Prediction of spatially explicit rainfall intensity-duration thresholds for post-fire debris-flow generation in the western United States

Dennis M. Staley[1], Jacquelyn Negri[1], Jason W. Kean[1], Jayme Laber[2], Ann Tillery[3], Anne Youberg[4]

[1]*U.S. Geological Survey, Landslide Hazards Program, Golden CO USA*
[2]*National Weather Service, Los Angeles-Oxnard Weather Forecasting Office, Oxnard CA USA*
[3]*U.S. Geological Survey, New Mexico Water Science Center, Albuquerque NM USA*
[4]*Arizona Geological Survey, Tucson AZ USA*

2007 California Wildfires
Courtesy of NASA: 22 October 2007

Debris flow emanating from the 2012 Waldo Canyon burn area
01 July 2013

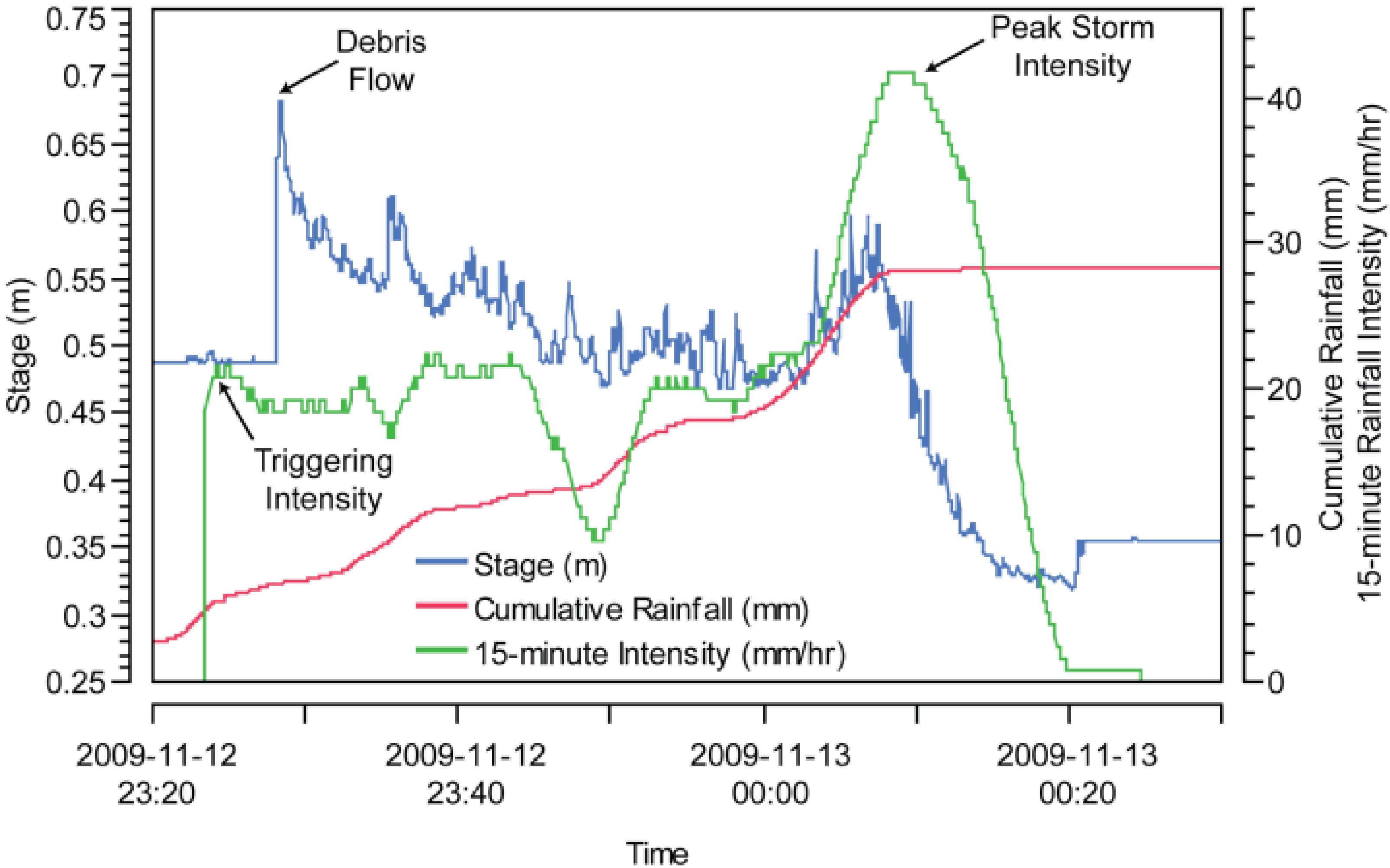
What Are Post-Fire Debris-Flows?

- Initiate from surface runoff and erosion processes.
- Progressive entrainment of sediment.
- Do not require a discrete source of material (e.g. landslide), with a significant percentage of material originating from shallow erosion.
- Impact constrained to gullies, stream channels and immediately adjacent areas.



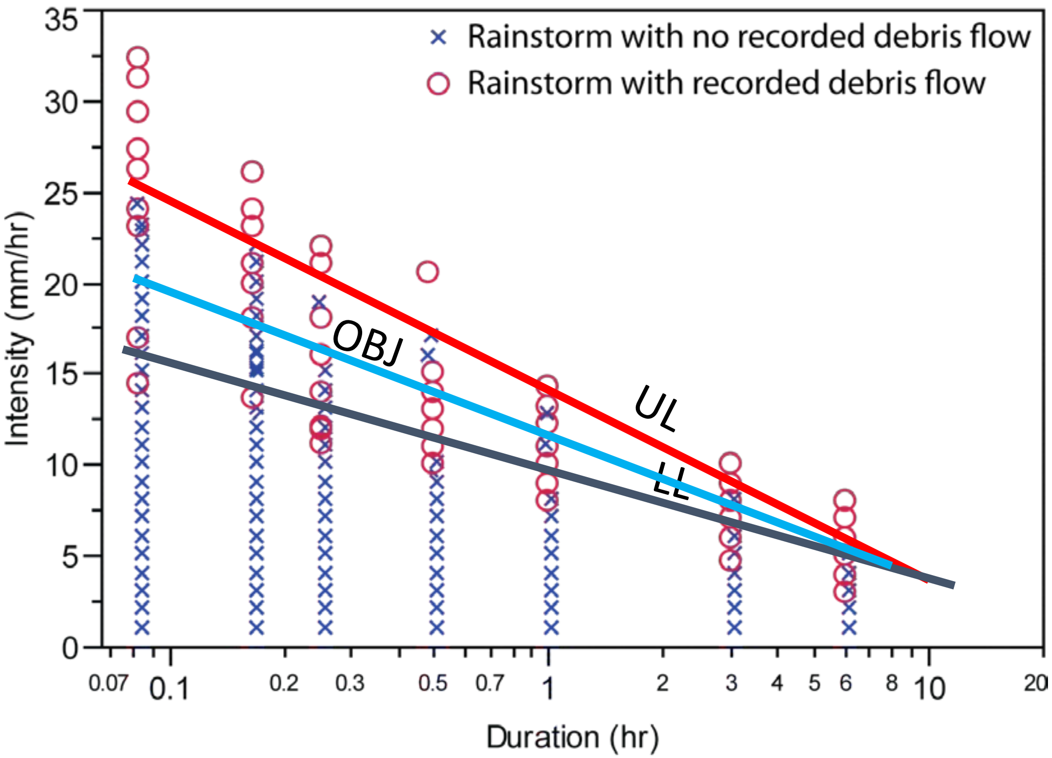
What Are Post-Fire Debris-Flows?

Debris-flows initiate during high-intensity rainfall.



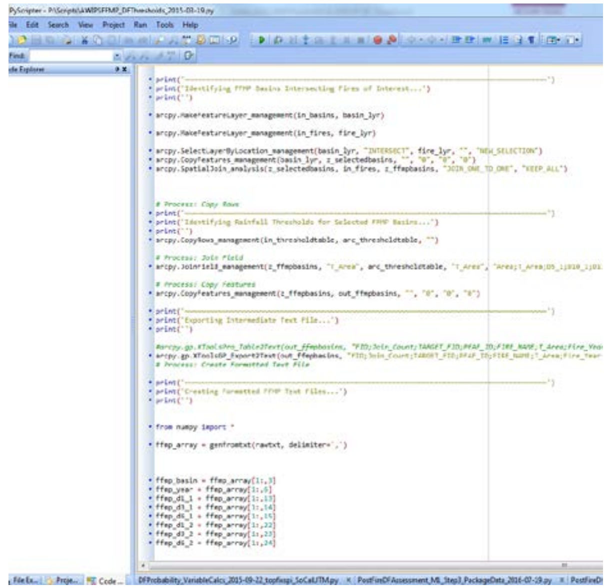
How Do We Predict Post-Fire Debris-Flows?

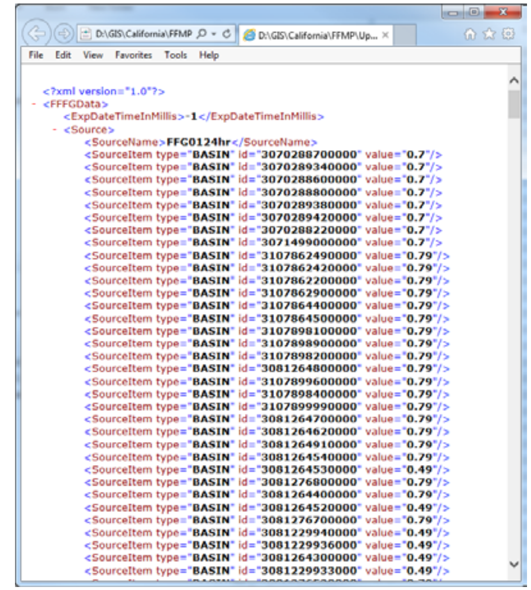
Post-fire debris-flows are well-characterized by rainfall intensity-duration thresholds.

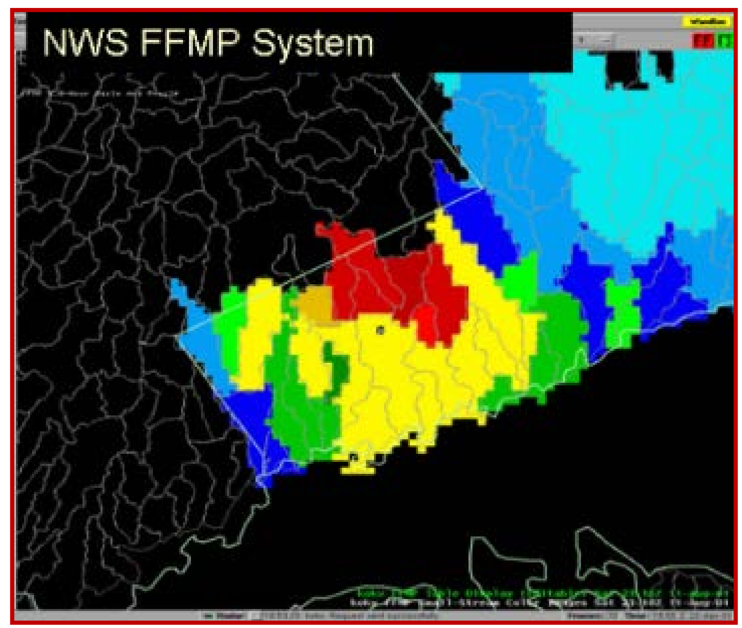


Debris-Flow Early Warning

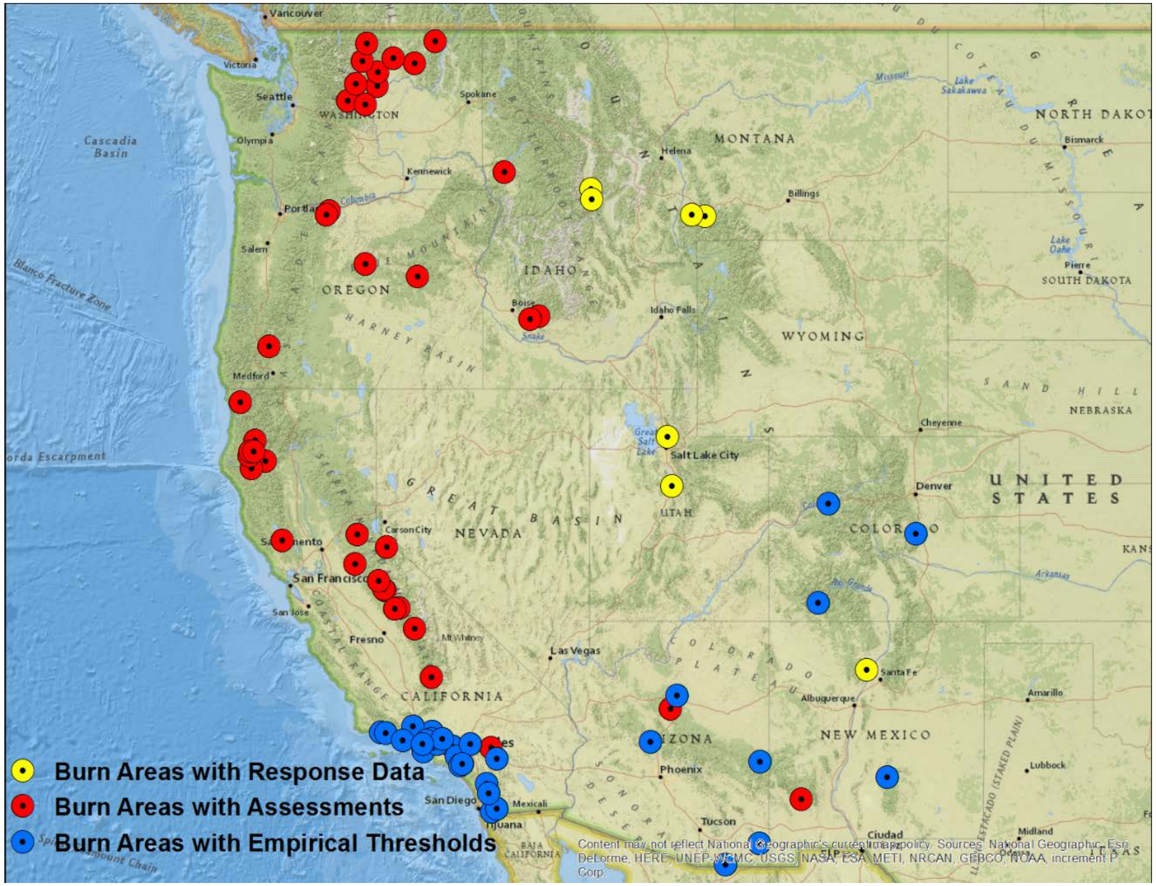
- Short lead times requires forecast-based outlooks, watches, and real-time warning.
- USGS provides LOX and SGX threshold guidance for early warning.
- Threshold guidance forced into NWS flash-flood monitoring system(s).
- Interest at USGS and NWS in expansion of early-warning capabilities.







Limitations of Current Approach

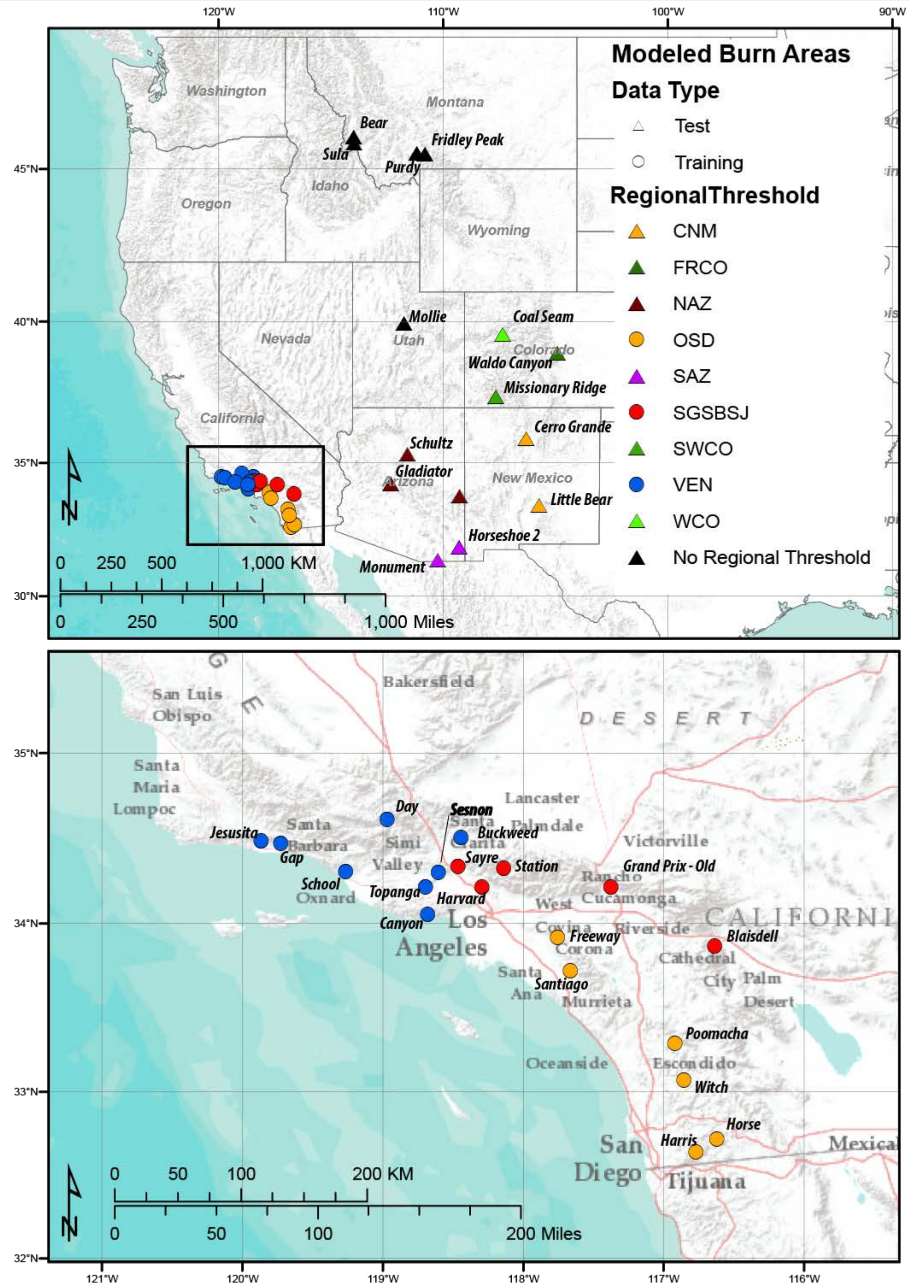


Area	Source	15
Coastal Santa Barbara	Staley In Review	30.5
Ventura County Mountains	Cannon 2008	21.8
San Gabes / San Bernadinos	Staley 2013	18.6
Granitic San Diego	Staley In Review	30.5
Little Bear (Ruidoso NM)	Staley In Review	27.4
Northern Arizona	Youberg PhD	62.0
Southern Arizona	Youberg PhD	43.0
Glenwood Springs CO	Cannon 2008	17.2
Durango CO	Cannon 2008	25.1
Colorado Springs CO	Staley 2015	30.6

- Requires extensive historical database of event occurrence (or non-occurrence) and rainfall information.
- Limited spatial extent of known thresholds.
- Thresholds are often highly regionalized.
- Threshold values are needed now, not in 2+ years…

New Approach

- Develop empirical model that integrates susceptibility mapping with threshold prediction using nationwide data sources.
- Develop model equations from 939 records of debris-flow response, rainfall characteristics, terrain steepness (T), fire severity (F), and soil properties (S) in southern California (Training Dataset).
- Test model predictions against 611 records from other burn areas in the western United States (Test Dataset).
- Compare model predictions to 6 existing regional thresholds for the test dataset.



New Approach

Logistic Framework:

$$p = \frac{e^x}{1 + e^x} \qquad x = b + c_1 c X_1 + c_2 c X_2 + \cdots + + c_n c X_n$$

Updated Link Function:

$$x = -3.63 + 0.41(T * R) + 0.67(F \ * R) + 0.70(S * R)$$

Terrain Steepness (T)	Fire Severity (F)	Soil Properties (S)	Rainfall (R)
Proportion of upslope area with moderate to high burn severity and gradients ≥ 23°	Average dNBR of upslope pixels / 1000	Average KF-Factor of upslope area	Peak rainfall accumulation, in mm (15 minute durations)

Staley, D.M., Negri, J.A., Kean, J.W., Tillery, A.C., and Youberg, A.M., 2016, *Updated Logistic Regression Equations for the Calculation of Post-Fire Debris-Flow Likelihood in the Western United States*, U.S. Geological Survey Open-File Report 2016-1106, 20 p.

Available online at: https://pubs.er.usgs.gov/publication/ofr20161106

New Approach

Solving for the rainfall rate at any P value:

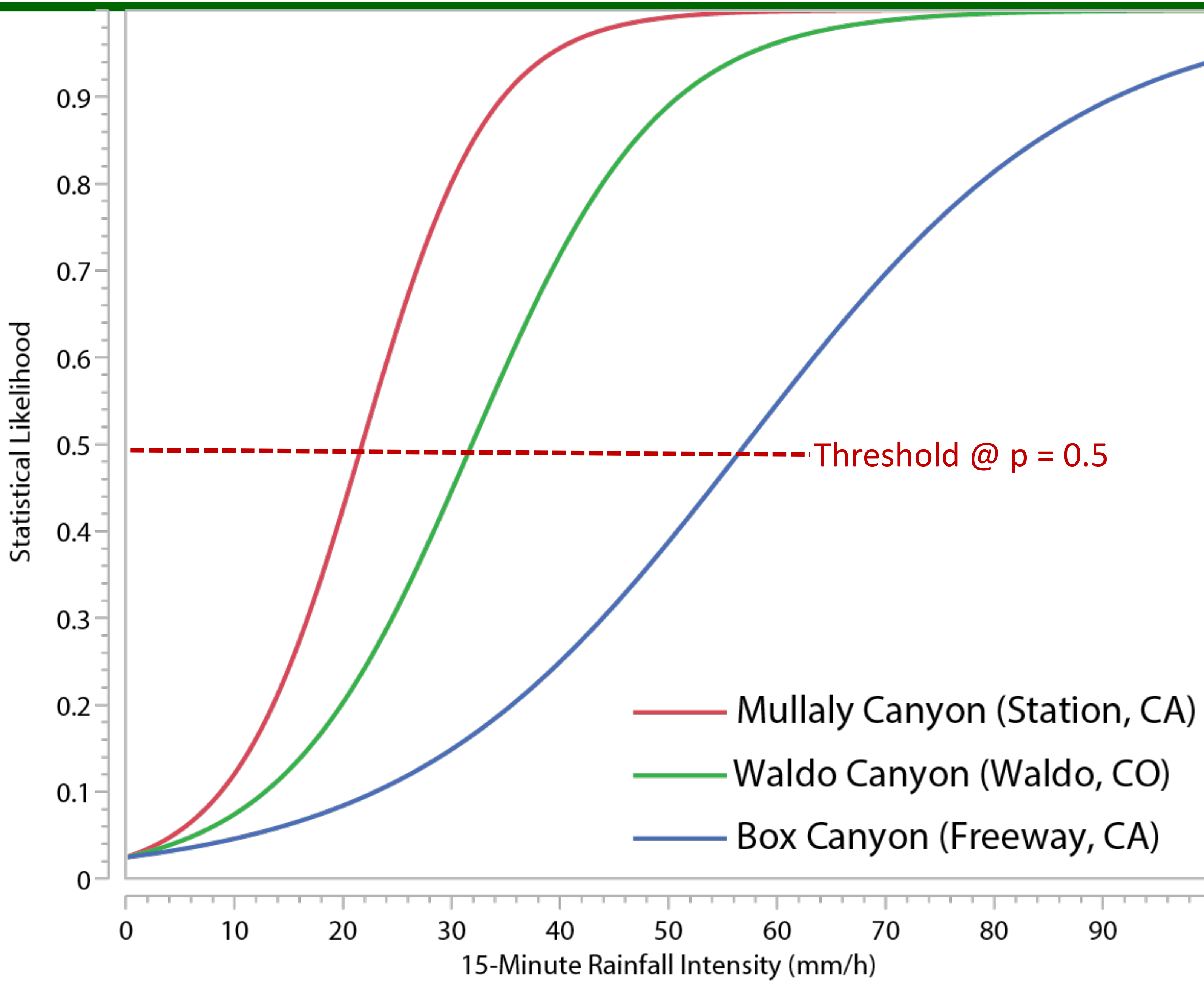
$$R_{(p)} = \frac{\ln\left(\frac{p}{1-p}\right) - b}{c_1 T + c_2 F + c_3 S}$$

Terrain Steepness (T)	Fire Severity (F)	Soil Properties (S)	Rainfall (R)
Proportion of upslope area with moderate to high burn severity and gradients ≥ 23°	Average dNBR of upslope pixels / 1000	Average KF-Factor of upslope area	Peak rainfall accumulation, in mm (15 minute durations)

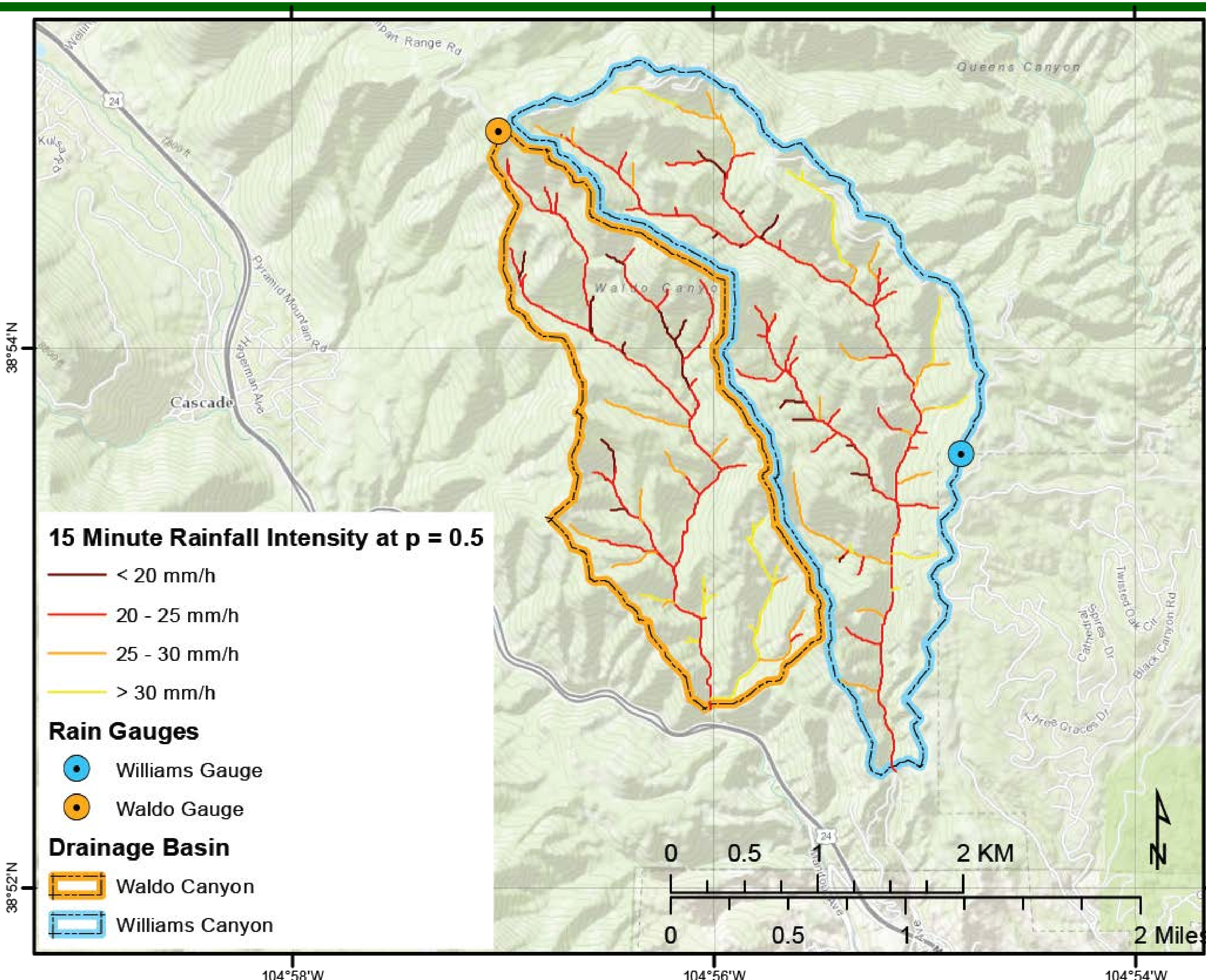
Staley, D.M., Negri, J.A., Kean, J.W., Tillery, A.C., and Youberg, A.M., In Press, Prediction of spatially explicit rainfall intensity-duration thresholds for post-fire debris-flow generation in the western United States. *Geomorphology.*

Available online at: http://dx.doi.org/10.1016/j.geomorph.2016.10.019

New Approach



Spatially Explicit Application



Model Evaluation

- For model predictions, establish threshold at rainfall accumulation that results in p = 0.5. Convert to intensity for consistency with previous work.

- Evaluate using threat score metric based upon receiver operating characteristics analysis.

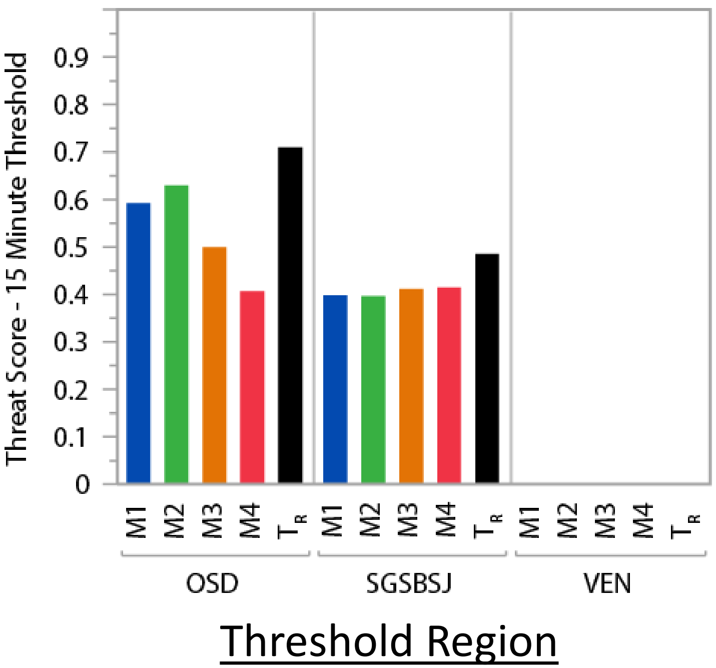
OBSERVED CLASS

MODELED CLASS		Debris Flow	No Debris Flow
	Above Threshold	**True Positive (TP)** *Above Threshold, Debris Flow Observed*	**False Positive (FP)** *Above Threshold, No Debris Flow Observed*
	Below Threshold	**False Negative (FN)** *Below Threshold, Debris Flow Observed*	**True Negative (TN)** *Below Threshold, No Debris Flow Observed*

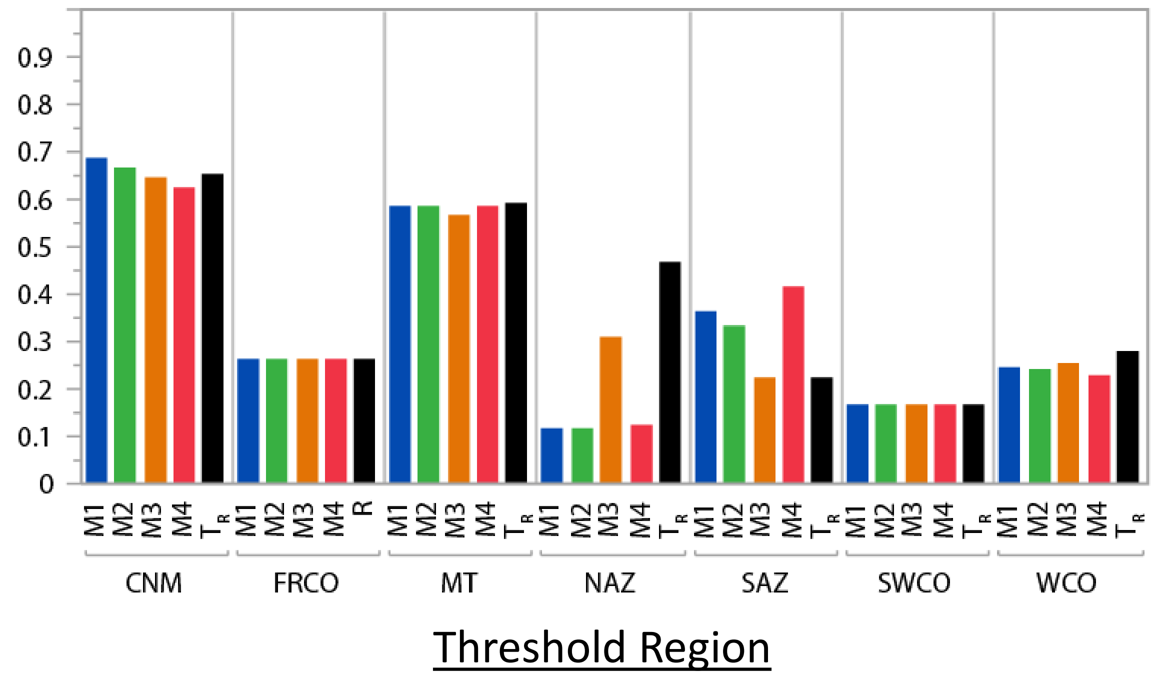
$$\text{Threat Score} = \frac{TP}{TP + FN + FP}$$

Model Evaluation

Training Dataset

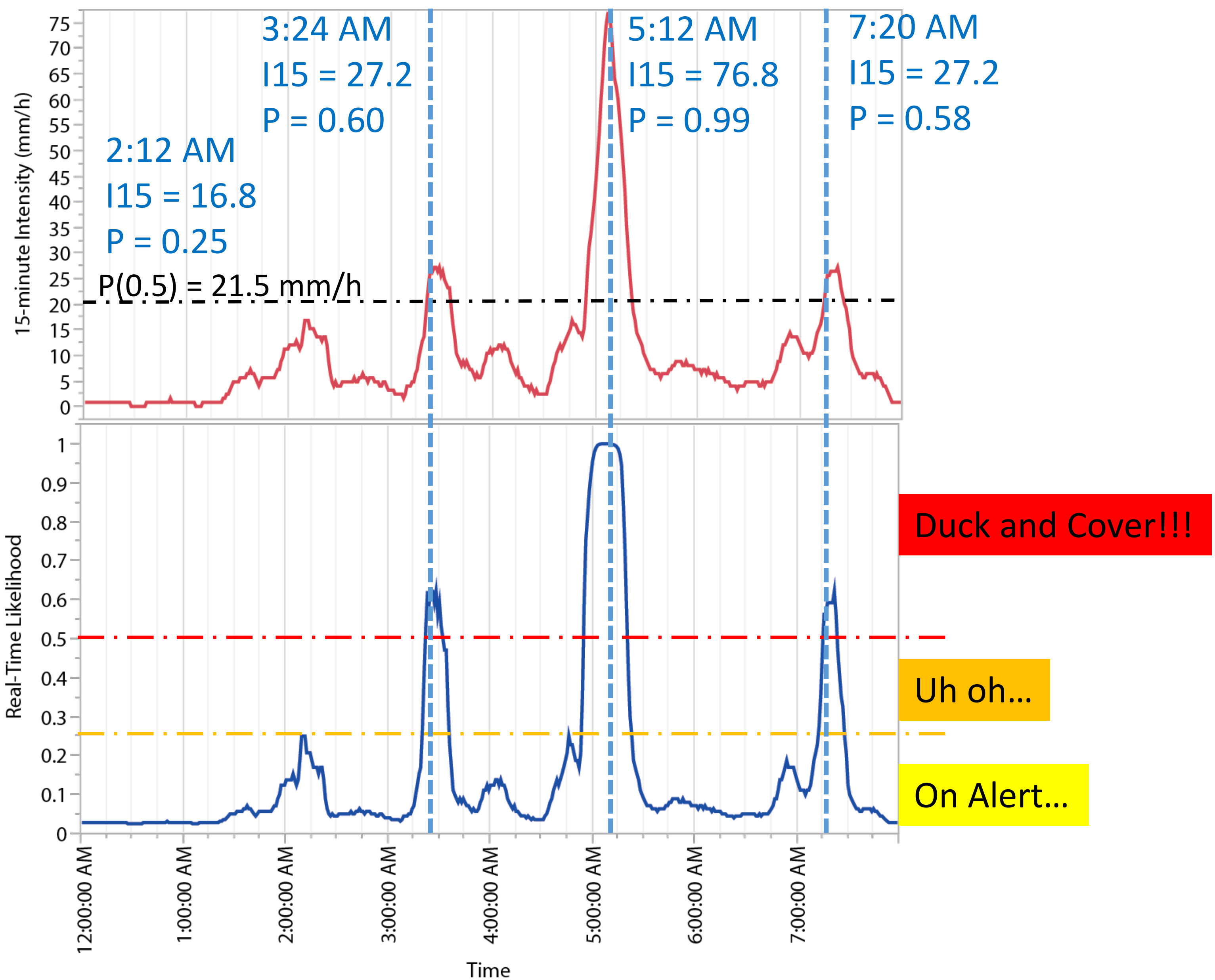


Test Dataset



Mullally Canyon Example

Mullally Canyon Example



Summary

New empirical model of debris-flow likelihood and spatially explicit threshold intensity prediction:

1) Model predictions compare well to what we "know" from intensive monitoring efforts.

2) Model does not require historic debris-flow occurrence information, therefore can be implemented in new areas.

3) Model allows flexibility in determining threshold values for emergency planning and early-warning.

4) Model form permits potential use in forecast-based warning and real-time monitoring.

More Information: Questions and Discussion

Questions?

Citations:

Staley, D.M., Negri, J.A., Kean, J.W., Tillery, A.C., and Youberg, A.M., 2016, *Updated Logistic Regression Equations for the Calculation of Post-Fire Debris-Flow Likelihood in the Western United States*, U.S. Geological Survey Open-File Report 2016-1106, 20 p. Available online at: https://pubs.er.usgs.gov/publication/ofr20161106

Staley, D.M., Negri, J.A., Kean, J.W., Tillery, A.C., and Youberg, A.M., In Press, Prediction of spatially explicit rainfall intensity-duration thresholds for post-fire debris-flow generation in the western United States. *Geomorphology.* Available online at: http://dx.doi.org/10.1016/j.geomorph.2016.10.019

Contact Info:

Email: **dstaley@usgs.gov**

Phone: 303-273-8568

Website: http://profiles.usgs.gov/dstaley

Email: **jwkean@usgs.gov**

Phone: 303-273-8608

Website: http://profiles.usgs.gov/jwkean