Proof that some, but not all wildland fires increase surface water supplies

Dennis W. Hallema
dwhallem@ncsu.edu

Ge Sun (P.I.), Peter V. Caldwell, Steven P. Norman, Erika Cohen, Yongqiang Liu, Steven G. McNulty

Eastern Forest Environmental Threat Assessment Center, Raleigh, North Carolina
USDA Forest Service Southern Research Station
Wildland fire

- Wildland fire = Wildfire OR prescribed fire
- Wildfire = Natural disturbance, enhances natural succession of forests, stimulates growth and biodiversity
- Prescribed fire = Low intensity, smaller
- Environmental effects (air and water contamination, landslides)
- Increased risk for water resources due to:
  - Longer wildfire seasons
  - Increasing annual area burned
  - More severe fires associated with forest densification
  - Persistent drought
  - Climate change
  - Increasingly populated wildland-urban interface
Cumulative burned area 1984-2012

Vertical axis: % of drainage area

East - West of Mississippi R.

- Calif.
- PNW
- Gr.Basin
- Lw.Col.
- Rio Grande
- S. Atl.-Gulf
Forest importance to surface drinking water (FIMP)

Water yield weighted by population served

Figure credit: Weidner and Todd (2011) USFS Forests to Faucets
Wildland fire impacts on water supplies

• 50% of freshwater resources originate on forest lands
• Fire impacts last up to decades after disturbance, effects transmitted downstream
• How to distinguish streamflow changes caused by fire from those caused by variations in climate?
• National Cohesive Wildland Fire Management Strategy (implementation of 2009 Federal Land Assistance Management and Enhancement Act)
  • Assist decision making with regard to prescribed fuel treatments
  • Enhance resilience of forest watersheds
  • Maximize municipal water supplies
• Objective: CONUS assessment of wildland fire impacts (wildfire and prescribed fire) on watershed annual streamflow

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Project background

- 50% of freshwater resources originate on forest lands
- Fire impacts last up to decades after disturbance, effects transmitted downstream
- How to distinguish streamflow changes caused by fire from those caused by variations in climate?
  - Assist decision making with regard to prescribed fuel treatments
  - Enhance resilience of forest watersheds
  - Maximize municipal water supplies
- Objective: CONUS assessment of wildland fire impacts (wildfire and prescribed fire) on watershed annual streamflow
Causes of hydrologic disturbance in forests

Wildfire
- Net precip
- ET, infiltration

Natural disasters:
- Volcanic eruption
- Erosion and mass movement

Wildfire
- Net precip
- ET, infiltration

Climate:
- Drought
- Climate oscillations

Human activity:
- Withdrawal
- River dams
- Thermal pollution

Biological:
- Invasive species

Question: How to distinguish wildland fire impacts on water supplies from climate variability impacts?

Natural disasters:
- Volcanic eruption
- Erosion and mass movement

Biological:
- Invasive species

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## Geospatial datasets

<table>
<thead>
<tr>
<th>Dataset Description</th>
<th>Spatial resolution</th>
<th>Time resolution</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTBS Burned area and burn severity</td>
<td>30 x 30 m</td>
<td>Annual</td>
<td>1984-2013</td>
</tr>
<tr>
<td>PRISM (Hamon PET)</td>
<td>4 x 4 km</td>
<td>Monthly</td>
<td>1899-2012</td>
</tr>
<tr>
<td>MODIS NDVI</td>
<td>236 x 236 m</td>
<td>Biweekly</td>
<td>2003-</td>
</tr>
<tr>
<td>Daymet climate</td>
<td>1 x 1 km</td>
<td>Daily</td>
<td>1980-</td>
</tr>
<tr>
<td>USGS GAGES-II streamflow Point locations</td>
<td>Daily</td>
<td>1900-</td>
<td></td>
</tr>
</tbody>
</table>
Selection of burned watersheds

- GAGES-II watershed boundary layer
  - Filter reference watersheds > 20 years data after 1990
  - Raster conversion (120 m)
- MTBS burn severity rasters (annual 1984-2013)
  - Scale MTBS (30 m) to watershed raster
  - Calculate BARs per watershed, year, burn severity class
  - Filter watersheds with BAR > 1%, years with greatest BAR for 1988-2008
  - Working set of burned watersheds
Selection of burned watersheds

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Data Analysis

Spatial timeseries data
- Populate
- PostgreSQL relational database
- Query

R software (analysis and modeling)
Change point analysis of streamflow (CPM)

$L_{max}$ statistic significant?
- Yes
- No

Double-mass analysis P-Q (DMC)

$F$ statistic significant?
- Yes
- No

Climate elasticity of streamflow (CEM)
Rainfall-runoff modeling (RRM)

CEM/RRM significant?
- Yes
- No

Attribution of streamflow change to climate and non-climate disturbance

Streamflow change not significant

Water yield change not significant

High interannual climate variability, attribution analysis not meaningful

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Attribution of 5 year streamflow change

1. Climate elasticity model (CEM) = Predict $dQ$ given $d[Climate]$
2. Rainfall runoff/reservoir model (RRM) = Predict $Q$ given climate
Attribution of 5 year streamflow change

Parsimonious modeling approach

\[ \Delta Q = \Delta Q_{\text{climate}} + \Delta Q_{\text{disturbance}} \]

1. Select best CEM and RRM (Bayesian Information Criterion)
2. Predict \( \Delta Q_{\text{climate}} \) for post-fire period
3. \( \Delta Q_{\text{disturbance}} = \Delta Q - \Delta Q_{\text{climate}} \)

## Attribution of 5 year streamflow change

### Climate elasticity models (CEMs) vs. Rainfall-runoff models (RRMs)

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
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<tbody>
<tr>
<td><strong>CEM&lt;sub&gt;0&lt;/sub&gt;:</strong></td>
<td>( \frac{dQ}{Q_0} = 0 ) (reference)</td>
<td><strong>RRM&lt;sub&gt;0&lt;/sub&gt;:</strong></td>
<td>( Q = a ) (reference)</td>
</tr>
<tr>
<td><strong>CEM&lt;sub&gt;1&lt;/sub&gt;:</strong></td>
<td>( \frac{dQ}{Q_0} = \alpha \frac{dP}{P_0} )</td>
<td><strong>RRM&lt;sub&gt;1&lt;/sub&gt;:</strong></td>
<td>( Q = a + bP ) (lin. reservoir)</td>
</tr>
<tr>
<td><strong>CEM&lt;sub&gt;2&lt;/sub&gt;:</strong></td>
<td>( \frac{dQ}{Q_0} = \alpha \frac{dP}{P_0} + \beta \frac{dP_{ET}}{P_{ET_0}} )</td>
<td><strong>RRM&lt;sub&gt;2&lt;/sub&gt;:</strong></td>
<td>( Q = a e^{(bP)} ) (nonlinear res.)</td>
</tr>
<tr>
<td><strong>CEM&lt;sub&gt;3&lt;/sub&gt;:</strong></td>
<td>( \frac{dQ}{Q_0} = \alpha \frac{dP}{P_0} + \beta \frac{d\sigma^2_m}{\sigma^2_{m,0}} )</td>
<td><strong>RRM&lt;sub&gt;3&lt;/sub&gt;:</strong></td>
<td>( Q = a e^{(bP \sigma^2_m)} ) (nonlinear res.)</td>
</tr>
<tr>
<td><strong>CEM&lt;sub&gt;4&lt;/sub&gt;:</strong></td>
<td>( \frac{dQ}{Q_0} = \alpha \frac{d(P - SWE)}{(P_0 - SWE_0)} + \beta \frac{DSWE}{SWE_0} )</td>
<td></td>
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Select best fit
Attribution of 5 year streamflow change

- S. Carolina: Impact of low severity prescribed fires very small
- Arizona: High impact of disturbance
- California: Disturbance effects attenuated by climate trends

Attribution of 5 year streamflow change (25 watersheds burned >10%, mod-high severity)

- Arizona: Dense ponderosa pine forest, high impact on streamflow
- California: Low growing chaparral vegetation, disturbance effects attenuated by climate trends

Hallema et al., 2016c. Wildland fire and climate variability impacts on annual streamflow in watersheds across the continental United States: Regional patterns and attribution analysis. Fall Meeting, American Geophysical Union, San Francisco, California, December 12-16, 2016.
% Observed change annual Q
(5y post vs. pre wildland fire, BAR>10%)
Climate contribution (%)
Contribution of fire disturbance (%)

\[ \Delta Q_{\text{disturbance}} = \Delta Q - \Delta Q_{\text{climate}} \]
Boosted regression of 5 year post wildland fire streamflow change (dQ)

Hallema et al., 2016b. Wildland fire and climate variability impacts on annual streamflow in watersheds across the continental United States: Regional patterns and attribution analysis. Fall Meeting, American Geophysical Union, San Francisco, California, December 12-16, 2016.

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Highlights


2. Eastern U.S.: No evidence of prescribed burning impacts on river flow

3. Sustained water supply depends on assessment of wildland fire impacts, forest interactions
Dennis Hallema, ORISE fellow  
dwhallem@ncsu.edu

- Hallema et al., 2016b. Wildland fire and climate variability impacts on annual streamflow in watersheds across the continental United States: Regional patterns and attribution analysis. Fall Meeting, American Geophysical Union, San Francisco, California, December 12-16, 2016.
- Hallema et al., under review. Burning forests impacts water supplies.

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• Variability of dQ and dP considerable throughout the Pacific Northwest and California basins, which had more watersheds than most other basins.

• Regression lines point to the predominantly positive correlation between dQ and dP, and a predominantly negative correlation between BAR and drainage area (i.e. the portion of the watershed burned decreased with drainage area).