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Five Years After the Flood: Analysis of a river twice "restored" in the Deerfield Watershed

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I. Introduction

Extreme floods and the subsequent human response can both have dramatic impacts on the geomorphic and ecologic condition of rivers.

<u>2011: Irene Flood</u>: The Chickley River in the Berkshire Mountains of MA experienced extreme flooding during Tropical Storm Irene, causing landslides, bank failures, channel migration, stripping of riparian vegetation, and woody debris.


Deerfield R. during Irene

<u>2011: 1st phase of human response</u>: A desire to restore the channel and mitigate future flood effects led to channelization and homogenization of the river, focused on 8 km of river. This included (1) removal of logjams, (2) moving the channel back to the pre-flood locations, (3) armoring stream banks, and (4) removing riparian vegetation, bed forms, large rocks, and woody debris. Mass DEP halted the work, citing violation of Clean Water Act and Wetland Protection Act.

<u>2012: 2nd phase of human response</u>: A "natural channel design" approach was taken to undo the negative effects of the 1st phase, including riparian planting, large woody debris emplacement, large rock placement, and grading the channel.

We take a quantitative approach to characterize and, when possible, to test predictions on these three aspects of the natural and human response to Irene:

- Channel stability
- Riparian vegetation
- Large woody debris

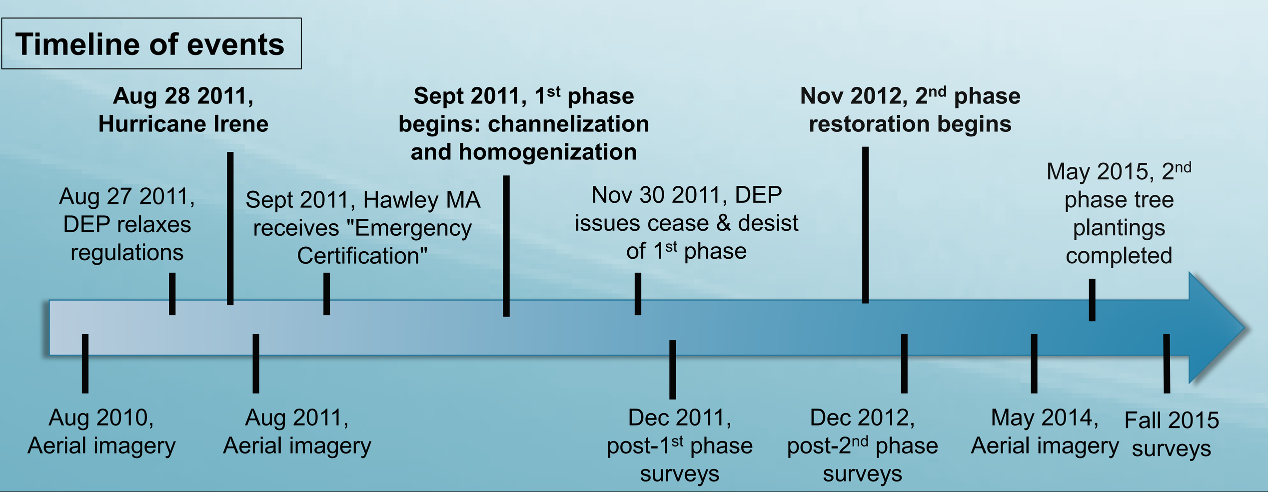
This large but natural flood provides rare insight into a possible pre-settlement condition of the river. We argue that the sculpting of the channel and recruitment of wood during Irene reset the geomorphic and habitat conditions on the Chickley River. This offset centuries of channelization and wood removal by the Army Corps, local government, and residents.


1st phase: channelization and homogenization
Photo source: Fly Rod Reel Magazine


Post 1st phase: knickpoint and bank erosion
Photo source: John Field


2nd phase restoration: recreating floodplain, adding wood and boulders
Photo source: John Field


2015 repeat surveys
Photo source: Stephen Lukas



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II. Riparian vegetation

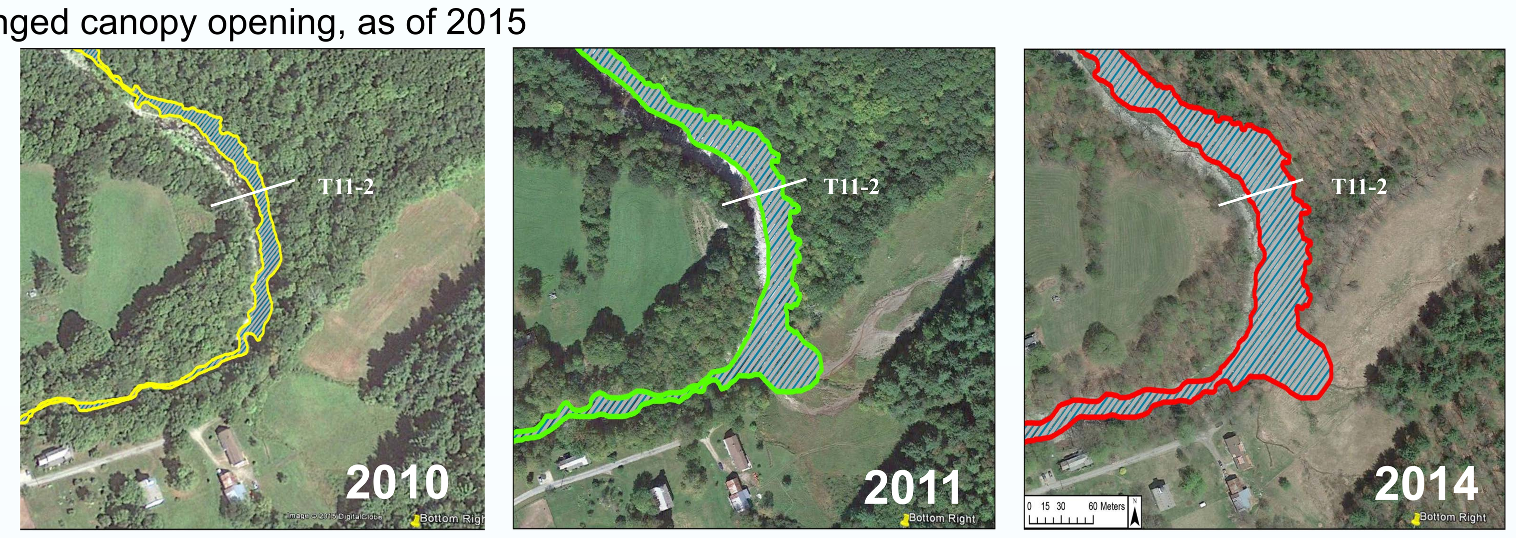
- Appropriate riparian vegetation cover is critical to ecological integrity of rivers to provide (1) bank stability, (2) habitat complexity, (3) cooler waters and high dissolved oxygen levels, (4) carbon inputs.
- How much did Irene, the 2011 channelization, and the 2012 restoration alter riparian cover?
- We use GIS analysis of aerial imagery from Google Earth, document review, and interviews.

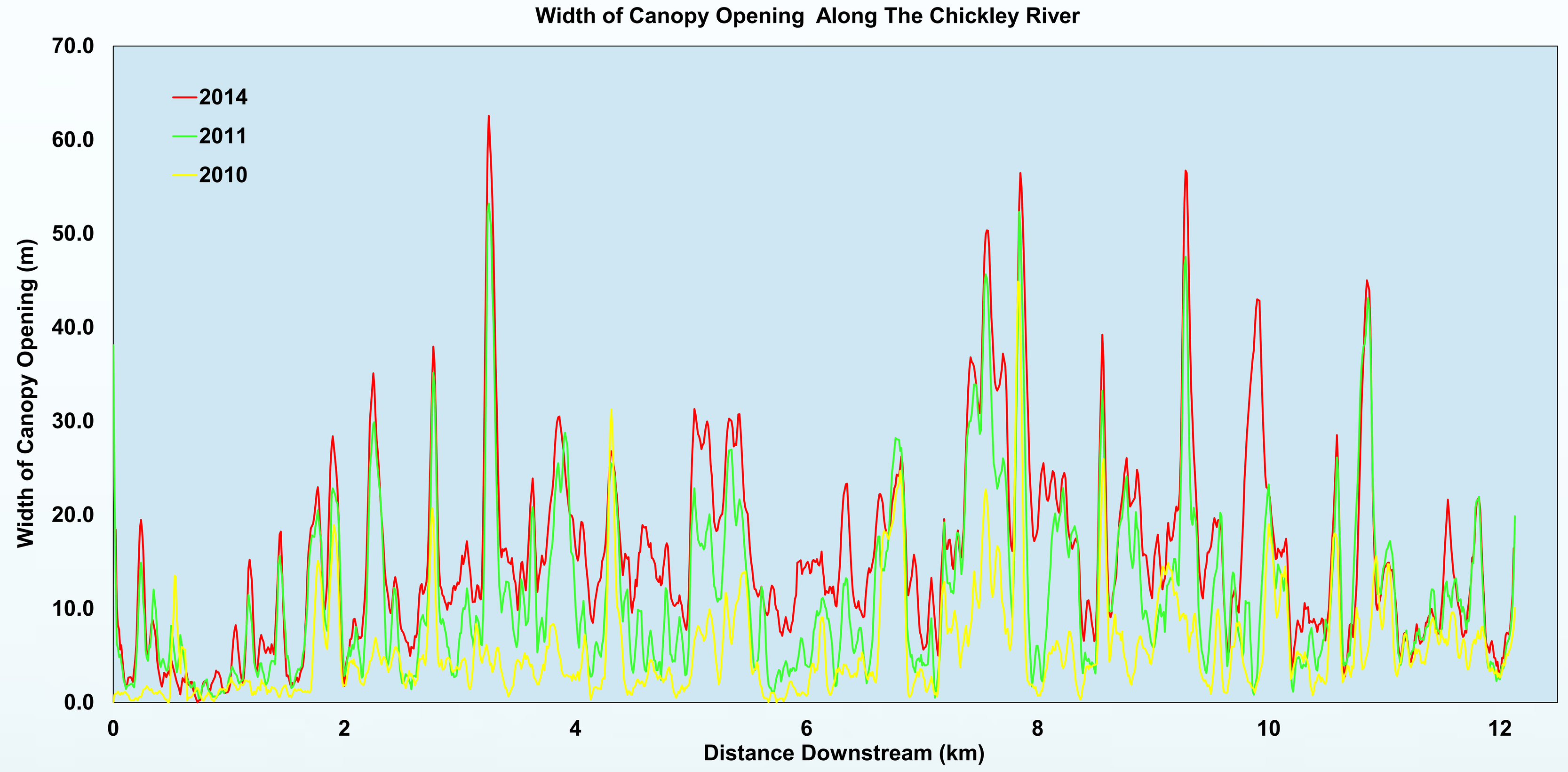
Methods:
After digitizing canopy edges, we used Euclidean allocation to find centerline, then Euclidean distance to compute width of canopy opening at points every 10 m along channel (analysis in ESRI ArcGIS).

Results:

- Irene more than doubled average canopy opening
- Locations with landslides, bank failures, and road failures show greatest widening, indicating sources of large woody debris
- Channelization (1st phase) increased average opening by 42%
- Control areas (not channelized in 2011) showed no appreciable change from 2011 to 2014
- Restoration (2nd phase) included over 500 tree plantings and no tree removal
- Immature vegetation from restoration plantings has not yet changed canopy opening, as of 2015

Canopy Opening (m)		
Year	Ave	Max
2010 Pre Irene	5.8	52.3
2011 Post Irene	12.3	62.4
2014 Post restoration	17.5	69.1





V. Conclusions

Attempts to restore the river to pre-flood location and protect against future floods in the 2011 channelization (1st phase of human response) led to

- Unstable channels
- Depleted riparian vegetation
- Loss of channel complexity

The 2012 restoration (2nd phase of human response) improved channel stability and complexity, but did not fully restore canopy or channel complexity engendered by accumulation of woody debris

The numerous large logjams (>25 logs)

- had local geomorphic effect (stored sediment, altered channel geometry)
- suggest these were common in pre-settlement era
- show an undocumented reference condition for river restoration

III. Channel stability

- Improving channel stability is a central goal for many river restoration activities.
- Did the channelization (2011) and later restoration (2012) alter channel stability, and could this have been predicted?
- We test Shields parameter as a quantitative predictor of channel stability.

Background:
Shields number: $\theta = \frac{\rho g H S}{(\rho_s - \rho) g D}$ $\theta_{crit} \approx 0.035$ Channel stability when $\theta \approx 0.04$

where H = flow depth, S = channel slope, D = grain diameter, ρ = water density, ρ_s = sediment density, g = gravity

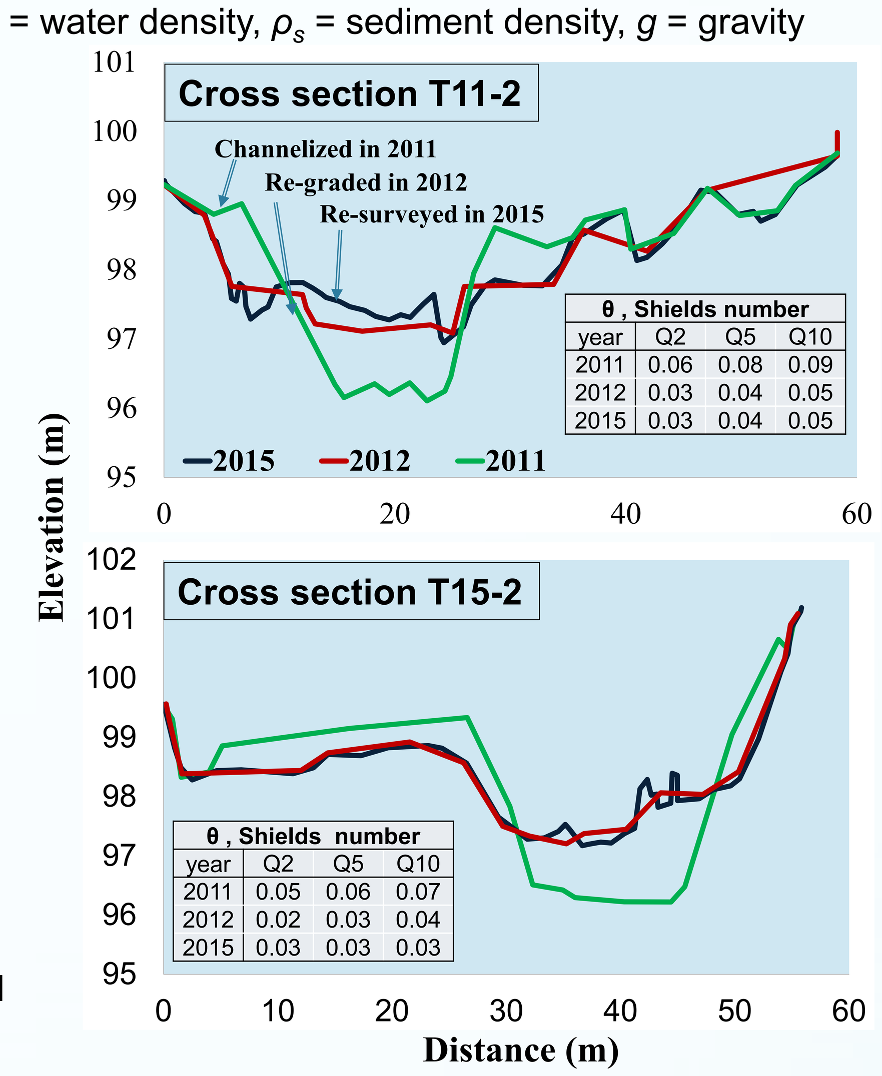
In alluvial rivers dominated by bedload transport (as opposed to suspended- or mixed-transport), channel geometry is typically configured such that $\theta \approx 1.2\ \theta_{crit} \approx 0.04 \pm 0.003$ at the bankful flow, often estimated as the 2-year recurrence interval flow (Parker, 1979; Dade and Friend, 1999).

We test if $\theta > 0.04$ after the 2011 channelization and 2012 restoration at the 2-, 5- and 10-yr flow using HEC-RAS analysis of cross sections measured in 2011, 2012, and 2015.

Findings:

2011 channelization:
- migrating knickpoints and bank failures indicate that channel was **<u>not stable</u>** (see Figure in introduction).
- $\theta \geq 0.05 \geq$ at 2-, 5- and 10-yr flow, showing that **<u>instability could be predicted</u>**

2012 restoration:
- repeat surveys (2012 to 2015) indicate channel was **<u>stable with some deposition</u>** at cross sections.
- $\theta \leq 0.04$ at 2-yr flow, and $\theta \leq 0.05$ at 5- and 10-yr flow, showing that **<u>stability could be predicted</u>**



Cross section T11-2:

θ, Shields number			
year	Q2	Q5	Q10
2011	0.06	0.08	0.09
2012	0.03	0.04	0.05
2015	0.03	0.04	0.05

Cross section T15-2:

θ, Shields number			
year	Q2	Q5	Q10
2011	0.05	0.06	0.07
2012	0.02	0.03	0.04
2015	0.03	0.03	0.03

IV. Logjams

- Large woody debris is a critical ecologic and geomorphic element of natural rivers because it provides (1) habitat complexity, (2) sediment storage, and (3) downstream flood abatement
- How did Irene and the human response affect woody debris?
- We use aerial photos, interviews, and surveys to characterize log jam size, frequency, and geomorphic effect.

Background:

- Pre-settlement wood occurrence in channels poorly understood in northeastern US
- Centuries of wood removal, reduced wood sources due to flood control and historic logging
- Previous studies: small amounts of wood, few channel-spanning logs or logjams, limited geomorphic effects in northeast compared to temperate mountainous rivers in Pacific NW (Fisher et al., 2010; Kasprak et al, 2012)
- Fortunately, we have aerial imagery immediately after Irene, before the channelization (1st phase of human response) was in full swing
- Field surveys of intact and human-altered logjams supplement this imagery data


A flow deposited logjam of ~ 90 logs
Image source: Google Earth

Results:

- Unexpected observation of many very large logjams (>25 logs)
- 1.2 logjams per km (14 total along Chickley)
- Frequency is consistent with expanded survey across Deerfield watershed
- 17 % at toe of landslides (@ 2 of 11 total landslides along 12 km reach)
- 83 % deposited by flowing water (all at river bends)
- Geomorphic effect locally: sediment storage, redirected flow, narrowed channel, increased local channel slope, created pools
- Sediment storage minor compared to sediment export during Irene


Large logjam of ~200 logs, stores 840 m^3 of sediment, creates pool, narrows and steepens channel over 70m

Landslides are major wood source (Dethier, 2015), but only partially indicate where logjams will occur.

2011 channelization (1st phase response): removed or depleted 75 % of logjams and 100% of woody debris in channel over 8 km of focused work

2012 restoration (2nd phase): installed 1 large logjam (> 25 logs) and many small engineered logjams of 1-5 logs (up to 25 small logjams per km)


Wood removed and stockpiled immediately post flood
Image source: Google Earth