Post-fire hydrologic model assessment for design storm runoff and mitigation

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Introduction

- Wildfires remove vegetation and create hydrophobic soils, resulting in increased discharge, sediment transport, and debris flow (Fig. 1)
- The USFS is tasked with mitigating wildfire impacts and protecting values-at-risk
- Burned Area Emergency Response (BAER) teams consult hydrologic models to estimate post-fire peak flows to assess values at risk

Figure 1: Post-fire discharge after the Station Fire, CA.

Motivation

- BAER Modeling Needs - Survey Response (Fig. 2; Napper, 2010)
- Evaluate ease of use, applicability, and accuracy of hydrologic model prediction of post-fire peak flow
- Evaluate uncertainty
  - Parameter estimation
  - Model preference
  - Post-fire adjustment
  - Model calibration
- Need for systematic calibration approaches

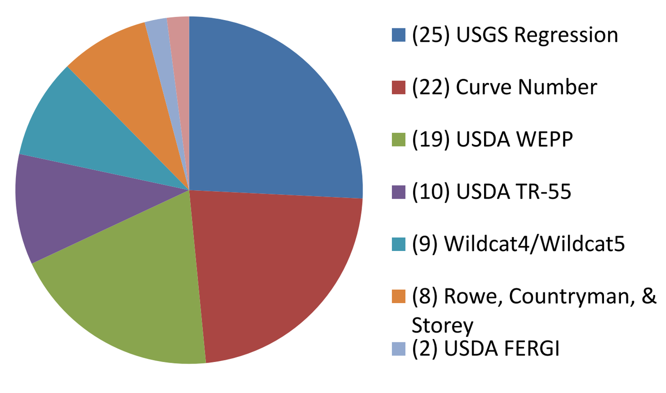


Figure 2: BAER Hydrology Model Questionnaire results

Models

Simple → Complex

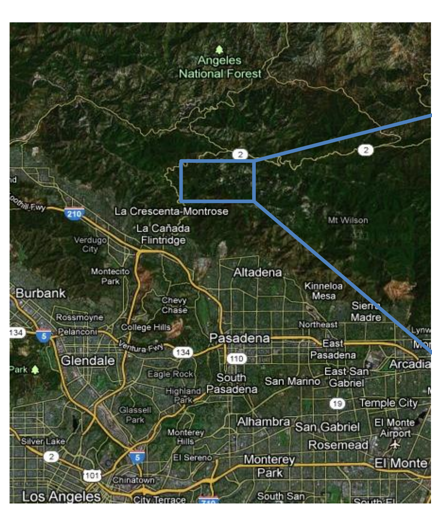
Model	Creator	Platform	Max Size	Outputs
RCS	Rowe, Countryman, and Storey	LUTs	N/A	Qpk, sediment
USGS Linear Regression	USGS	Regional USGS regression eqns	>5 mi^2	Qpk
Curve Number (CN) Models				
WinTR-55	USDA NRCS	WinTR-55	<25 mi^2	Qpk and time, hydrograph
Wildcat5	USFS, Stream Team, Fort Collins, CO	Microsoft Excel macros (2003 or later)	<5 mi^2	Qpk and time, hydrograph
HEC-HMS 3.5	U.S. Army Corps of Engineers	Windows	Flexible	Storm hydrograph, Qpk and time

Study Areas

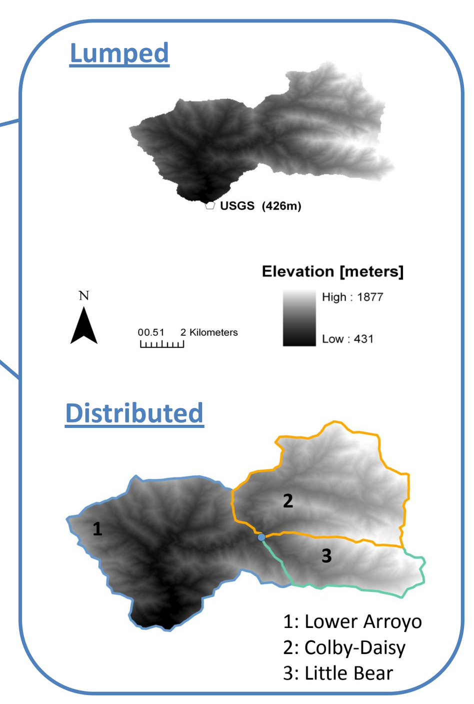
11 watersheds from Southern Sequoia (CA), San Bernardino (CA), Colorado, and Montana are selected to evaluate models under pre- and post-fire conditions

Case Study: Arroyo Seco

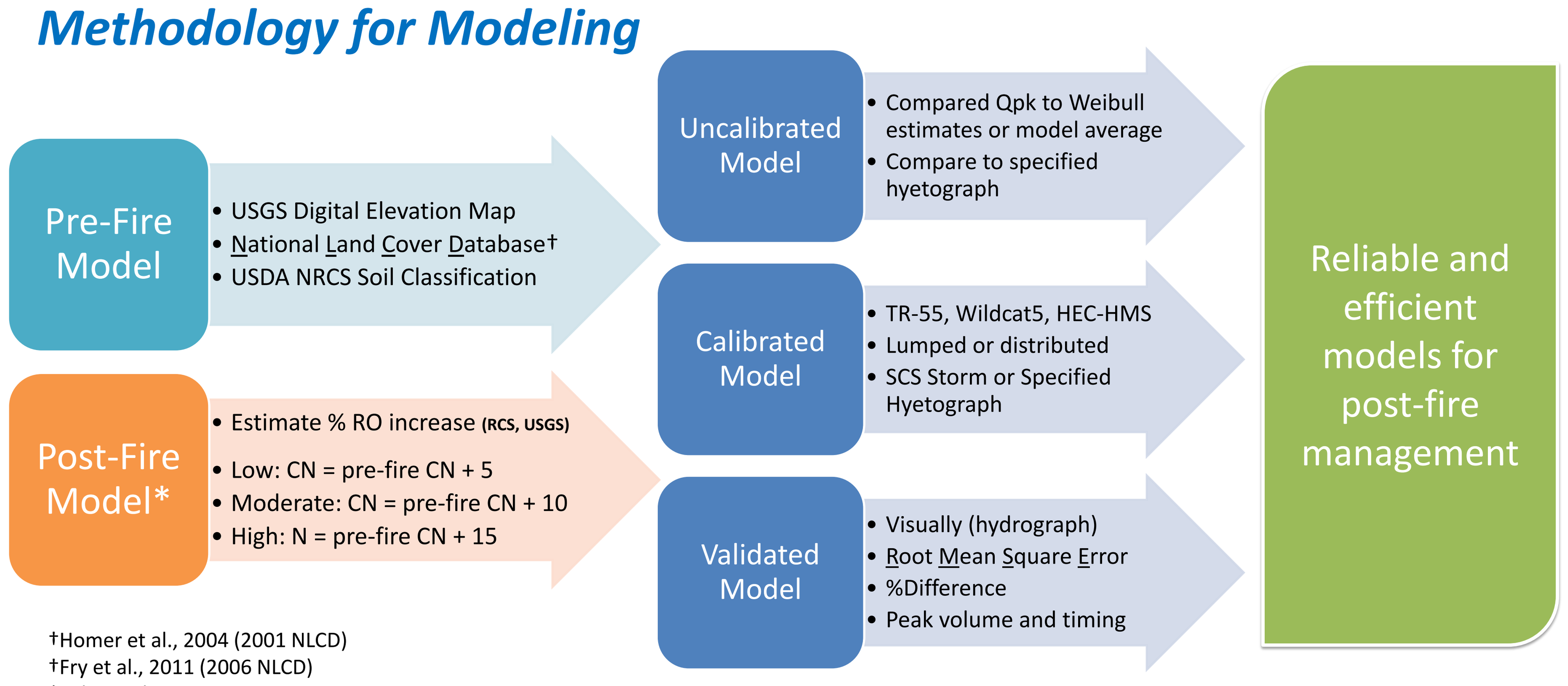
Station Fire, California – 2009
Size: 160,557 Acres
Cause: Arson
Damage > $900 Million
Suppression Cost > $90 Million



Arroyo Seco
- 40.14 km^2
- 100% burned (moderate severity)
- Steep terrain
- 23% Forest, 71% Shrubland†



Methodology for Modeling



†Homer et al., 2004 (2001 NLCD)
†Fry et al., 2011 (2006 NLCD)
*Foltz et al., 2009
*Higginson and Jarnecke, 2007

Uncalibrated Arroyo Seco Models

Pre-Fire Design Storms

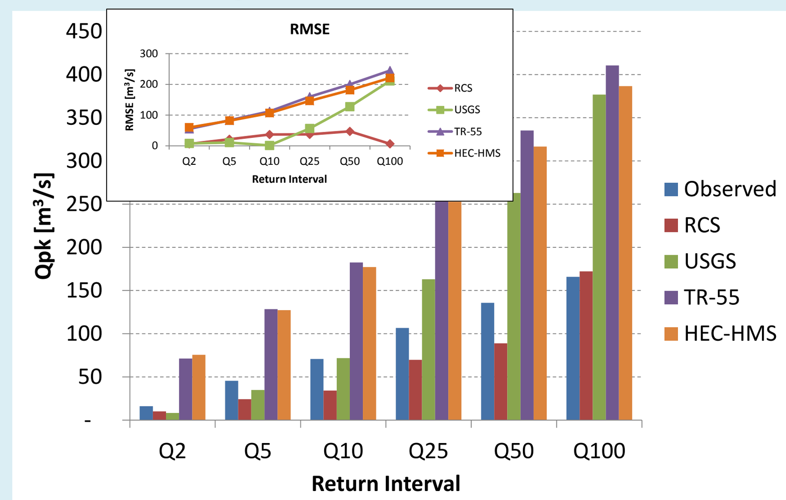


Figure 3: Pre-fire Qpk for all models excluding Wildcat5 and RMSE (upper left)

- Wildcat5 cannot be used for Arroyo Seco (>5 mi^2)
- RCS performs the best overall
- USGS performs well for low return intervals and increases in error for large return intervals
- Uncalibrated CN models over-predict Qpk

Post-Fire Design Storms

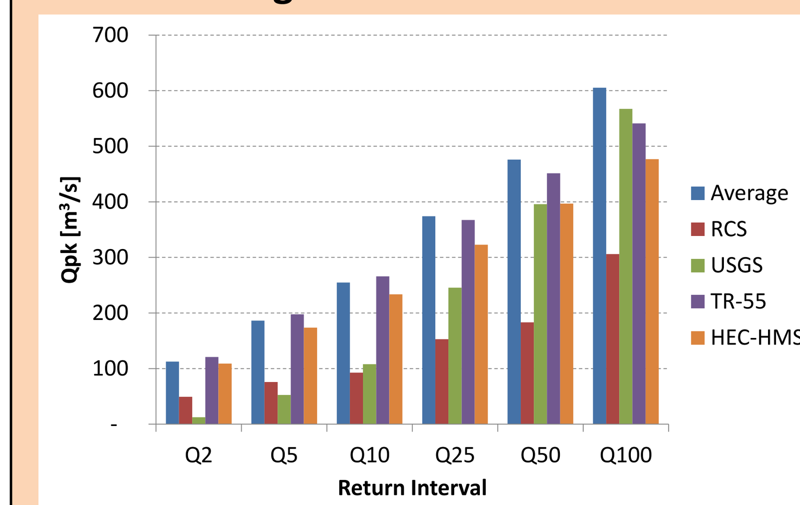


Figure 4: Post-fire Qpk for all models excluding Wildcat5

- Alteration of uncalibrated pre-fire models to post-fire conditions contributes to increased uncertainty

Calibrated and Validated Arroyo Seco Models

Using Specified Hyetograph in HEC-HMS

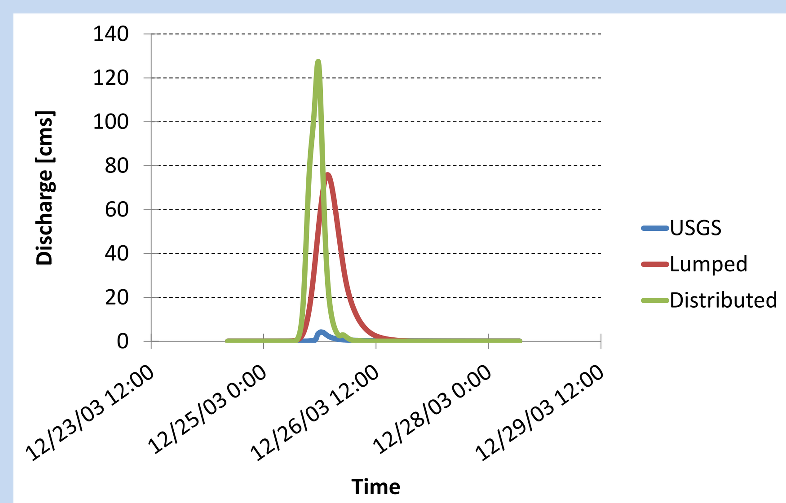


Figure 5: A December 2003 (pre-fire) with observed (USGS) and **uncalibrated** discharge estimates

- CN models need to be calibrated to improve predictions
- HEC-HMS specified hyetographs: timeseries of observed storm precipitation and discharge
- HEC-HMS lumped and distributed Arroyo Seco models over-predict discharge (Fig. 5) at 15-min resolution for an observed storm in December 2003 (pre-fire)
- 4 pre-fire storms for the Arroyo Seco are selected for calibration

Specified Hyetograph Calibration

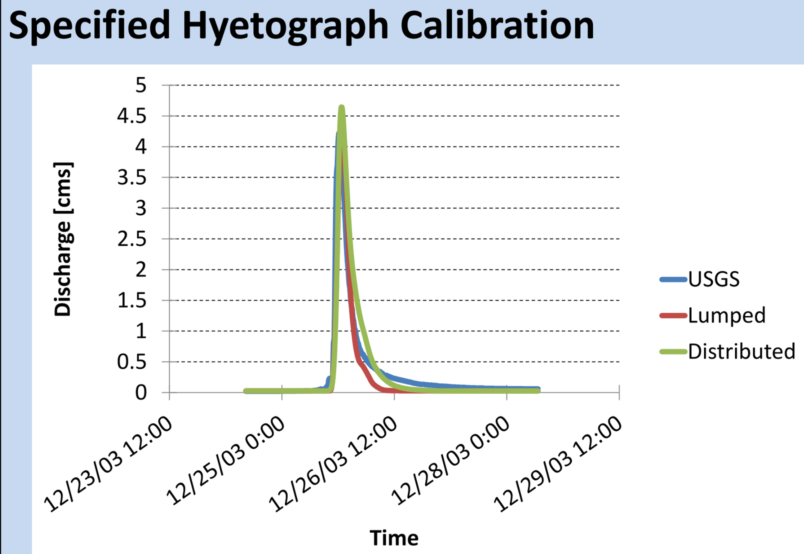


Figure 6: A December 2003 (pre-fire) with observed (USGS) and calibrated discharge estimates

- Two models developed (Fig. 6)
  - **Lumped**: all governing attributes are assumed uniform over the entire basin
  - **Distributed**: the basin is divided into 3 sub-basins to better represent hydrological processes
- Parameters (CN, initial abstractions (I_a), and lag time (T_L)) for the lumped and distributed models **are adjusted** until model discharge matches observed discharge

Specified Hyetograph Validation

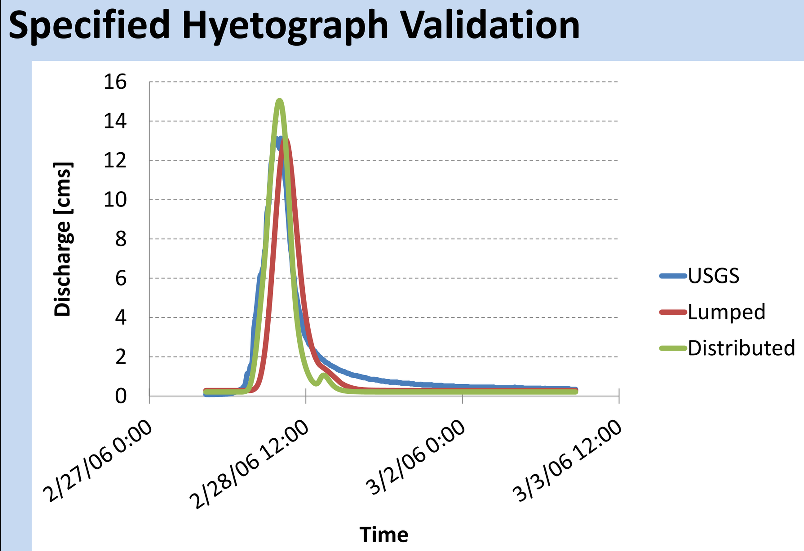


Figure 7: A February 2006 (pre-fire) with observed (USGS) and validated discharge estimates

Improved HEC-HMS Design Storm

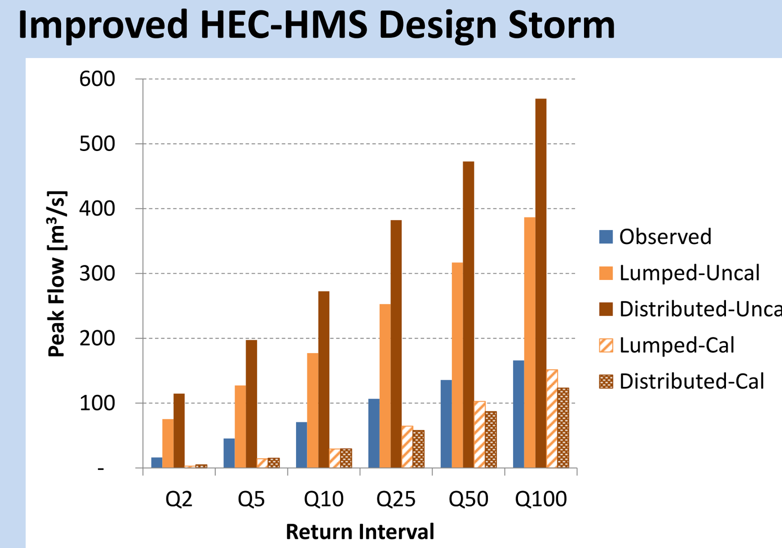


Figure 8: Pre-fire Qpk for observed, uncalibrated, and calibrated HEC-HMS Arroyo Seco models

- 2 observed storms are selected for validation, where "best" parameter sets are used to estimate discharge **without adjustment** (Fig. 7)
- Qpk predictions at specific recurrence intervals are improved with calibration techniques (Fig. 8)
- Model performance is evaluated and validated parameter sets are used to improve post-fire models

Improved HEC-HMS Model Predictions

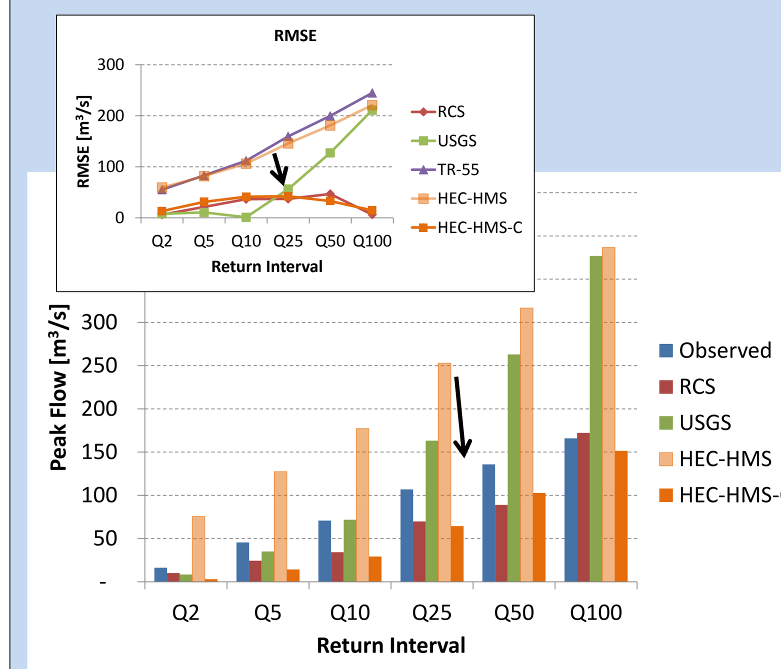


Figure 9: Pre-fire Qpk with calibrated HEC-HMS model and RMSE

- Pre-fire calibrated HEC-HMS Qpk is significantly improved
- RCS performs well in So. California
- Calibrated HEC-HMS RMSE is decreased and similar to RCS
- Potential to decrease error in CN calibrations (i.e. TR-55)
- Unable to calibrate and reduce error in the USGS

Post-Fire Models

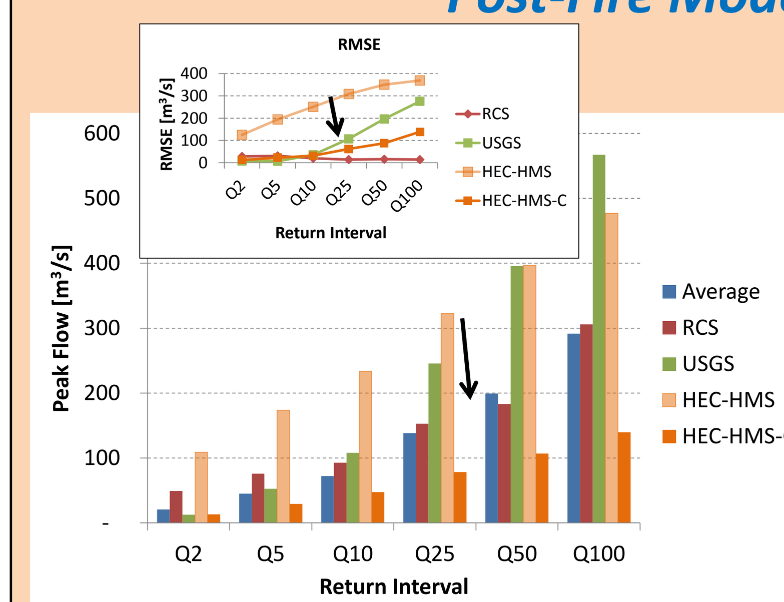


Figure 10: Post-fire Qpk with calibrated HEC-HMS model and RMSE

- Post-fire distributed HEC-HMS model predictions are significantly decreased
- Error resembles USGS model

Summary

RCS
- Easy method that performs well, where LUTs are available (So. Cal.)
- Changing geomorphology and climate increase uncertainty in this method
- Limited regional application
- Cannot be calibrated

USGS
- Simple method that tends to underestimate low return intervals and overestimate large return intervals
- Performs best for large watersheds
- Cannot be calibrated

TR-55
- Moderately complex model that performs best for large watersheds
- Uncalibrated models overestimate discharge
- Model allows limited calibration
- Calibrated models perform better and lead to more confident post-fire models

Wildcat5
- Moderately complex model that performs well for small watersheds
- Not an applicable model for large watersheds
- Model allows limited calibration

HEC-HMS
- Highly complex model that performs best overall for all watershed sizes and locations
- Uncalibrated models overestimate discharge in large watersheds and underestimate in small watersheds

- Not all models are designed/suitable for calibration
- More complex models allow for calibration and allow variability in watershed representation (i.e. lumped or distributed)
- Unless a model is specifically designed for a region (i.e. RCS, USGS), "uncalibrated" model predictions should be used with caution
- If feasible, models should be calibrated to improve pre- and post-fire performance with more confidence

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