility K-factor

(3) High-intensity, short-duration (e.g., 15-minute) rainfall

Post-fire debris flow likelihood, debris volume (Gartner et al., 2014; Staley et al., 2016), and combined hazards are estimated at both the drainage basin scale and in a spatially distributed manner along the drainage network within each basin (e.g., Figure 12). These are described as basin and segment probability maps, respectively. Hazard maps (e.g., Figure 13) are also produced for basins as the combination of probability and volume, referred to as combined hazard maps. The most hazardous basins show both a high probability of occurrence and a large estimated volume of material.[3]

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[3] USGS debris flow model results for past wildfires are posted at: https://landslides.usgs.gov/hazards/postfire_debrisflow/.

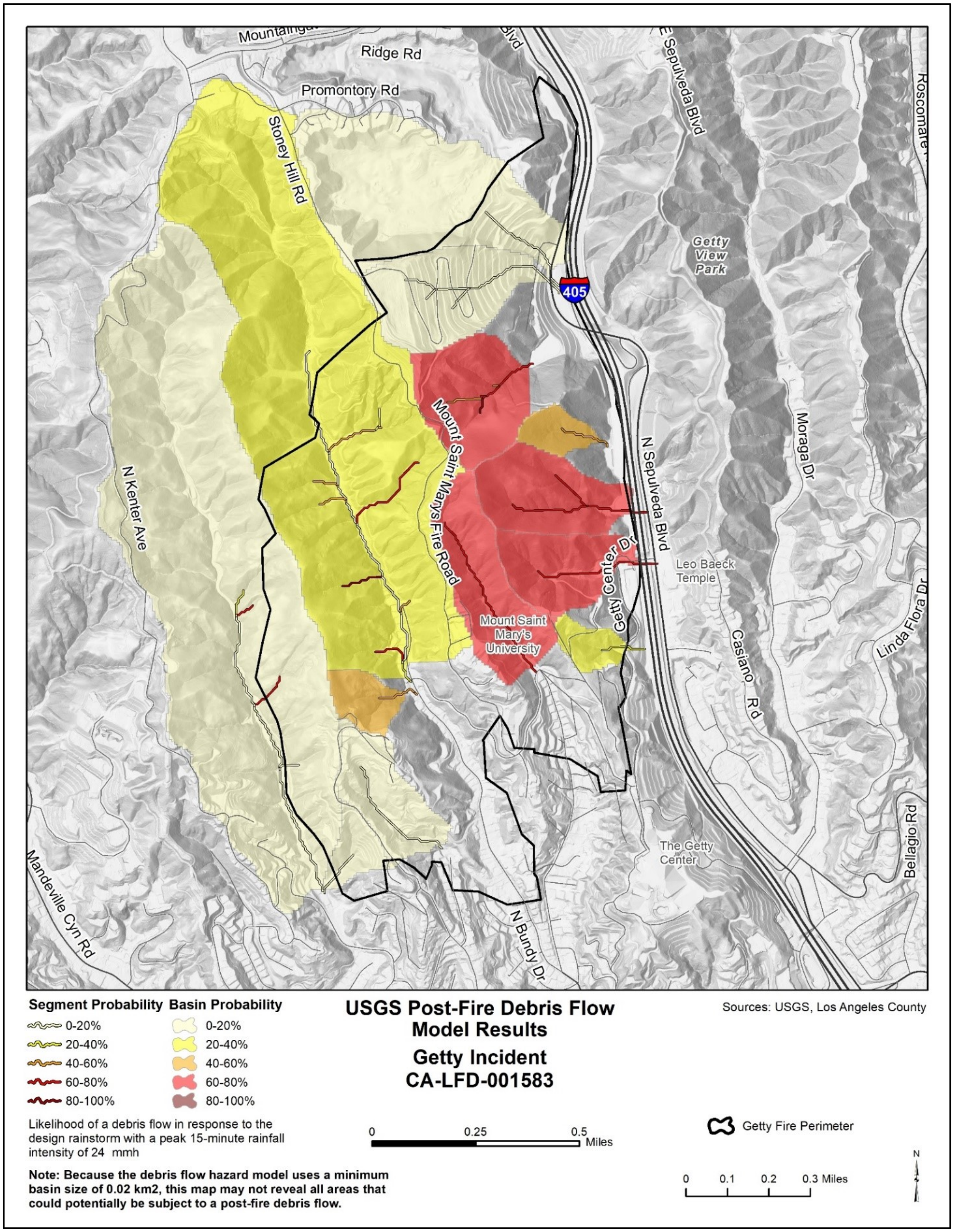

Figure 13. Hazard map produced for the 2019 Getty Fire in Los Angeles County.

WERT use debris flow model basin and segment maps from the USGS that are loaded onto tablets for field VAR evaluation, along with multiple other layers (e.g., SBS map, FEMA 100-year flood zone, LiDAR, permitted structures map, hydrography, roads, geology, soils, slope gradient, landslides) in the Esri Arc Collector application.

Surface Erosion Hazards

WERT and Federal BAER teams model erosion estimates in two ways: hillslope erosion rates (what is detached and transported from the slope) and watershed sediment production (what enters the fluvial system, accounting for hillslope re-deposition). Peak flow/flood modeling and erosion modeling are usually set up using the same set of watersheds and sub-watersheds or pour points for direct source-area comparisons. The most commonly used model for WERT and Federal BAER teams is Batch ERMiT (Erosion Risk Management Tool). ERMiT is a Water Erosion Prediction Project (WEPP) web-based interface tool developed to predict surface erosion from pre- and post-fire hillslopes and to evaluate the potential effectiveness of various erosion mitigation practices (Robichaud et al., 2011).[4] WERT and Federal BAER teams calculate soil loss from erosion when needed for a specific VAR. ERMiT requires input for climate parameters based on:

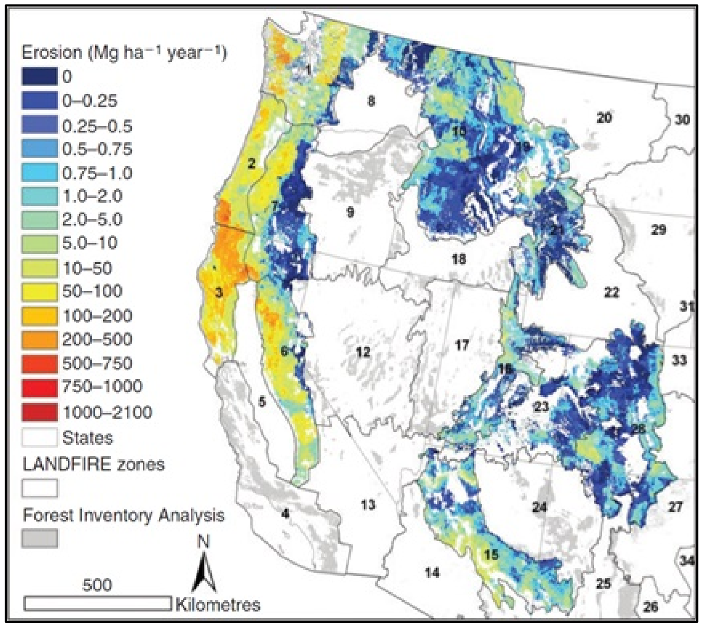

Figure 14. Erosion rates in sloped areas across the western United States (Miller et al., 2011).

- Location (PRISM interface)
- Vegetation type (forest, range, chaparral)
- Soil type (clay loam, silt loam, sandy loam, loam textures and rock content)
- Topography (slope length, profile, and gradient)
- SBS class (unburned, low, moderate, high)

This model provides probabilistic estimates of post-fire hillslope erosion from single recurrence interval "runoff events" by incorporating variability in rainfall characteristics, soil burn severity, and soil characteristics into each prediction (Robichaud et al. 2011). ERMiT only predicts rill and inter-rill erosion due to runoff events generated by precipitation.

[4] https://forest.moscowfsl.wsu.edu/fswepp/

There are many other erosion models and WEPP variants occasionally used by WERT and BAER teams, they are available tools that offer utility in many circumstances. These models which are attractive in modeling flow increases and hillslope erosion concurrently in the same model, which has obvious comparability-advantages. These erosion models include:

- Automated Geospatial Watershed Assessment (AGWA)
- WEPP/GeoWEPP/QWEPP
- WEPP cloud, WePPCloud for lake Tahoe and WEPP PEP
- Rapid Response Erosion Database (RRED-QWEPP)

Any of the WEPP interfaces will provide reports after running a model. These reports can be copied and pasted into a spreadsheet. Additionally, a URL is provided that can be shared or referenced later. As an example, the Sediment Delivery report provides soil data, sediment discharge from the outlet and sediment delivery from the hillslopes. The discharge from the outlet is the sediment from the hillslopes that did not re-deposit on the hillslope or settle out in the channel before it made it to the point of discharge identified in the model. Using the WEPP PEP for a 4,500 acre area in the Camp Fire burn scar, one watershed generated 68,000 tons from the hillslopes and discharged 14,000 tons at the identified discharge point. One can infer from this that 54,000 tons settled out before the outlet.

Dry ravel can be the dominant erosion process in certain geologic terrains with soils having low- to no-cohesion. It occurs where slopes exceed the angle of repose (i.e., approximately 60 percent slope). A dry ravel model is under development for use in such areas. Dry ravel tends to accumulate in seasonally dry, high-gradient stream channels, which can greatly contribute to debris flow risk and volume yield with significant rain events (Lamb et al., 2011).

Value-at-Risk Inventories and Report Generation

In addition to the three types of post-fire watershed hazard assessments, Value-at-Risk inventories are conducted by the WERT and BAER teams. Each team determines where potential VARs are located within and downstream of the fire perimeter using Google Earth imagery, local knowledge, helicopter, field observations and other mapping and satellite imagery. WERT staff often have 15-20 GIS data layers available on field tablets to rapidly query and overlay for verification of risk at specific VAR field sites. WERT conduct detailed, labor intensive VAR investigations throughout downstream housing developments to inventory individual sites at risk, or larger groups of houses at risk with a polygon designation. In addition to houses, VARs may include infrastructure facilities such as highways and low volume roads, power generation facilities, water conveyance structures, and recreational facilities (e.g. hiking trails, parks, campgrounds). Federal BAER teams are more focused on risks to VARs located on Federal lands but do conduct downstream/non-Federal land VAR inventories in a coarse fashion to characterize relative risk. They communicate with other Federal, State and local emergency managers and other cooperators, the calculated peak flow, debris flow risk, and soil erosion potential to jurisdictions downstream.

Federal BAER teams are not only focused on life-safety and property threats from flooding and debris flows, but a broader inventory of other types of VARs (e.g., critical natural and cultural resources).

Figure 15. Woolsey Fire DOI BAER/WERT Coordination Field Meeting, Santa Monica Mountains (November 21, 2018).

WERT members develop and digitally record VAR preliminary emergency protection measures (e.g., early warning system use, storm patrol, structure protection, channel clearance work near crossings, signage to close road crossings). This information is summarized in a detailed spreadsheet and as GIS shapefiles, which are rapidly disseminated to local agency representatives at a "close-out" meeting. A detailed final report is generated summarizing the physical setting, methods and modeling approaches, modeling results, and observations and recommendations. Report appendices include WERT contacts, GIS maps, the VAR spreadsheet, VAR information sheets, and photographs.

USFS BAER teams summarize their findings in a Final BAER Report. This report also functions as an initial funding request for emergency treatments (when needed) that are based upon the rapid assessment conducted. This document includes:

- Description of the burned area
- Detailed information on watershed conditions and predicted post-fire responses (flood flows, debris flows, surface erosion rates)
- Summary of the analyses conducted
- Critical values potentially at risk with attendant risk assessment (an identified critical value is not a VAR until the risk assessment process establishes unacceptable risk)
- VAR summary table
- Emergency treatment objectives and descriptions
- Estimated treatment and monitoring costs

The highest priority of this funding request is emergency stabilization in order to prevent further damage to life, property, or natural and cultural resources on Federal lands as a result of changed watershed conditions post-fire. The BAER program is not intended to repair fire-caused damages.

For the USFS, the BAER team works directly for the Forest Supervisor during the assessment phase. The BAER assessment is supposed to be completed within seven days of fire containment, so, on large and complex incidents, the assessment typically begins around 60-70% containment. This timeline is intended to be short so that necessary treatments can be implemented as rapidly as possible, and before future post-fire damaging events occur.

Once the assessment is complete, a closeout meeting is held with the Forest Supervisor and staff, and sometimes local agency representatives; a separate public closeout is common on high-public-interest fires. If the BAER team recommends treatments and the Forest Supervisor approves them, funding for treatments is requested. In addition, detailed specialist reports with accompanying GIS mapping products are generated to support the Final BAER Report. Common assessment reports are geologic hazards, soil resources, hydrology, engineering/roads, botany and invasive plants, and heritage resources. These specialist reports will usually have more detailed and useful information for future emergency response managers than the BAER Report.

DOI BAER reports are similar to the USFS reports, and include sections on watershed, wildlife, vegetation, infrastructure, cultural resources, and forestry. DOI BAER plans include funding requests. Emergency stabilization is a one year, emergency mitigation program, while rehabilitation is a long-term program to rehabilitate lands not likely to recover naturally. The emergency stabilization plan will specify only emergency treatments and activities to be carried out within one year following containment of a wildland fire. Generally, emergency stabilization activities are prescribed only within the perimeter of a burned area. They communicate with other Federal, State and local emergency managers the calculated peak flow, debris flow risk, and soil erosion potential to jurisdictions downstream.

The submittal timing of DOI BAER emergency stabilization plans often depends on the environment/landscape of the fire and the complexity; however, initial submission of the emergency stabilization plan must be shortly after the containment of a wildland fire in order to ensure credibility and to document the urgency of the situation. The initial emergency stabilization plan must be submitted within seven calendar days after total containment of the fire. If additional time is needed, extensions may be negotiated with those having approval authority.

In summary, Federal BAER teams and State WERT are the first boots-on-the-ground after a fire that meets their agency response parameters. They conduct rapid assessments of VARs, or "what's in harm's way", that are threatened by post-fire events. The rapid nature of assessment and modeling methods may be coarse for users of this toolkit. However, these teams rapidly produce reports and spatial products that help to identify VARs and high hazard areas in a geospatial context, and the preliminary information provided can help focus where more in-depth (Time Tier 2 and 3) modeling efforts should be employed for flood hazard prediction and emergency response planning efforts.

3.2. GIS (Time Tier 1)

In this part of the timeline, a wildfire is occurring and continues to burn, and its magnitude makes it apparent that disastrous consequences are going to result. The GISS or technician will be tasked to provide the situational awareness of the event. The initial focus will be on the wildfire event itself, understanding the scope and immediate impacts of the fire. Additionally, however, the impact of possible flooding in the burn area will be a secondary focus. Event data collection and organization will begin for the affected watershed(s) and downstream areas. The information may need to be updated as the wildfire expands. Preliminary assessments and analysis can provide immediate answers to the impact that could occur from a rain event. H&H staff will require watershed data to begin the cursory modeling of flood inundation and debris flows. Agency management and other officials will want to see cartographic products to visualize the event scope, and understand the areas at risk of impacts from floods after the fire. The products will require an understanding of what specific questions are being asked, and who the audience will be. Good communication between GISS, modelers, and management is key to collecting the right information, answering the important questions, and presenting them in an understandable format that informs the audience.

GIS team members have numerous tasks in the initial phases of a BAER or WERT deployment, including:

- Obtaining data consisting of:
  - A BARC map containing raster data that can be layered onto a variety of maps
  - A fire perimeter shapefile for the incident
  - ArcGIS layers needed for post-fire flooding, debris flow, and surface erosion modeling[5]
- Generating and printing on a plotter large-scale paper maps showing BARC soil burn severity classes, the complete road layer, and other features aiding in field identification. Geo-referenced PDF maps or equivalent base maps are to be made and loaded onto iPads/tablets with the Avenza PDF Maps application and the ArcGIS Collector application.
- Working with the field team to divide the fire area into pour point watersheds based on identified VARs for hydrologic analysis. The GISS will extract relevant data as part of this process (e.g., watershed drainage acreage, acreage burned at each soil burn severity category, etc.). This method should be set up as an automated GIS process.
- Following established data management procedures to include: file names, locations, metadata, versioning or archiving, and preserving the availability of final GIS data and products for retrospective studies.

[5] The purpose of each data type, their limitations, underlying assumptions, and their inter-relationships should be articulated as GIS metadata. The data may include, but are not limited to, topographic maps (current and historical); published geology maps; LiDAR (where available); Digital Elevation Models (DEMs); USGS peak flow information and reports; FEMA floodplain maps; DWR flood awareness maps; and fire history, CalVeg, GIS road, parcel, and hydrography layers.

- Ensuring that appropriate computer programs are available to conduct the field assessment, including ArcGIS and Adobe Acrobat Pro. Additionally, iPads or other GPS-equipped tablets are desirable their ability to input detailed field information. The GIS team member will ensure that appropriate software/apps, such as Avenza PDF Maps, ArcGIS Collector, and Google Earth, are installed on the tablets.
- Ensuring that field personnel are trained for proper data collection and data transfer. The GIS team member will be responsible for data management. If available, the GIS team member will incorporate data collection schema (fields) for field data collection software such as PDF Maps and ArcGIS Collector.

3.2.1. Event Data: Collection and Organization

The first task for GIS personnel is the collection and organization of data related to the wildfire event. There will be data specific to the wildfire, and data for the affected watershed(s) and downstream areas. Most data are publicly available through agency websites, but some may require direct communication between agencies. Data specific to the watershed and impacted population and infrastructure can come from the initial base data collection. Data collected will also be determined by assessment questions being asked, and products that are required. The following is a list of key datasets for collection, and they are also listed in Appendix 6.2, the Spatial Data Matrix:

- Fire Perimeter – This will be used to map the scope of the event, and identify the watershed(s) initially affected.

- BARC – Identifies the burned vegetation condition, and is categorized into four classes: high, moderate, low, and unburned/very low. After field verification and possible modification, this helps to determine the burn fire severity locations, and where debris flow risks can be highest.

- Terrain – This is used on the initial status maps to provide a sense of the topography in the affected area. It is also probably the most important data for H&H modeling. The better the resolution, the better the modeling detail. Datasets are readily available on the USGS National Map (TNM) website for download: 10-meter DEM, Interferometric synthetic aperture radar (IFSAR, 3 to 5 meter), and LiDAR (0.5 to 2 meter).

- Hydrography Data – The best available data will be the USGS National Hydrography Dataset (NHD). This database will have the most detailed rivers/streams and water bodies. Additionally, it has the delineated watershed boundary data (WBD) in HUC that can be used to select the affected watersheds. It will be used for the status maps, initial assessments, and H&H modeling. Additional hydrologic data like flood zones from FEMA's National Flood Insurance Program (NFIP) can be useful for the initial analysis of impacts, as well.

- Infrastructure – This category covers roads, railroads, bridges, culverts, flood control structures, and buildings. Creating subsets of these base data layers helps with quick assessments of assets that may be directly impacted by the fire, and secondarily by flooding and debris flows. Many of these datasets can be found on national, State, or local websites. They may also be part of an agency's own databases.

- Census and Boundary – Examples of data from this category are population centers, State/County/city boundaries, agency boundaries, tribal land, and political boundaries. Again, creation of subset data layers to the affected area can help expedite assessment and analysis, and provide management with information on which agencies and entities are directly impacted. It also identifies the officials that will be directly involved with the disaster.

- Land Cover – Using data layers from the National Land Cover Dataset (NLCD), as well as vegetation datasets, helps with the initial description of the affected area. It will also be used in the H&H modeling efforts by providing the pre-fire baseline.

These datasets may need to be updated regularly as the fire expands and impacts additional watersheds and communities. Using an established organizational format makes this task easier. Additionally, it is recommended to use a naming convention incorporating the event name, data name/description, agency origin, and a date obtained. Under the commonly fast-paced conditions of emergency operations, there may be little time for complete metadata documentation, so descriptive file names help. As a reminder, if the total path/file name length is too long, spatial analysis processes may not execute. Also establish a projection for the datasets that are commonly used for the area. Statewide Albers projections or State Plane Lambert Conic projections are the most used. Many raster datasets are unprojected or in Universal Transverse Mercator (UTM) coordinates, so it is important to remember that cells will be skewed when projected or reprojected. Vector data can be reprojected without consequence.

3.2.2. Event Status: Initial Assessments & Analysis

As the fire is occurring, management and officials are going to have a multitude of questions relating to the status of the event, and the possible flood after fire impacts. The following GIS assessment and analysis tasks can provide the initial answers, before a full H&H modeling study is required:

1. Identification of Impacted Watersheds – Start with the watershed boundary dataset (WBD) from the NHD database. The database has HUCs for boundaries ranging from two digit regions down to 12 digit subwatersheds. In this analysis, it is recommended to use the appropriate 8, 10, or 12 digit HUC polygons. Doing a simple intersection selection with the current fire perimeter will identify the watershed(s) and subwatershed(s) directly affected.

2. Identification of Rivers/Streams and Water Bodies – Using the NHD flow lines and water bodies datasets, the stream reaches, lakes, and reservoirs can be selected. Additionally, the stream lines can be used to identify the downstream watersheds that may also be impacted.

3. Identification of Impacted Population – In this analysis step, census category layers are used: census tract points, County parcels, structures, and city/County boundaries. Using the identified impacted and downstream watersheds, another simple selection process is used to the create subsets of impacted features.

4. Identification of Impacted Critical Infrastructure – This category assesses the schools, fire stations, police stations, airports, hospitals, hazard material sites, power plants, power lines, sewage treatment facilities, gas and oil lines, communication towers etc. Again this is strictly a selection of the features from HIFLD (Homeland Infrastructure Foundation-Level Data) databases that intersect affected watersheds.

5. Identification of In-Stream Infrastructure – This is an assessment of bridges, culverts, dams, diversions, weirs, levees, floodwalls, closure structures, and stream gauges. Many of these features can be found in the National Bridge Inventory (NBI), the National Inventory of Dams (NID), and the National Levee Database (NLD). Culvert data may be available from State or County transportation, public works, and/or flood control agencies.

6. Identification of Impacted Agency Assets – These are features that are specific to an agency. This can be infrastructure and cadastral, or personnel and working sites. As an example, the USACE uses the Corps Projects Notebook database for identification of projects and studies in the Civil Works and Military Programs.

After these items are identified as impacted features, initial analysis can done. Basic information might be the total watershed area impacted, and total counts for each of the assessment categories. A deeper analysis could be done using a distance proximity from the affected stream lines, or using the existing FEMA flood zones (see example in Figure 16). This analysis can provide estimates for population at risk, number of structures and critical infrastructure possibly impacted, which dams, bridges culverts, and roads are threatened. Deeper analysis could lead to initial H&H modeling requests. This is where a GISS needs to become an interpreter at times. In other words, listening to management questions and needs, and translating that into data that will be required by the H&H engineers for modeling, to get answers.

3.2.3 Event Status: Cartographic Products

Many cartographic products can be produced to convey the situational awareness and display the results of the analysis and assessments. The type and format of the product depends on the audience, questions or message, data restrictions, and software and/or hardware limitations. Many questions need to be asked before the product can be created:

Figure 16. Example of a FEMA Flood Zone Map.

Who is the audience?

- Internal Agency Management
- Inter-agency Collaboration
- H&H Teams
- Public Use

What's its purpose or use?

- Situational Awareness
- Decision Making
- Accountability
- Public Knowledge

What is the scope or extent to be represented?

- Regional View – State, Multiple Counties, Multiple Fires
- Event Specific – Large Fire covering multiple watersheds
- Community Specific – Population Center or Facility (Impact Area)

What are the data, software, and hardware limitations?

- Detail restricted at scales or FOUO (For Official Use Only)
- Digital Views – Online Maps, GIS Software, Google Earth, PDF Reader
- Printer/Plotter – Page Size, Color

The quality of a map will depend on time restraints, man power, data accessibility, data quality, and software and hardware. The following is quick list of map formats with notes on their capabilities and limitations.

Google Earth

- Built in base data (aerial imagery background only)
- Quick layer generation
- Intuitive interface
- Easily shareable
- Data attribute and categorization limitations

- Not recommended for 50+ records
- No analysis capabilities
- Not for hard copy printout

GIS file map with export to PDF

- Online base data
- Multiple background choices (aerial imagery, topographic, streets, etc.)
- PDF output easily shareable
- PDF can be set to toggle layers on/off and with attributes
- Designed for hard copy printout
- Designed for spatial analysis
- Requires GIS software and knowledge
- Edits required to be done in GIS software
- Map creation can take time

Online GIS Maps and Dashboards

- Easily shareable (URL link)
- Online base data
- Multiple background choices (aerial imagery, topographic, streets, etc.)
- Toggle layers on/off and with attributes
- Excellent for assessment accounting and display
- Capable of hard copy printout (not great)
- Can be designed with spatial analysis tools
- Requires additional GIS software and knowledge
- Edits required to be done in GIS software
- Data creation and uploads can take time
- Map/Dashboard design and creation can take a lot of time

A list of example maps for this time tier can be found in the GIS and H&H Output Products Matrix (Appendix 6.4). Figure 17 below is an example of a situational map of the Camp Fire for use by USACE Emergency Management.

3.3. H&H Event Checklist

Prior to the deployment of technical resources, basic information on the geomorphic setting is needed to develop a conceptual geomorphic process-based understanding of the area being evaluated. A preliminary geomorphic setting evaluation will help provide a framework for the modeling plan.

Certain physical processes dominate specific domains as a result of rainfall regimes, geology, slope, soil and regolith production, and soil burn severity. For example, concentration of flow may occur within ravines on first-order stream segments in the upper watershed, but flow behavior may differ more dramatically in sediment concentration and flow viscosity than with larger river systems. In watersheds with abundant sediment supply, where channel segments reach 10 to 15%, sediment concentrations typically reach those of debris flood and debris flows. When the channel bed is steeper than 20%, sliding-type en mass instability of the channel bed occurs (Rickenmann, 2016). Thus, in the absence of stabilizing bed structures, channels with bed slopes of more than 20% may be expected to produce debris flows where soils and hillslope regolith production are conducive (Rickenmann, 2016; DiBiasi and Lamb, 2020). Conversely, in gently sloping riverine environments, the armoring of channel beds tends to inhibit the production of sediment laden flows.

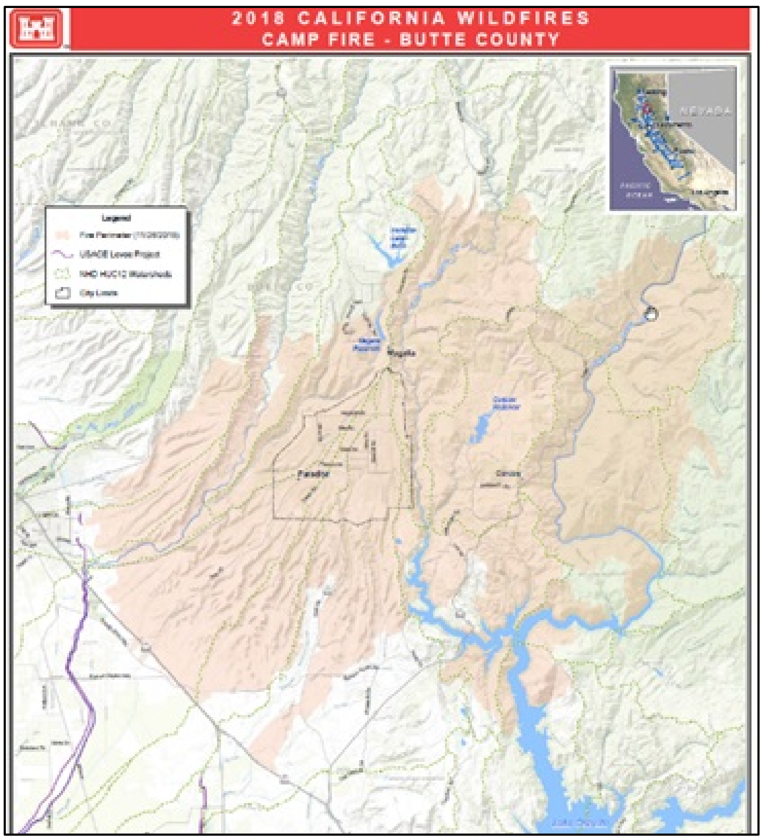

Figure 17. USACE Situation Map used during the 2018 Camp Fire in Butte County.

Depending on the type of problem being addressed and the staff involved, the geomorphic setting will need to be characterized to determine the position in the watershed and attendant energy of the environment. The BAER and WERT reports may provide key geomorphic observations in areas of interests. However, in the absence of BAER and WERT, a basic recognition of process domains is needed as indicated in Figure 18. Such an effort will require an interdisciplinary approach between geomorphologists and H&H modeling professionals. As described in the sections above, a review of watershed slope and sediment availability will help the practitioner understand potential flow behavior types at points of interest. However, a basic landform recognition should be used to determine whether the area of interest is within a tributary system such as a river, or a distributary system, such as an alluvial fan. In mountainous regions of the State that have high fire frequency, it is common to find alluvial fans of varying size that are constructed by a range of processes.

Alluvial fans are categorized as stream flow fans, debris fans, and composite fans based on their geomorphology (Bull, 1977; NRC, 1996). Debris flow dominated fans have steeper gradients (generally ≥6°) built by successive debris flows and sediment-gravity deposits, where water-borne sediment concentrations are generally greater than 50% by volume (Pierson and Costa, 1987; Iverson, 1997). Alluvial fans formed primarily by debris flow processes differ markedly from fans formed primarily by fluvial processes. The magnitude and consequences of debris flow impacts on the former are far more dramatic and impactful than turbid flood-flows on fluvial process dominated fans. This includes greater potential for channel avulsion near the fan apex (breaching and leaving the existing channel) and unpredictable overflow runout paths.

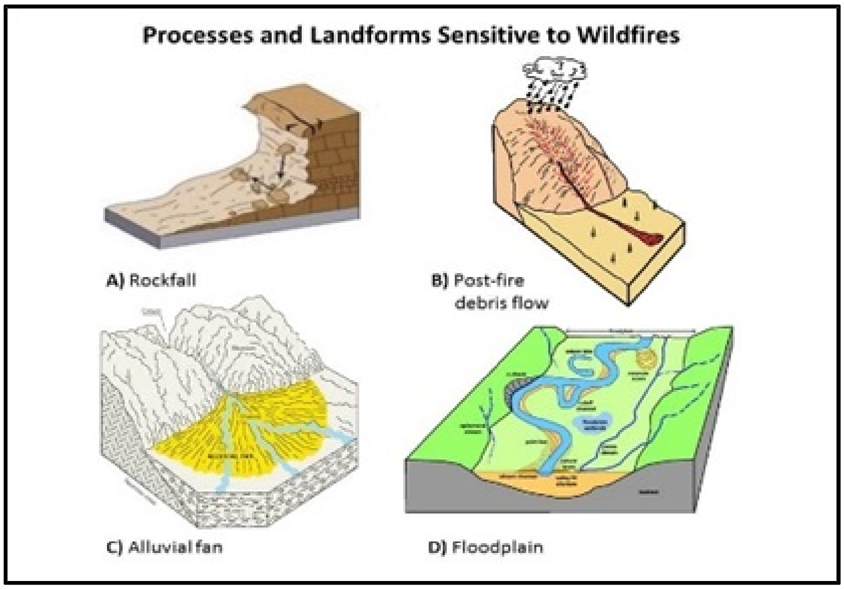

Figure 18. Processes and Landforms Sensitive to Wildfires.

A list of core data inputs for a majority of H&H methods are listed in Table 3. Data are used for flood, debris flow, and erosion analysis. Each fire presents unique concerns for evaluation, therefore product needs and inputs may vary according to location and event.

Table 3. H&H data checklist.

DATA OWNER	DATA	DATA SOURCE
USDA/Multiple	Terrain/DEM (LiDAR or minimal resolution of 10 meter)	https://gdg.sc.egov.usda.gov/; https://www.arcgis.com/apps/View/index.html?appid=9204adf2fd1546379b845d163ef2544a
	Soil Data (Gridded format)	https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053628
	Basin Perimeter HUC	Subregions-map: https://gdg.sc.egov.usda.gov/
USGS/USDA	Basin Perimeter HUC	https://www.usgs.gov/media/images/watershed-boundary-dataset-
CAL FIRE/USFS	Fire Perimeter Map	https://maps.nwcg.gov/sa/#/%3F/39.8212/-96.2709/4; https://www.nifc.gov/fireInfo/fireInfo_maps.html
Derived	(% Burn) Combined HUC and Fire Perimeter	GIS Staff
BAER /WERT/ USFS/USGS	BARC-Final Soil Burn Severity Map	https://www.fs.fed.us/eng/rsac/baer/barc.html
Derived	(% Severity per Category) Combines HUC and BARC	GIS Staff
USDA	Soil Data (Gridded format)	https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053628
Derived	(% Soil Type per HUC and Burn Severity) Combined HUC, Soil, and % Severity	GIS Staff
USGS/CAL FIRE	Land cover and Vegetation Cover Grid	https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/land-cover-data-download?qt-science_center_objects=0#qt-science_center_objects; https://www.arcgis.com/home/item.html?id=35b4d77128264b3bacd31d9685f974b7
Derived	(% Land cover per % Severity) Assigns post-fire infiltration and Manning's **n**	GIS Staff
USGS	Debris Flow Hazard Maps	https://www.usgs.gov/natural-hazards/landslide-hazards/science/post-fire-debris-flows
ESRI	Infrastructure Asset Maps	https://hifld-geoplatform.opendata.arcgis.com/
NOAA	Precipitation Frequency	https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html
USGS	Streamflow Gaged/Ungauged	https://waterdata.usgs.gov/nwis/sw; https://streamstats.usgs.gov/ss/

3.3.1. Watershed Model Setup

Several models are currently used for comparing and predicting pre-fire and post-fire hydrologic impacts, some of which are described above in Section 3.1. However, the application of a suitable hydrological model depends on the major purpose of study, model complexity, and the data requirements. Major impacts that have been of common interest during post-fire assessment include peak flow magnitude and frequency, total runoff volume, peak timing for runoff and hyperconcentrated flow, along with the probability and volume of runoff generated debris flows. Runoff combined with debris-flow has caused considerable physical, environmental, and economic losses, including loss of human life; heavy damage to major infrastructures such as roads, pipelines, rail lines; and disruptions of major physical and electrical systems (e.g., Kean et al., 2019). Many field-based studies have shown that runoff-generated debris flows are common in steep burned watersheds where water floods can transition into debris flows (Cannon et al., 2001, 2003; Santi et al., 2008).

Flood hydrologic modeling options available to evaluate these post-fire related hydrological impacts vary from simple to complex, are statistical to semi/empirical to process-based, and were developed by different organizations. A brief description of various types of models used by different organizations, their applicability based on study purpose, along with their suitability, advantages, and limitations are summarized in the H&H Model Matrix included in Appendix 6.3. These models have been used during post-fire conditions mainly in the western U.S. Note that the modeling matrix for the H&H models does not encompass all hydrologic models that successfully simulate post-fire conditions. This flood after fire toolkit is focused on California and the models in the matrix are primarily those used in California. In addition, flash floods and debris flows are highly complex events that commonly occur in ungauged watersheds, and no predictive model will predict the magnitude and spatial extent of a flood or debris flow with a high degree of accuracy.

Common statistical models developed by regression analysis require minimal data and can be applied quickly to estimate hydrologic response in terms of peak runoff and debris flow (used in Time Tier 1). Major data requirements for these models include rainfall intensity and watershed characteristics, including soil parameters and soil burn severity which are directly contributing and most sensitive to runoff and debris flow. Although they are quick and easy to apply, most of the regression equations are semi-empirical or empirical, region-specific, event based, and developed for specific outputs. Therefore, these equations are more suitable for watersheds with underlying characteristics used in the equation. For simple and quick applications in regions with limited or minimum data availability, statistical models are well suited for evaluating pre-fire and post-fire watershed conditions.

Semi-distributed and distributed models are process-based models which incorporate the physical processes controlling the hydrologic response of the watershed (typically used in Time Tier 2). These models are more comprehensive and mainly developed for both event-based and continuous simulations while incorporating various components of the hydrological cycle and their interaction. Most process-based models use parameters that reflect measurable landscape characteristics and are spatially explicit, which makes it easier to understand the distribution of state-variables[6] such as velocity and depth at different time steps during a rainstorm (Blöschl et al., 2013). Therefore, structure of process-based models help to conduct hypotheses and parameter sensitivity testing, and to fully explore the importance of different factors in controlling the hydrologic response and explain the overall process controls within a watershed (Beven, 2001). However, complexity of these process-based models and their data requirements increase for fully distributed models as compared to semi-distributed models.

Most of these models are applicable to simple and complex watersheds. Depending on model parameterization and quality of available data, their application may be more suitable to specific regions (arid, semi-arid) and type of watersheds (small, large, rural, urban). Similar to empirical models, simple to moderate process-based models are rainfall/runoff dominated, where runoff or storm related processes are fully incorporated and parameterized compared to other processes. These models are suitable to simulate hydrograph properties including peak flow and runoff volume. The same sets of models could be used to simulate sediment transport, sediment volume and concentration with a lower to higher degree of limitations. The major inputs for this set of models include rainfall intensity (storm events) and watershed characteristics such as topography, soil, and vegetation. An actual profile of pre-fire and post-fire storm events along with delineated sub-basins within a watershed, and GIS-based distributed data are required for each sub-basin to simulate runoff mechanisms. Additional sub-basin and soil parameters (based on infiltration mechanism used), and channel characteristics are required to perform debris flow based simulation. Calibration of this type of model is less intensive compared to fully distributed models.

Complex models incorporate more physical processes and evaluate runoff and debris flow mechanisms using fully distributed models and process-based numerical models (typically used in Time Tier 2 or 3). These models are developed to handle multiple scenarios for a wide range of watersheds and storm events, and are capable of shorter or continuous simulation over longer periods. They incorporate detailed physical processes thereby requiring a large number of input parameters that complicates model parameterization and calibration. Therefore, the user needs a complete understanding of the overall hydrologic processes incorporated in the models and parameter sensitivity within those processes. Although these models are considered more accurate at representing physical processes as compared to statistical and semi-distributed models, the accuracy of results largely depends on measurement errors of the input dataset. Depending on the overall purpose of the study, major input parameters for this set of models require spatial and temporal distribution of higher resolution data for a wide range of watershed,

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[6] State variables are those which define the current condition which could help predict future conditions.

soil, and storm characteristics. The major characteristics include: climate and weather (storm) data; soil texture, moisture, and temperature properties; land use and land cover; and types of land management practices. The major sources of higher resolution data include all newer technologies such as DEMs, LiDAR, radar, and satellite-based sources which are preprocessed through GIS and incorporated into the model.

Similar to semi-distributed models, additional data are needed to simulate soil loss, debris flow and debris flow paths, sediment transport and deposition, and sediment volumes/concentration. These data include:

- Channel characteristics
- Types of sediment and sediment concentrations
- Fluid viscosity
- Sediment and pollutant transport mechanisms (common in post-fire debris flow)
- Additional watershed features and debris contributing area
- Change in ground cover before and after the event

These models run at smaller time steps and process a larger set of higher resolution data to capture watershed physical processes more accurately, thereby making it data intensive, time consuming, and complex. This further complicates model parameterization, calibration, and validation.

Additionally, flow through a network of natural and constructed channels can be simulated using the non-Newtonian[7] flow module included in two or three dimensional (2D/3D) models and distributed hydraulic models (e.g., 2D/3D Adaptive Hydraulics Model (ADH), FLOW 2D/3D, and HEC-RAS). Using the non-Newtonian flow simulation module, flow and sediment yield produced from the watershed can be routed through the channels to predict the inundation boundaries, depths, and arrival time for a range of flood frequency hydrographs. These outputs can be an aid to decide areas to be protected or evacuated during an emergency response plan. In addition, the model can be used for the channel optimization design to increase the capacity of the debris basins and channels to convey the predicted sediment yield from the watershed.

During the post-fire condition (Time Tier 3), it is important to plan and implement solutions that can reduce potential physical, environmental, and economic losses. Hydrological models are available that incorporate several management options which help to evaluate the effectiveness of physical and management practices to address post-fire conditions. These include reduction in flood peak, volume and inundation, and soil erosion prevention and control. Models such as HEC-HMS (model used by USACE) provide management options for planned diversions and construction of physical water control structures (on/off stream detention) to reduce and store storm runoff volume. Models such as ArcSWAT provide options for pond and reservoir storage,

[7] Non-Newtonian fluids are those with viscosity that is dependent on the stress or pressure placed upon them. Some debris flows behave as non-Newtonian fluids.

along with land use and land management practices, to evaluate the impacts on runoff and sediment at a local and regional scale. Additional input data related to ongoing and planned management practices, size of storage, and location of diversions, are required to simulate current and future developments in with or without project conditions. This allows practitioners to evaluate the impacts of watershed management practices. Further detailed studies could be performed for the management option considered the best option to handle future post-fire runoff conditions.

3.3.2. Initial Modeling: Pre-Event Conditions

Rule-of-thumb and empirical methods used in estimating flood and debris flow risk can commence once fire damage severity and coverage are estimated. The degree of effort involved in higher fidelity modeling is related to preparedness and data availability. The modeling efforts follow an iterative methodology:

- Do models and associated input data exist now?
- If data and/or models exists, what are their capabilities and efficacies?
- If data and/or models do not exist, what am I analyzing and what do I need to do so?
- What level of fidelity do I need?

For example, a stakeholder may have an existing model used for water quality but the upstream model extents are located at a gage, and that gage is downstream of the upper watershed fire damage. This model would need to be extended. Perhaps both hydrologic and hydraulic models exist, but the inflows were based on a particular reservoir release assumption, such that the hydraulic model is suitable but the hydrologic inputs need adjustment. As another example, a modeled area may have been created before a dam or large development was built. These are just a few examples which emphasize that not all existing models fit the needs of today.

If a hydrologic, hydraulic, or combined model must be created from scratch, the user has to weigh the time and funds available against the analysis required. Does the model offer the fidelity to study erosion and mass wasting but the input data are unavailable in the time limits afforded? What is good enough? Given the data available at this time, what can I confidently conclude?

Table 3 describes the common input data needed in H&H analysis (simple to complex needs). Terrain, field verified SBS data, fire perimeter, soil data, land use, gage, and flow data are staples for most analysis.

4. Post-Fire/Pre-Flood (Time Tier 2 & 3)

As California's fire season continues to grow longer and drier, post-fire analyses are critical for evaluating flood risk in severely burned watersheds, particularly those with critical infrastructure and residences close to or within the fire perimeter. For some wildfires (e.g., those with significant values-at-risk), H&H analysis begins during Time Tier 2, after the fire has been contained and BAER or WERT data are available. The time the GISS and H&H engineers have to collect event data and analyze it will vary, depending on when the fire burned (i.e., summer vs. fall) and weather forecasts. They may need to produce maps, such as Flood Advisory Maps (Figure 19) rapidly after the fire is contained, or they could have months before the next major rain event is anticipated.

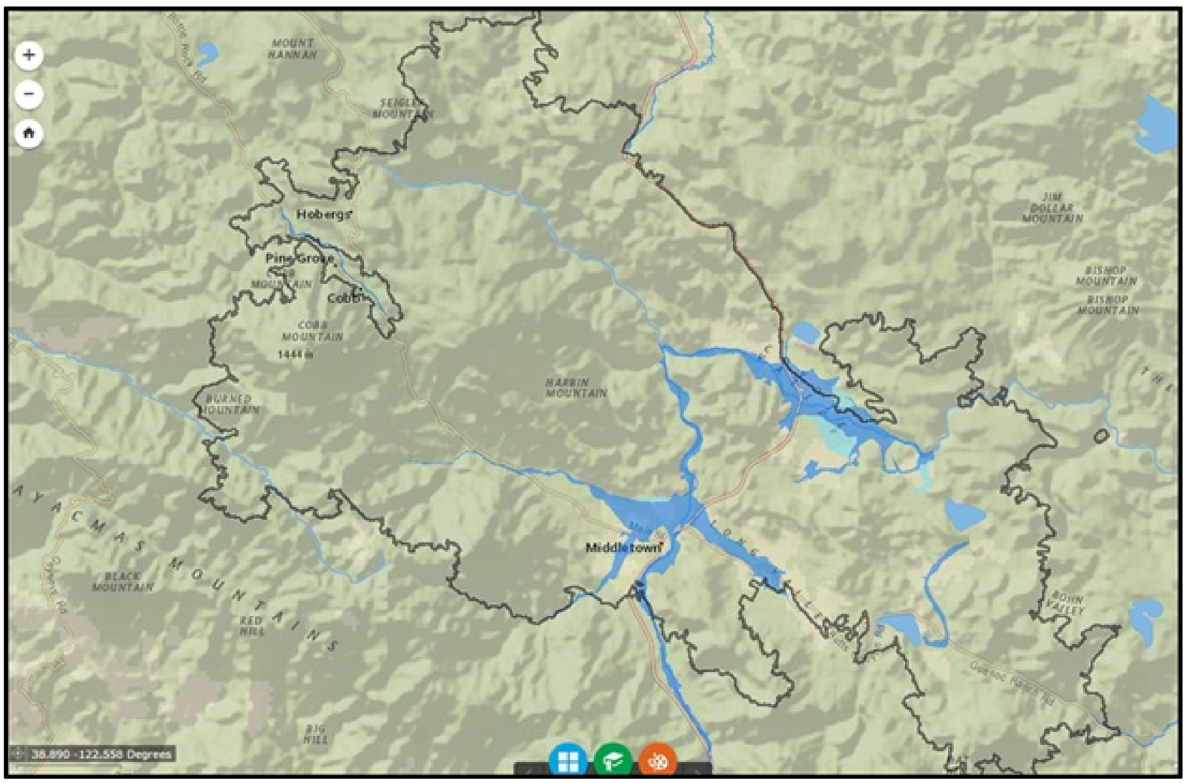

Figure 19. Example Flood Advisory Map produced for the 2015 Valley Fire, Lake County, California.

Regardless of how long Time Tier 2 lasts, modeling flood and debris flow hazards are contingent on the location and severity of the fire. Many large fires occur in remote locations with little downstream impacts. Therefore, the need for detailed H&H analyses may not exist. Efforts by local governments or communities to implement flood risk management measures or prescribed best management practices may be sufficient to prepare for post-fire runoff. Alternatively, if the fire was small but situated above a drinking water reservoir, a sediment study might be in order to better understand how the watershed – modified by wildfire – will react to significant storm events, and in turn effect the water quality in the reservoir. However, depending on the level of effort needed, these types of robust studies and analyses may be undertaken during Time Tier 3; months after the fire is contained (see Chapter 5).

Assuming terrain, land use, BARC, and fire perimeter data are available, there are three common methods of H&H response. Each method should compare pre- and post-fire conditions:

1) Hydrologic analysis only (with or without bulked flows)
2) Hydrology outputs (hydrographs) as inputs to hydraulic models (bulking used in either)
3) Hydraulic model using hydrograph or precipitation inputs (bulked or full sediment analysis[8])

The first method involves a hydrologic approach only, addressing primarily changes in watershed characteristics including soil infiltration and channel roughness. Changes in these factors will affect runoff volume and flood wave arrival time. Fire affected changes in runoff are not representative of every post-fire impact. Non cohesive soils and steep slopes in a watershed may dictate the addition of soil bulking to accommodate added flood volume. The modeler may choose a suitable method to incorporate bulking depending on available tools and techniques. For a series of examples, see the Ventura County's report on bulking factor methods in Gusman (2011).

The second method, which typically requires more time and effort, uses outputs from a hydrologic model to increase the accuracy of flow and precipitation inputs to the hydraulic model. For example, the input of a precipitation hyetograph in a hydraulic model will not include infiltration, canopy, or storage losses, which may be lacking necessary information. Running both hydrologic and hydraulic models generates products that can be verified against a historic event or known probabilistic flow, which adds confidence to the post-fire solution. Furthermore, based on post-fire conditions, the hydrologic or hydraulic model can be bulked in addition to hydrologic adjustments.

The third method solely utilizes a hydraulic model, which is commonly in a 2D format. A 2D hydraulic model is dependent on terrain. For this method, terrain dictates the watercourse for the modeler, and they do not need to invest time in calculating watercourse location, lengths, slopes, and Manning's **n** (roughness coefficient). Combining land cover, terrain, and burn severity grids further allows for quick input of roughness factors and is easily adjusted to post-fire conditions. Event-based post-fire condition grids are GIS products derived from post-fire observations. From these grids, moderate to high soil burn severity locations are paired with land cover, allowing for adjustments to roughness values using engineering judgment. For example, a pre-fire shrub or grassland roughness value will likely be reduced in the post-fire analysis. Changes to vegetation and land cover roughness can be expected based on burn severity and area. Depending on the types of products needed, sediment and debris solutions are modeled

[8] Sediment analysis often adds more time than Time Tier 2 allows

through bulking flows or sedimentation methods within the hydraulic model (See H&H Model Matrix for modeling examples).

Infiltration is incorporated in some hydraulic models, but generally speaking infiltration is not commonly a parameter in hydraulic models. See Appendix 6.3 for details on model use.

4.1. GIS (Time Tier 2 & 3)

By this point in the timeline, the wildfire is out, and its final magnitude and extent are known. Many agencies are now involved with recovery and cleanup after the fire event. While this is taking place, the focus for watershed teams shifts to the next possible disaster. With the final fire perimeter and burned area intensity determined, the affected watersheds and downstream areas can be finalized. Datasets needed for H&H modeling now have more complete information. A GISS will need to complete the collection and development of these datasets to hand them off to the modelers. The final assessments and analysis of impacts can be completed. Additional analysis using the post modeling outputs can be performed and cartographic products created. From the modeling efforts and analysis, information can be disseminated for decision making and public awareness to potential flooding impacts.

4.1.1. Event Data and H&H Model Preprocessing

After the fire is out, the extent of potential impacts is known. The final fire perimeter polygon will be used to identify the directly affected watershed(s), and determine the downstream impact areas. The terrain, hydrography, land cover, infrastructure, and census datasets collected from the previous timeline can be updated and finalized for these areas. Attention will now shift to providing H&H engineers with these updated layers, as well as, additional data to input into their models:

- Fire Perimeter – The final polygon perimeter will be used to identify the directly affected watershed(s), as well as determine the downstream impact areas.
- Soil Burn Severity (SBS) – The field verified version of the BARC data.
- Terrain – The terrain can be clipped to the area being modeled for faster model processing. Additional datasets like slope can be created by processing the terrain with ArcHydro or GeoHMS spatial tools.
- Hydrography Data – The stream network centerlines may need to be refined and updated for the inundation modeling. A stream gauge dataset for the watersheds should be compiled. The highest order watershed HUC level should also be defined to the affected area.
- Infrastructure – Datasets for bridges, culverts, and flood control structures should be updated for the defined impact area.
- Land Cover – Clip the National Land Cover Dataset (NLCD) and vegetation datasets to the modeling area. These datasets can be processed to produce Manning's **n** values in a raster format. Additionally, clip the Imperviousness and Tree Canopy rasters for the area.

- Soils – Clip the Gridded Soil Survey Geographic (gSSURGO) Database to the modeling area.
- Climate/Meteorological – NOAA rainfall event rasters (duration/return period). A climate gauge dataset should be compiled for the affected watershed and immediate surrounding watersheds.

The pre-model processed data:

- (% Burn) Combines HUC and Fire Perimeter
- (% Severity per Category) Combines HUC and BARC
- (% Soil Type per HUC and Burn Severity) Combines HUC, Soil, and % Severity
- (% Land cover per % Severity) Assigns post-fire infiltration and Manning's **n**

Post fire data layers produced by other agencies should also be collected for the spatial library for use in additional assessments and analysis.

- USGS Debris Flow Risk Polygons
- USGS Watch Streams
- Alert Gauges
- Structural Assessment (Fire Damage)
- Values at Risk

In addition, datasets will also be added from the geoprocessing results of impact analysis and post H&H modeling.

4.1.2. Event Updates: Assessments and Analysis

The questions coming from incident management and other officials related to potential flooding and debris flow will now be at a more granular level from the previous timeline. Information and statistics for specific impact areas will be requested. The questions will be more refined and may relate to recovery efforts in the area. Here are a few queries that may be raised:

- Are there any hazardous material facilities at risk?
- Debris clean up teams are in the area. What sites are at highest risk from flood?
- What are the critical bridges, culverts, and roadways that may impact evacuation routes?
- Where are the potential riverine choke points for debris flows? And what are the potential impacts to population and infrastructure upstream and downstream?
- How soon will a flood impact this area in a rain event?
- Are there any water supply threats from a potential debris flow?
- Where should we not place a temporary or long term shelter facility?

The quality of information to answer to these questions will depend how soon it is needed and to what level of detail (Time Tier 1 versus Time Tier 2). Immediate answers can be obtained from simple assessment analysis used in the previous timeline. As an example, existing 100-year flood plains and best available inundation mapping polygons can be used to query for the hazardous material sites found in the critical infrastructure layers of the HIFLD data. The polygons are limited in detail and are based on the watershed's pre-fire baseline. A higher quality analysis will require outputs from the modeling team that will have better input data, with current parameters of the wildfire impacts. This means it will take longer to produce a better answer. Impacts to population and infrastructure can be run using a suite of rainfall events based on duration (6 hr, 12 hr, 24 hr, etc.) and return period (2-yr, 10-yr, 100-yr, etc.)

It is important to document the datasets used and geoprocessing steps taken to complete the assessments and analysis so that these steps can be reviewed, refined, and repeated during future events

4.1.3. H&H Post-Modeling Processing and Cartographic Products

A multitude of products can be created from the assessment analysis and modeling efforts. Typically, a GISS will take the H&H model results to produce inundation depth grid rasters for the suite of rainfall events run. These rasters are displayed on the terrain for the watershed and defined impact areas, such as the example shown in Figure 20. Additional layers from the assessment analysis, like structures, bridges, culverts, and critical infrastructure can be added to cartographic products. Here are a few examples:

- USGS Debris Flow Combined Hazard Risk for a Selected Rainfall Return Period Event - Life Hazard Sites (BAER/WERT)
- USGS Debris Flow Combined Hazard Risk for a Selected Rainfall Return Period Event - Bridges/Culverts/Dams
- H&H Modeled Watersheds/Reaches for a Selected Rainfall Return Period Event - Population Centers and Critical Infrastructure at Risk
- H&H Modeled Watersheds/Reaches for a Selected Rainfall Return Period Event - Endangered Species/Sensitive Habitat at Risk
- Potential Debris Flow Choke Points and Simulated Debris Dam Inundation

More examples are shown in Appendix 6.4. As indicated in Section 3.2.3, the products can be presented as digital maps, or layers for Google Earth or online maps and dashboards.

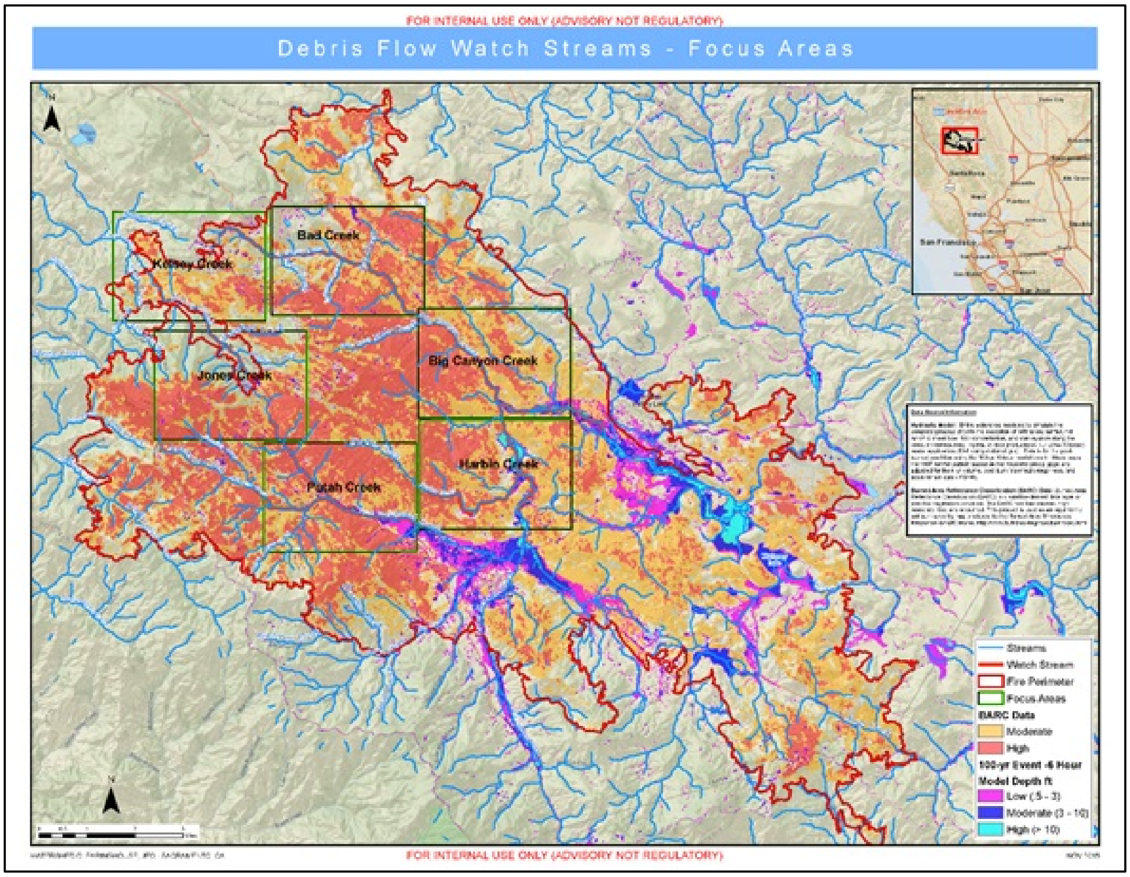

Figure 20. Inundation depth map for debris flow watch areas in the perimeter of the 2015 Valley Fire in Lake County (USACE, 2015).

Additionally, statistical information on the population at risk or types of critical infrastructure threatened can be represented in tables for reports. This can then be augmented with attributes such as watershed, County or City jurisdiction, political representation, and structural value. Economic analysis often requires GIS layers for processing. It can represent another aspect of the potential impacts to the community.

4.2. H&H Products & Deliverables

As H&H analyses are completed prior to a flood (Time Tier 2), a number of products are delivered. What products, and to whom they are delivered, will depend on the analysis conducted and end user requesting the analysis. The deliverable will be predicated by the requesting local, State, or Federal agency. For example, a long-term post-fire monitoring study, such as a groundwater study or best practices alternative, would require an in-depth set of products. In contrast, a short-term flood map used for evacuation would require less analysis than a long term sediment study. Regardless of the level of complexity, a typical suite of post-fire and pre-flood products includes:

- H &H models
- Terrain and GIS files used as input
- Raw data such as spreadsheet calculations, gage data, collected soil or survey data, assumptions, datum references, and As-Builts

The pace during emergency conditions places limitations on data availability and quality control efforts, especially during Time Tiers 1 and 2. For this reason, it is recommended that H&H solutions are presented as a "change in flow and sediment conditions," owing to post-fire conditions rather than presenting a solution as a deterministic forecast. Although H&H deliverables state these constraints, results and models are often picked up by unknowing users with an assumed expectation of accuracy. This can lead to decisions being made without complete knowledge of solution limitations and associated risks, resulting in liability issues. Therefore, stressing that H&H results during a response simply represent a 'delta' (potential change in flow or sedimentation), rather than a deterministic value, is paramount to the effectiveness of the response team and decision makers.

5. Post-Fire & Post-Flood

Wildfires bring drastic changes to the natural processes effecting geomorphology, hydrology, and sedimentation processes in the affected region. Producing complex and varying spatial effects to a given watershed and impact hydrology by removing the vegetation inception canopy, covering the surface through the production of ash and burned material, reducing organic binding material in soils, development of hydrophobic (or water repellant) soils, and altering the physical transport properties of the soils and sediments (Certini, 2005; Moody et al., 2009; Ebel et al., 2012). These processes all increase water and sediment runoff. Additionally, post-wildfire environments can cause a spectrum of hydrologic and sedimentation responses ranging from minor runoff events to catastrophic floods and deadly debris flows. The high sediment concentration and debris exacerbate damages from these events, which have been documented around the world (Rowe et al., 1954; Lane et al., 2006; Shin, 2010; Shakesby, 2011; Moody et al., 2013). These destructive flows often carry large boulders, trees, and even cars because of the high mass density and momentum of the sediment laden flows. Since burned regions lack vegetation to intercept and slow surface runoff produced by rainfall events, post-wildfire peak flows in those areas have reached all-time highs, with documented non-Newtonian hyperconcentrated (sediment laden) flows (Tillery et al., 2012; Rio Grande Water Fund, 2015).

Figure 21. Hyperconcentrated ash flow in the Rio Grande River (Rio Grande Water Fund, 2015).

It is important to determine what the dominant flood conditions (i.e., 'normal' flood, hyperconcentrated flows, mud flow, debris flow) for the watershed(s) of interest. Debris flows and similar non-Newtonian sediment-laden flow events are not only more destructive but behave quite differently from 'normal' flood events physically requiring different prediction and management approaches. Distinguishing between these types of flows is accomplished using both GIS-based data and field evidence. Additional information on both field and GIS-based identification can be found in Pierson (2004) and Jakob (2001).

Post-wildfire debris flow impacts are commonly defined by the given event probability, magnitude, and intensity. Magnitude is typically expressed as total flow, peak flow discharge, or area inundated. Intensity parameters are useful metrics since post-fire floods can vary along the flow path and include velocity, depth, runout potential, pressure, and force. Probability is the likelihood of an event to occur in the future, while frequency represent how often a given event occurs. Post-fire frequency-magnitude relationships are necessary for post-fire flood risk management because they allow approximation of the flood magnitude for any given return period. The post-fire frequency-magnitude can be determined using approaches developed by Cannon et al. (2010; see also Floyd et al., 2019).

5.1. GIS Reports

If a significant post fire flooding event occurs, the GISS will most likely be involved in the recovery efforts of that disaster. The assessment and analysis in the preceding timeline is being used to help make informed decisions for saving lives and mitigating damage to critical infrastructure and property. The tasks for a GISS post-flood will be to map the impacts (e.g, Figure 22) that have occurred. Questions from this scenario might be:

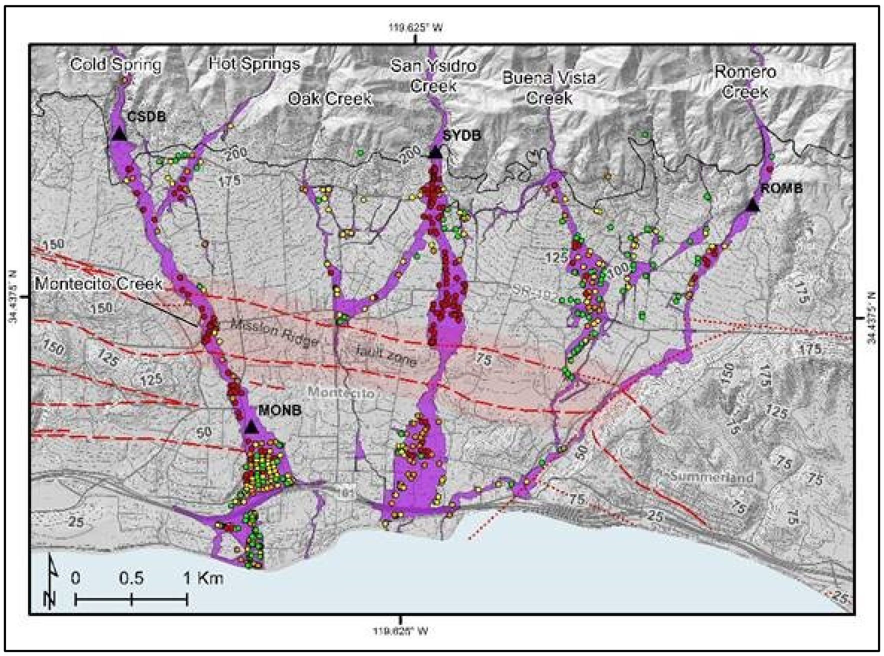

Figure 22. Impact map for Montecito area after a debris flow event on January 9, 2018, that resulted from the 2018 Thomas Fire in Santa Barbara County.

- How many homes were damaged or destroyed and where?
- What critical infrastructure were impacted?
- What bridges, roadways, or railways are impassible from debris?
- How has the geomorphic landscape changed? How are runoff and future inundation from rainfall events impacted?
- Are there riverine choke points creating impounded water and secondary inundation threats?

The final assessments for answering these questions and others will be used to produce cartographic products and tables for post-event reports. Additionally, the work will help to determine where to begin recovery efforts, and provide data for economic analysis.

A GISS will also be asked to contribute to After Action Reports (AAR), where lessons learned can be applied to future flood after fire events. Additionally, they may be asked to contribute long-term study reports and watershed restoration projects.

5.2. Long-Term Responsibilities

Large wildfires, especially in geomorphically sensitive regions, represent a significant perturbation to the natural system and dramatically alter the short-term hydrology, ecology, and sedimentation regimes. High geomorphic sensitivity describes systems that cannot handle large changes, such as fast vegetation growth (e.g., chaparral). The term implies a conditional instability in an environment, with the possibility of rapid and permanent changes (Phillips, 1999; Thomas, 2001). Effects on the hydrology can last years. Effects include increased runoff potential, changes to evapotranspiration, altered surface and substrate moisture storage, decreased watershed runoff lag time, higher peak flows, and reduced infiltration capacity (Neary et al., 2005; WEST, 2011).

In the years following a wildfire, vegetation type changes, rill and gully formation, mass wasting, and channel incision alter the hydrologic response. This often results in prolonged and dramatic changes in hydraulic and sediment impacts downstream. This requires long term monitoring and management plans.

Monitoring of burned watersheds and attendant storm rainfall induced flooding and debris flows is an important feedback on the results of risk assessments conducted after wildfire. In many regions of the State, there is little to no quantification of actual post-wildfire runoff events, including documentation of runoff, sediment concentrations, woody debris, avulsion characteristics, and storm rainfall rates and distribution. Because of this lack of data, it might be irresponsible to apply the methods described in this toolkit without consideration for developing a monitoring plan that may include, but not be limited to:

(1) Installation of rain gages

(2) Installation of stream gages

(3) Installation of radar

(4) Installation of monitoring cameras

(5) Performance of post-storm repeat observations

A basic monitoring plan that incorporates observation and measurement will greatly improve the ability to refine these FAF tools over time, resulting in incremental advancements in risk reduction.

In geoscience and engineering communities of practice in many parts of the western U.S. there is an increased demand for operational-based quantitative post-wildfire flood and debris flow analysis and guidance. This post-wildfire flood risk analysis and management are no trivial exercises. Post-wildfire flood and debris flow hazard analysis requires diverse interdisciplinary teams composed of experts from different organizations with varying technical backgrounds in fields such as, geology, geomorphology, sedimentology, soil mechanics, H&H, sediment transport mechanics, computation fluid dynamics, and ecology among others. Additionally, mitigation and management decisions should be based on approaches and computer models that facilitate both flood and debris flow modeling as part of post-wildfire flood risk management. These technical skills should be coupled with some basic understanding of the regulatory framework in a given wildfire affected area.

5.3. Conclusion

A major effort in today's response to wildfires is assessing and predicting wildfire effects on watershed hydrology in a timely manner, typically during and following the fire, so that necessary measures against flooding and erosion can be taken. For that purpose, agencies responding to wildfire need (a) fast but reliable methods to assess the risks of wildfire effects on watershed hydrology, and (b) quantitative methods to predict changes in stream flow and sediment yield for planning and designing flood and debris flow control measures. In addition, in most of the western arid and semi-arid United States, post-wildfire vegetation recovery can take years or even decades. This poses potential long-term management concerns for Federal, State, and local agencies beyond those of restoring watershed hydrology alone. With that in mind, this toolkit provides data, methods, and principles that will assist in evaluating changes to watersheds and flooding or debris flow risks that result from wildfires. However, this toolkit is still a single, narrowly-focused resource in a long-term management toolbox that is always expanding.

This toolkit is also a living document, which will benefit from being used in different environments by technical staff that have differing levels of experience in post-fire flood and debris flow modeling. This document tries to emphasize that many agencies and disciplines are needed to address the increasing risks of post-wildfire flooding and debris flows. Indeed, an interagency and interdisciplinary team of writers and reviewers, brought together through Silver Jackets, was needed to complete this first edition of the California Flood After Fire Toolkit. Future editions of this toolkit will benefit from more disciplines and agencies contributing to it, so that the complete picture of wildfire response can be realized.

6. Appendices

The following matrices were developed with two purposes in mind. First, they are broad summaries of material provided in the main body of this toolkit. They act as "quick reference" tools for those with experience in GIS, modeling H&H, or other related disciplines. They work well as a quick reference when an individual is already familiar with the general tasks or actions required for a flood after fire response.

Second, the matrices are supplemental reference material to the main body of the toolkit. They are self-referential, and as a result can be redundant with material provided elsewhere. This supports the matrices being able to act as a quick reference, however, they do not exist independently of the toolkit. Using the matrices as standalone tools or products demands and in-depth knowledge of wildfire response methods and requirements for flood after a fire preparation.

Descriptions of each matrix, including how to use them, are included in the following sections.

6.1. Resource Timeline Matrix (LINK)

Fire responses constitute a range of activities occurring throughout a temporal spectrum. The timeline commencing with fire initiation and can extend up to two years after fire containment. Responses vary by need, fire severity, fire location, stakeholder, allotted response time, funding, and potentially other factors. For purposes of this toolkit, the spectrum is divided into three general time tiers:

- Time Tier 1 begins with the fire (pre-containment) until shortly after containment
- Time Tier 2 begins after containment and covers FEMA activation (if it occurs) until approximately two months post-containment
- Time Tier 3 is considered a post fire monitoring, detailed study, and restoration period

Flooding can occur at any point along this timeline, and as fire seasons extend farther into the winter, floods and fires may become more coincident in California. Additionally, government and non-government stakeholder responses may vary according to the specifics of each fire and flood event that follows. The Resource Timeline Matrix included as this Appendix is not an exhaustive list of stakeholder needs and methods, but describes common fire response needs, methods, and sources used in a tabular format.

6.2. Spatial Data Matrix (LINK)

The Spatial Data Matrix is designed as a reference for data layers to begin a library for flood after fire response, analysis, and modeling. The data is grouped into seven general categories covering a number of data types. It provides a brief data description, metadata, data origination, typical format, if a map or feature service is available, where it falls in the timeline, whether it is used for H&H model inputs, last known web link, and notes on the data purpose. This Appendix should not be seen as complete, but rather as a living document that can be updated (possibly by the user) with information or links for existing datasets, or the addition of new layers.

6.3. H&H Model Matrix (LINK)

The H&H Model Matrix is organized by model complexity, which is based on their general use, data requirements, and incorporated processes. The first set of models are empirical models (1-4) which have fewer data requirements, and easier and quicker application, for estimating outputs. Empirical models are followed by semi-empirical models (5-10) which incorporate some linked hydrological processes, and therefore have additional data requirements. Both empirical and semi-empirical models may or may not be event based. These models are followed by a set of semi-distributed models (11-18), which are process-based and incorporate more physical and hydrological processes, thereby requiring larger sets of data for model simulations. Finally, the semi-distributed models are followed by distributed and fully distributed models (19-22). These are comprehensive, highly parameterized, and complex, and require a greater number of refined input parameters.

The first column of the H&H Model Matrix shows the name of model itself, or the agency/organization that provides model. The second column includes the major purpose (peak flow magnitude, peak timing, or debris flow) of the model, which is followed by the model's applicability to varying sized watersheds. The consideration of the size of watersheds was included based on model user manuals or field applications by different agencies/organizations. The infiltration/runoff mechanism column briefly summarizes the primary technique(s) incorporated into the model to handle the physical and hydrologic processes. This information should help users better understand the major mechanism and data needs for a particular model. The next column summarizes the major parameters, or dataset(s), required for the model. Although all data types are included in this column for most models, bear in mind that regression models usually only require data incorporated in the model and are directly related to the desired output. Major parameters are followed by an appropriate reference for downloading the model and assessing relevant documents and publications for model applications. The type of model (empirical, semi-empirical, semi-distributed, and fully-distributed) and simulation (event based/continuous) is defined in the next column. The final column provides various advantages, disadvantages, and limitations of the model.

6.4. GIS and H&H Output Products Matrix (LINK)

This Appendix provides examples of cartographic products that are usually produced during a wildfire response. The products are divided into the 4 time periods: Pre-Fire Offseason, Fire Event/Pre-Flood (Time Tier 1), Fire Event/Pre-Flood (Time Tiers 2 and 3), and Post Fire/Post Flood. This matrix should not be seen as complete, but rather as a living document that can be updated, by the user if applicable, with additional cartographic examples or work products

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7.1. Case Studies

A number of case studies accompany this toolkit to share how different post-fire goals and questions have been answered using methods, tools, and information found in this toolkit. To a degree, the provided case studies supported the inclusion of the material that makes up this toolkit. Some of these case studies represent efforts undertaken by a single local, State, or Federal agency. Others are reports from an interagency team. Each case study should speak for itself in terms of when (Time Tier/FAF continuity) and why certain actions were undertaken or methods were used. When used in conjunction with this toolkit, these case studies should assist a user in decision-making and assignment completion. They are also useful “refreshers” in the absence of formal training.

1) USGS and CalGS – Thomas Fire, California

2) County of Lake, California – Mendocino Complex Fire

3) USACE – Los Conchas Fire, Bland Canyon, New Mexico

4) USACE – Los Conchas Fire, Cochiti Canyon, New Mexico

5) USACE – Los Conchas Fire, Frijoles Canyon, New Mexico

6) USACE – Los Conchas Fire, Peralta Canyon, New Mexico

7) USFS – First Creek Fire, Washington

8) CALFIRE – Holy Fire WERT Report, California

9) CALFIRE – Thomas Fire WERT Report, California

10) CALFIRE – Valley Fire WERT Report, California

11) CalGS – Inyo Complex Fire, California

12) USACE – Atlas and Nuns Fires, California

13) USACE - Russian River Modeling Methods, California

For more information or assistance accessing these case studies, please call 915-557-5100 or email spk-pao@usace.army.mil.

File #: 26-0055 **Agenda Date:** 1/26/2026 **Agenda #:** 15.

Lake California Drive - Informational Presentation

Requested Action(s)
Informational presentation from staff providing a status update on the Lake California Drive Reconstruction Project, including current scope development, programming, funding strategy, conceptual design work, and the anticipated path forward.

Financial Impact:

No action required.

Background Information:

This item is presented for informational purposes only. Tehama County Transportation Commission staff will provide an update on the Lake California Drive Reconstruction Project, including current funding sources, FTIP programming, project concept development, and anticipated next steps. The presentation will summarize recent coordination between TCTC and Tehama County Public Works, outline the proposed project scope, emphasizing multimodal and emergency-access components, and discuss the strategy for securing additional funding.

Lake California Drive serves as the sole access route for a rural community of over 3,500 residents. The corridor is in critical need of full-depth reconstruction due to pavement failure, inadequate shoulders, poor drainage, and lack of multimodal or redundant access.

The project has been prioritized as a resilient infrastructure investment and is being advanced through a layered funding strategy. Current and potential funding sources include:

- Congressionally Directed Spending (CDS) earmark (secured)
- Highway Safety Improvement Program (HSIP)
- Congestion Mitigation and Air Quality (CMAQ)
- Inclusion in the Regional Transportation Improvement Program (RTIP)
- Upcoming BUILD grant application

TCTC is actively coordinating programming, conceptual design, and consultant scoping in partnership with Tehama County Public Works. The design includes a multiuse path built to emergency vehicle standards, supporting wildfire evacuation and redundant access in alignment with state and federal resilience goals.