Hydrological Modeling of the Potential Impact of a Forest Fire on Runoff in a Mediterranean Catchment

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Outline

- Mediterranean forest fires and impacts on hydrology
- HEC–HMS model description
- Modeling requirements
- Study site and data
- Calibration of parameters
- Results
- Conclusions
- Applications and significance
- My further steps
Mediterranean forest fires

From 2000 to 2005 – 95,000 fires in European countries
Almost 600,000 ha of forest burned every year (Barbosa et al., 2009)
Two-thirds of fires (65,000) in 5 Mediterranean countries (Portugal, Spain, France, Italy, Greece)

Causes of fire – human (accidents or intentional) and lightning (Konstantinos et al., 2010).

Forest fires and hydrology

Impacts of forest fire on hydrology:
- Combustion of soil organic matter and loss of soil structure
- Conversion of organic compounds into soluble ash
- Potential increase in hydrophobicity & water repellency
- Reduced infiltration
- Increased overland flow
- Greater flow velocities
- Decreased water holding capacity
- Risk of downstream flooding

Water repellent surface after burning pine needles (Photo: D. Fox)
Destruction of vegetation at hillslope/landscape scales (Photo: D. Fox)

2) Loss of litter layer decreases infiltration (Photo: D. Fox)

3) Increase in runoff after forest fire: risk of flooding downstream with potential loss of life and property

Study Area: Giscle watershed

- Mediterranean Watershed
- Area of 234 km²
- 70% of watershed is forest
- *Quercus suber* (cork oak), *Pinus pinaster* (pine), *Quercus pubescens* are the dominant trees
- Urban area and vineyards in lowland area
Study Sight: Giscle watershed

Giscle Watershed

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Study Sight: Giscle watershed

Gamma image of Fire: about 2,000 ha, August 2003

Upper part of catchment burned (Photos: D. Fox)

HEC HMS

- Computer program developed by US Army Corps of Engineers HEC
- Simulates precipitation–runoff and routing process–natural and controlled
- Allows user to subdivide the watershed into smaller sub basins for analysis and route to corresponding outlet
- Uses separate sub models to represent each component of the runoff process like models that compute rainfall losses, runoff generation, base flow, and channel routing
Model Development in HEC HMS

Sub Models used in HEC HMS

- Basin Model
- Runoff Volume Model
- Base flow model
- Meterological Model
- Direct Runoff Model
- Channel Routing Model
- Control Specification
## Adopted Model, methods and parameters

<table>
<thead>
<tr>
<th>Model</th>
<th>Method</th>
<th>Estimated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff Volume Model (Loss)</td>
<td>SCS Curve Number</td>
<td>Initial Abstraction, Curve Number, Impervious rate</td>
</tr>
<tr>
<td>Direct Runoff Model (Transform)</td>
<td>Clark Unit Hydrograph</td>
<td>Time of Concentration, Storage Coefficient</td>
</tr>
<tr>
<td>Base flow Model</td>
<td>Recession</td>
<td>Initial Discharge, Recession Constant, Threshold Flow</td>
</tr>
<tr>
<td>Channel Flow Model</td>
<td>Muskingum Routing</td>
<td>Muskingum K and X</td>
</tr>
</tbody>
</table>

### Parameters

- **Transform method: Clark Unit Hydrograph Model**
  - **Time of Concentration (min)**
  - Kirpish’s equation: \( T_c = 0.0195L^{0.77}/S^{0.385} \)
  - L = flow length (m)
  - S = average slope along the flow path

- **Loss method: SCS Curve Number**
  - Initial abstraction (mm)
  - \( I_a = 0.2*S \)
  - \( S = (25400 - 254*CN)/CN \)
Parameters

Routing method: Muskingum

Muskingum’s parameters $K$

$K = \frac{L}{u}$
$L =$ flow length
$U =$ flow velocity

Muskingum’s parameters $X$

$0 \leq X \leq 0.5$

<table>
<thead>
<tr>
<th>CN LOSS</th>
<th>SB1</th>
<th>SB2</th>
<th>SB3</th>
<th>SB4</th>
<th>SB5</th>
<th>SB6</th>
<th>SB7</th>
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<tbody>
<tr>
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<td>51.5</td>
<td>58.5</td>
<td>57</td>
<td>57</td>
<td>45</td>
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<td>SCS CN</td>
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<td>40.3</td>
<td>36</td>
<td>40.7</td>
<td>37.6</td>
<td>33</td>
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<td>Impervious</td>
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<td>0</td>
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<table>
<thead>
<tr>
<th>CLARK UNIT HYDROGRAPH</th>
<th>Time of Concentration (Hr)</th>
<th>Storage Coefficient (Hr)</th>
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<td></td>
<td>46.77</td>
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<td>37.9</td>
<td>3.7</td>
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<td>33.21</td>
<td>3.3</td>
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<td>52.51</td>
<td>5.2</td>
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<td></td>
<td>21.33</td>
<td>2.1</td>
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<td>50.94</td>
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<table>
<thead>
<tr>
<th>RECESSION *</th>
<th>Initial Discharge (m³/s)</th>
<th>Recession Constant</th>
<th>Threshold Ratio</th>
<th>MUSKINGUM</th>
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<tbody>
<tr>
<td></td>
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<td>REACH1</td>
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<td>0.15</td>
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<tr>
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<td>Recession Constant</td>
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<tr>
<td>Threshold Ratio</td>
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<td>0.1</td>
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</tbody>
</table>

Methods and their parameters involved for normal condition
Selection of storm

Storm I

- 4\textsuperscript{th} Nov–29\textsuperscript{th} Nov 1984
- Two peak rainfall in 9\textsuperscript{th} and 15\textsuperscript{th} Nov.
- Two peak discharge
- Not wet environment
- Low initial soil moisture

Storm II

- 13\textsuperscript{th} April 1976 to 22\textsuperscript{nd} April 1976
- Only one peak discharge
- Wet environment
  - second rainiest time of year
  - Observing rainfall data before two week
  - Hence correction was applied in CN

Storm I (before fire)

Precipitation and discharge plotted against time for Storm I

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Storm I (before forest fire)

<table>
<thead>
<tr>
<th>Sub Basins</th>
<th>Curve Number</th>
<th>Initial Abstraction</th>
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<tbody>
<tr>
<td>1</td>
<td>56.2</td>
<td>39.6</td>
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<tr>
<td>2</td>
<td>45.8</td>
<td>60.1</td>
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<td>3</td>
<td>44.5</td>
<td>63.4</td>
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<td>4</td>
<td>39.9</td>
<td>76.5</td>
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<td>37.6</td>
<td>84.2</td>
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<td>6</td>
<td>32.9</td>
<td>103.7</td>
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<td>7</td>
<td>36.2</td>
<td>89.4</td>
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</tbody>
</table>

Result obtained without calibration

Changed parameters for normal condition after forest fire

Result obtained after calibration (before forest fire)

Storm after forest fire

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Storm II

Precipitation and discharge plotted against time for Storm II

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<table>
<thead>
<tr>
<th>Sub Basins</th>
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<tbody>
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<td>58.08</td>
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<td>53.00</td>
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<td>7</td>
<td>56.61</td>
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Changed parameters for wet condition before forest fire

<table>
<thead>
<tr>
<th>Sub Basins</th>
<th>Curve Number</th>
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<tbody>
<tr>
<td>1</td>
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<td>3</td>
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<td>6</td>
<td>53.00</td>
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<tr>
<td>7</td>
<td>56.61</td>
</tr>
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</table>

Changed Curve Number for wet condition after forest fire
After forest fire, peak discharge increased in the range 10%-50%
In some instances, discharge rate was not in sync with precipitation
Soil moisture amongst others was the possible cause
Curve number varies from normal to wet condition
Sensitivity analysis of the parameters is crucial for calibration
Model can be improved by estimating the effect of soil moisture condition before the event and modeling for longer period
Application and Significance

- Early warning system
- Can be used to predict flood risk and possibly save loss of life and property
- Attempted in Mediterranean region but can be used elsewhere
- Helps in mitigating the loss or building the protection in low cost
- Prevents erroneous flood forecasting

My further study

- Research in remote sensing
- Boise Center Aerospace Laboratory
- Scaling up plot level data to Lidar (ALS) scale
- Using TLS and ALS
- Might use statistical approaches like Random Forest, Bayesian Hierarchical or even simple regression
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